

# Temperature Relationships of Great Lakes Fishes:

A Data Compilation

by

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## 1.0 INTRODUCTION

### 1.1 Purpose

The purpose of this report is to compile a temperature database for Great Lakes fishes. The database was prepared to provide a basis for preliminary decisions concerning the siting, design, and environmental performance standards of new generating stations and appropriate mitigative approaches to resolve undesirable fish community interactions at existing generating stations.

The contents of this document should also be useful to fisheries research and management agencies in the Great Lakes Basin.

### 1.2 Summary

The data base provides easy and rapid access to temperature data on fish species in terms of temperature categories which are pertinent to assessment of thermal effects on fish populations.

Thermal criteria for 116 fish species inhabiting the Great Lakes are summarized from published scientific literature. These data are categorized in four tables for each species as follows:

- (1) Lethal temperatures and thermal resistances
- (2) Temperature preferences and avoidances
- (3) Optimal and limiting temperatures for growth
- (4) Temperatures for reproduction and early development

The database tables are preceded by a brief text. The contents of the text are summarized in this paragraph. Section 1.3 is a review of similar literature. Section 1.4 presents a short discussion of the advantages and limitations of this report. The methods are outlined in Section 2.0. Section 2.1 is a discussion of the species list. The format used for the temperature data tables is described in detail in Section 2.2. The terms used in the database tables are defined in Section 2.3. A brief overview of the content of the temperature database tables is provided in Section 3.0. Section 3.1 explains the species cataloging and organization. The distribution of temperature data across species is described in Section 3.2. References for the text and database tables are in Section 4.0. Section 5.0 is the fish temperature database, the first page of which is a list of abbreviations.

### 1.3 Literature Review

The published information on the temperature requirements of freshwater fishes is found in thousands of documents. It is convenient that several authors have condensed this information into reviews of the literature. The general reviews of fisheries biology by Carlander (1969,1977) and Scott and Crossman (1973) include some temperature data. Several reviewers have focussed on thermobiology, specifically: lethal and/or preference temperatures (Coutant 1977a; Cherry et al 1977; Kowalski et al 1978; Houston 1982). Others have widened their reviews to include data on growth, preference and lethal temperatures (Leidy and Jenkins 1977; McCauley and Casselman 1980; Jobling 1981). Comprehensive reviews on the whole range of temperature requirements for fishes (i.e., lethal, preference, growth, reproductive) were given by EPA (1974) and Brown (1974).

A summary of thermal effects literature is published each year for aquatic organisms in the June issue of the Journal of the Water Pollution Control Federation (Talmage and Coutant 1978, 1979, 1980; Cravens 1981, 1982; Cravens et al 1983; Harrelson et al 1984).

The temperature requirements of Great Lakes fishes have been reviewed by two authors. Firstly, Reutter and Herdendorf (1976) presented lethal and preference temperatures for 46 species of Lake Erie fishes. Secondly, Spotila et al (1979) reviewed 80 species covering: thermal requirements for survival, temperature preference, growth, reproduction and early development.

#### 1.4 Database Advantages and Limitations

The major limitation of this document is its lack of an overall synthesis. The initial terms of reference did not provide for any attempt to integrate the data into summary values, figures or discussion. A brief overview of the distribution of temperature data among families of species is provided in Section 3.0. The reader is referred elsewhere for scholarly discussion of the use and application of fish temperature data (Cherry et al 1977; Richards et al 1977; Spotila et al 1979; McCauley and Casselman 1980; Jobling 1981; Mathur et al 1981; Houston 1982; Giattinna and Garton 1982; Ellis 1984).

The data summary in this report enjoys several advantages over other similar reviews. One of these is that it is current. This is the only compilation in the published literature since 1982. More importantly, the scope of the review is wider than any previous one in relation to the total species coverage and scope of thermobiological information. Furthermore, the design of the database tables makes for easy data access which aids comparisons within and across species. Access to the review of data by Spotila et al (1979) was hindered by the use of inconsistent categories of data within each table.

## 2.0 METHODS

### 2.1 Species List

The species list for this study was compiled from Christie (1982) and Scott and Crossman (1973). A total of 116 Great Lakes fishes were included. This species total is representative for the Great Lakes (Manny 1984).

Several species were omitted that no longer have a Great Lakes distribution. These species were: Atlantic salmon (*Salmo salar*); blue pike (*Stizostedion vitreum glaucum*); deepwater cisco (*Coregonus johanna*); and blackfin cisco (*Coregonus nigripinnis*) (Scott and Crossman 1973; McAllister et al 1985). The only species of the family Petromyzontidae represented in this summary was the sea lamprey (*Petromyzon marinus*). Three other Great Lakes species of this family not included in this summary were: northern brook lamprey (*Ichthyomyzon fossor*); silver lamprey (*Ichthyomyzon unicuspis*); american brook lamprey (*Lampetra lamottei*). Also, I have included the stoneroller (*Campostoma anomalum*) in the database since it is reported to have a marginal Great Lakes distribution (Scott and Crossman 1973; Spotila et al 1979; McAllister et al 1985).

### 2.2 Database Design Considerations

The design of the temperature database was developed after review of the literature, some of which was cited in Section 1.4. The goal was to structure a database format that would accommodate the major thermal requirements for fishes. These temperature requirements have been identified by others as pertaining to: survival, temperature preference; growth; reproduction and early development (EPA 1974; Gift 1977; Jobling 1981; Giattinna and Garton 1982). The temperature criteria for preference - avoidance and survival are useful for predicting short-term direct effects on fish

behaviour and metabolism. The thermal requirements for reproduction and growth provide a basis for estimating the long-term sublethal effects of unnatural temperature change on fish populations.

### 2.3 Definition of Terms

The types of data furnished in the fish temperature database are described and defined in this Section. All temperatures are in degrees Celsius. Data are listed under the scientific name of the fish species, arranged in alphabetical order. Within each species category, the information is organized in four different tables. These tables are titled as follows in order of their appearance in the database:

- (1) THERMAL TOLERANCES
- (2) PREFERRED TEMPERATURES
- (3) GROWTH TEMPERATURES
- (4) SPAWNING AND DEVELOPMENT TEMPERATURES

The types of temperature data found within each of these four major categories are described below.

#### (1) THERMAL TOLERANCES

This table contains data on laboratory-derived lethal temperatures and thermal resistances. These temperature thresholds were observed in experiments that were explicitly designed to measure thermal doses. Other lethal temperature values were reported in the literature from laboratory studies whose experimental designs did not conform to the accepted standards for determination of thermal tolerances and resistances. These standard methods are described in Fry et al (1946) and McCauley (1981). These latter temperature values and those reported from the field studies are less reliable than those derived from standard experimental designs. The less robust estimates of thermal tolerances are reported elsewhere in the table entitled: SPAWNING AND DEVELOPMENT TEMPERATURES. These include lethal temperature thresholds for entrainment, heat shock and cold shock.

##### (a) Size or Age:

Lethal temperatures vary with size and age of fish. The various descriptions of size and age used in the database are explained in Section 5.0.

##### (b) Acclimation Temperature:

The acclimation temperature is defined as a constant temperature in the laboratory at which fish have been held for a time sufficiently long to erase the influence of previous thermal exposure (McCauley 1981).

##### (c) Acclimation Time:

The time for holding fish at a given acclimation temperature. This is usually assumed a standard seven days unless reported otherwise.

##### (d) Season:

Lethal temperatures vary seasonally. See Section 5.0 for abbreviations used in the database.

(e) Upper Incipient Lethal Temperature:

and

(f) Lower Incipient Lethal Temperature:

The upper and lower incipient lethal temperatures represent the temperature values beyond which 50 percent of the population can no longer live given an indefinite period of time (Giattinna and Garton 1982). A standard seven-day week is used as the lethal test exposure time (McCauley 1981). The incipient lethal levels define the upper and lower boundaries to the "zone of thermal tolerance" within which there is no mortality from temperature (Figure 1).

(g) Thermal Resistance Equation:

A glance at Figure 1 will show a "zone of thermal resistance" located above the upper incipient lethal temperature. Within this zone, mortality due to temperature extremes occurs as a function of time. The length of time that 50 percent of the population will survive temperatures above the upper incipient lethal temperature is calculated from a regression relationship as follows:

$$\log(\text{time in minutes}) = a + b(\text{temperature in } ^\circ\text{C}),$$

where a and b are the intercept and slope, respectively, determined from each acclimation temperature (EPA 1974).

The values of the intercept a and slope b are provided to four decimal places in the fish temperature database tables. The value of b is almost always negative and is preceded by a minus sign in the table. This minus sign, located between the values for a and b, should not be erroneously misinterpreted as signifying a range of values.

(h) Data Limits {Upper and Lower}:

These are the data limits of the regression relationship as reported by Brown (1974).

(i) Exposure Temperature:

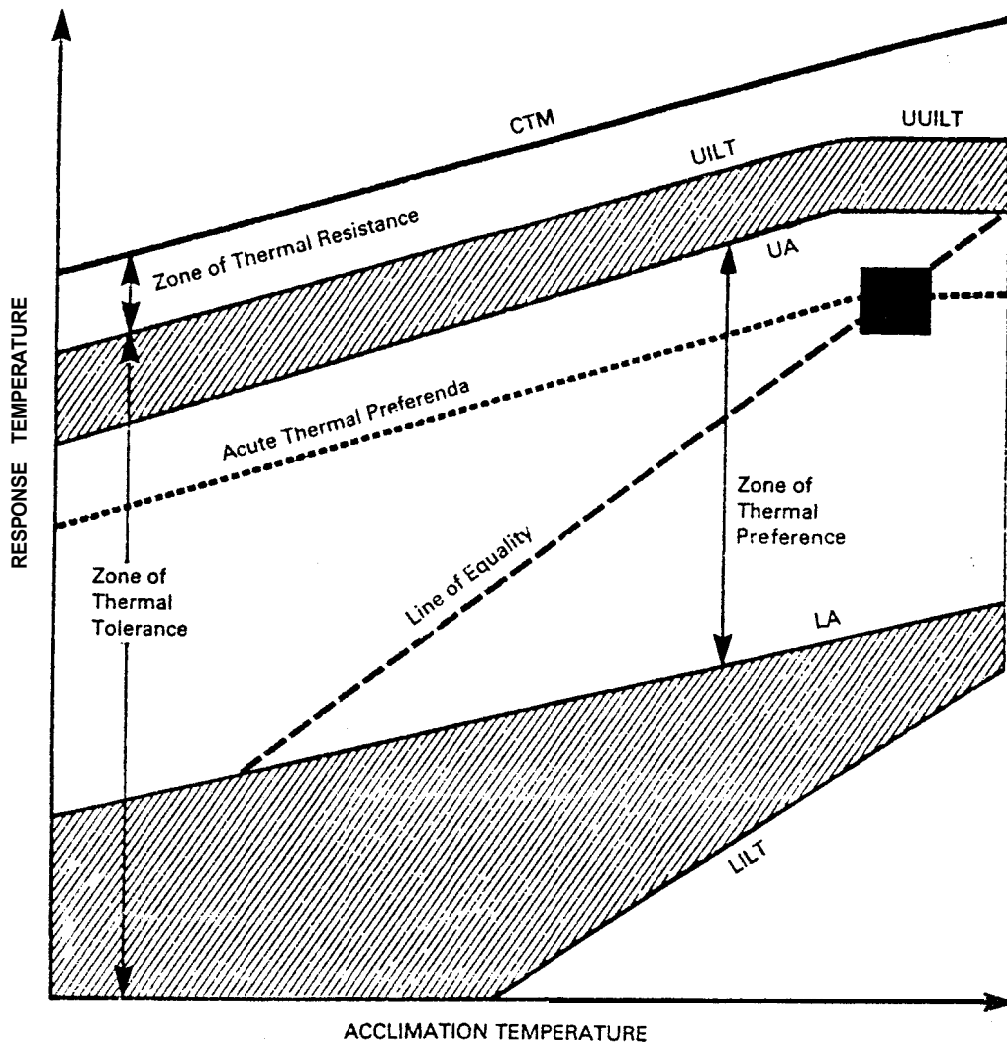
This is the test temperature a fish is exposed to in the laboratory in order to determine the time to mortality.


(j) Resistance Time:

This value is the amount of time that a sample of test fish were able to resist an exposure temperature before 50 percent mortality, or some other specified survival level, is experienced. The resistance time equation can be used to calculate thermal tolerance limits for a fish species for several time intervals up to 10,000 minutes (seven days) (Jinks et al 1981).

(k) Critical Thermal (Max):

The upper boundary of the "zone of thermal resistance" is the critical thermal maximum (CTM) (Figure 1). The CTM is lethal if fish are allowed to remain at or above that temperature (Bonin et al 1981). The CTM is determined in the laboratory by gradually increasing the water tempera-



 Zone of Final Preferendum and Optimum Growth

Broken line (line of equality) represents points at which preferred temperature equals acclimation temperature, and is often used in estimating final preferendum. CTM = critical thermal maximum; UILT = upper incipient lethal temperature; LILT = lower incipient lethal temperature; UUILT = ultimate upper incipient lethal temperature; UA = upper avoidance threshold; LA = lower avoidance threshold.

Adopted from Jobling (1981), Giattina and Garton (1982)

FIGURE 1  
 Diagram Showing Temperature Relations of Fish

ture from acclimation levels to the temperature at which the onset of spasms occurs, followed by complete loss of equilibrium. This differs from determination of the upper incipient lethal temperature (l(e)) in which fish are transferred directly and abruptly into a constant lethal temperature bath from acclimation temperatures (McCauley 1981). The rate of temperature increase used by any single investigator to determine CTM can vary within a range of 1 to 60°C h for routine applications (Becker and Genoway 1979; Bonin et al 1981).

(l) Location:

This is a laboratory. Sometimes its geographic location is given.

(2) PREFERRED TEMPERATURES:

This table contains temperature preference and avoidance values. These are derived from both field and laboratory observations.

(a) Size or Age:

Preferred and avoided temperatures vary with size and age, See Section 5.0 for a description of life stages and units of size used in the database.

(b) Season:

Preferred and avoided temperatures vary with season. See Section 5.0 for abbreviations.

(c) Day or Night:

Diurnal variation in temperature preference and avoidance is common (Coutant 1977a, Giattinna and Garton 1982). See Section 5.0 for abbreviations.

(d) Upper and Lower Avoidance:

The avoidance threshold is defined as the temperature at which fish spend significantly less time in comparison to controls. Avoidance temperatures (upper and lower) can be measured directly in the lab by providing fish with a choice between water which is heated or cooled and water at the acclimation temperature of the fish (Giattinna and Garton 1982). The upper and lower avoidance temperatures define the boundary of the "zone of thermal preference" (Figure 1). Avoidance temperatures reported from field studies are less precise than those of laboratory studies because they include the influence of other non-thermal environmental influences (i.e., competition, predation, changes in water quality, food availability, physiological condition).

(e) Final Preferendum:

Within a laboratory thermal gradient, over a short period of time (two hours or less) fish will gravitate toward certain temperatures. These are termed "acute thermal preferenda" (PT) and are highly dependent upon acclimation temperature (Cherry et al 1977; Giattinna and Garton 1982) (Figure 1). The "final temperature preferendum" (FP) is the temperature around which fish will ultimately congregate in an infinite temperature gradient (Giattinna and Garton 1982) (Figure 1).

The values for PT and FP are both entered in the column labelled *Final Preferendum* in the database. One can distinguish between the two values since PT are usually accompanied by values for *Acclimation Temperatures* in the seventh column of this table. Values cited from



Coutant (1977a) are for FP only. Review of the data in Coutant (1977a) indicates values for FP vary within a narrow range of 4C. Estimates of FP from field studies whose ranges exceed 4C should be assumed to be PT for the given season and location. The manner in which temperature preference data was typically reported in the literature did not allow explicit separation of values for PT and FP. Field reported values include much uncontrolled error due to the influence of other non-thermal environmental factors. Some of the reported values from field studies are representative of only a single point-in-time field occurrence. Users of the database are encouraged to refer to the source literature for an indication of the reliability of the preferendum temperature.

(f) Acclimation Temperature:

This term was previously defined for laboratory investigations (see item I(b) in the THERMAL TOLERANCES section). In field situations, fish are exposed to a whole set of conditions and are usually subjected to fluctuating rather than constant temperatures. Adaptation to all of these variables is known as acclimatization or sometimes field acclimation (McCauley 1981).

(g) Acclimation Time:

This term was previously defined (see Item 1 (c) in the THERMAL TOLERANCES section).

(3) GROWTH TEMPERATURES:

This table contains data on thermal limits and optima for growth.

(a) Size or Age:

Sizes and or ages are specified since younger, smaller fish grow faster than older, larger fish. See Section 5.0 for a description of the terms and units of size and age.

(b) Optimum:

The optimal temperature for growth is the temperature at which growth rate is highest. This value is determined while fish are reared under conditions of maximum, or excess feeding and held at constant temperatures over the temperature range tolerated by the species (Jobling 1981; McCauley and Casselman 1980). The difference between the final thermal preferendum and temperature for optimum growth is less than 2°C for some species (Kellogg and Gift 1983) (see Figure 1).

(c) Range:

This value is the range of temperatures over which growth is known to occur.

(d) MWAT:

The maximum weekly average temperature for growth (MWAT) is a measure of the upper temperature limit for long-term exposure. The MWAT lies somewhere between the physiological optimum temperature and the ultimate upper incipient lethal temperature (UUILT). The UUILT is the highest temperature to which the species can be acclimated; above this all temperatures are lethal regardless of previous thermal exposure (Jobling 1981) (Figure 1). The MWAT is calculated as one third of the range between the optimum temperature for growth and the UUILT (EPA 1974; Wrenn 1980).

(e) ST Max:

These values are the maximum temperatures for short-term exposure (24 hours) during the

growth season to prevent against lethal effects (Wrenn 1980). It is calculated as the difference between the upper incipient lethal temperature, at an acclimation temperature equal to the MWAT, minus 2°C (EPA 1974).

(f) No Growth Limits (Upper and Lower):

These are estimates of the actual temperature end points, above or below which no growth is possible.

(4) SPAWNING AND DEVELOPMENT TEMPERATURES

This table contains information on temperature requirements for reproduction and larval development. The table also has data on lethal temperatures that are not the conventional incipient lethals or critical thermal maximas defined previously. This includes temperatures reported in the literature from field observations of mortality or lethal values which were not derived from standard laboratory techniques for estimating thermal dose. (These standard methods are described in McCauley (1981)).

(a) Event:

This column contains a keyword(s) that describes the type of temperature requirement referred to in the corresponding row. These "events" are aspects of reproduction and larval development or thermal effects from power plant cooling water intakes or discharges. The event categories found in this column include: life stage (egg, embryo, larval, juvenile, adult); mode of reproductive behaviour (migration, spawning, incubation, hatching, embryo or larval development); and type of power plant effect (entrainment, heat or cold shock). The three types of power plant effects included above are defined as follows:

entrainment: The passage of ichthyoplankton (eggs, larvae, small juveniles) through the screens of cooling water intakes into the condenser cooling system of a power plant; subject to mechanical, chemical and thermal stresses. (Temperature requirements are derived from laboratory simulation studies; laboratory thermal tolerance work and in *situ* studies of fish survival at operating power plants (Jinks et al 1981).

heat shock: Fish resident in a power plant thermal discharge are subject to a rapid increase in temperature due to changes in power plant operations.

cold shock: Fish resident in warm water discharges are exposed to a rapid decrease in temperature and a sustained exposure to low temperature that induces responses of abnormal behaviour and physiological function often leading to death (Coutant 1977b). Cold shock events occur usually in colder months due to planned or accidental shutdowns.

(b) Season and/or Acclimation Temperature:

Numerical values in this column are acclimation temperatures in degrees Celsius. The letter symbols in this column representing the four seasons are defined in Section 5.0.

(c) Optimum Temperature:

The temperature of peak occurrence, or most frequently associated with the given event.

(d) Temperature Range:

The range of temperatures over which the given event is reported to occur.

(e) MWAT:

The maximum weekly average temperature during the month of peak spawning. This should not exceed the optimum temperature for spawning or, if such data are not available, the middle of the reported range of temperatures for spawning (EPA 1974; Wrenn 1984).

(f) ST Max for Embryo Survival:

The short-term (24-hour) maximum temperature for successful embryo survival from experimental data, or if not available, the reported maximum temperature for spawning (EPA 1974; Wrenn 1984).

(g) Acclimation Time:

See item 1 (c) in THERMAL TOLERANCE section for definition.

(h) Lethal Limit (Upper and Lower):

These are any lethal temperatures observed in the field or from laboratory experiments that do not conform to the prescribed methods for determining lethal temperatures as set out in Fry (1946) and McCauley (1981).

(i) Median Lethal  $\Delta T$ :

This value represents the increase from a base temperature required to kill larval fish during entrainment. This lethal value is usually much higher than a conventional upper incipient lethal temperature since the time of exposure to the lethal  $\Delta T$  in a condenser is very brief allowing for no gradual acclimation (Moore 1979).

A median lethal  $\Delta T$  for heat shock or cold shock events represents the change in temperature above a given acclimation level that causes abnormal behaviour or physiological responses. The numerical value for the median lethal  $\Delta T$  is preceded by a plus (+) or minus (-) sign in the table to indicate whether it pertains to heat shock (+) or cold shock (-).

(j) Median Lethal Final:

This is the ultimate lethal temperature value experienced by entrained fish (ambient or base temperature +  $\Delta T$ ) Moore (1979).

### 3.0 DATABASE SUMMARY

#### 3.1 Organization

A summary of the species list and general categories of temperature data recorded for each species is given in Table 1. The species are listed by family, scientific name and common name. The species grouping is phylogenetic as is conventional in fisheries surveys (Christie 1982; Scott and Crossman 1973; Jobling 1981; Houston 1982). An alphabetical listing of the reviewed fish species by common name is provided in Table 2.

The bulk of the report consists of the fish temperature database tables arranged in taxonomic order by family. The species within families are in alphabetical order, according to their scientific name. Temperature data tables for each species appear in the following order: thermal tolerances; preferred temperatures; growth temperatures; spawning and development temperatures.

### 3.2 Content

The species frequency distribution for the four temperature data tables is summarized in Table 1. Evaluation of the availability of this data with respect to both these four temperature categories and fish species highlights the fact that large gaps in the available data presently exist. Complete temperature data, in all four major categories, was available for only 45 species. Of the remaining 71 species, only 17 were represented by data in three categories, 24 species represented in two categories and 23 species in only one category. In the database, a total of 45 commercial/game fish species were listed. Of these, 84 percent were represented in at least three of the four major tables of temperature data. This contrasts sharply with the situation for forage/coarse fish species where only 41 percent of a total of 71 species were represented in the database by at least three major data tables. Spotila et al (1979) noted the lack of temperature data on forage or coarse fish species such as darters (*Etheostomidae*), minnows (*Cyprinidae*), and suckers (*Castostomidae*), which are among the most thermally sensitive species. The temperature requirements of salmon and trout (*Salmonidae*); basses and sunfishes (*Centrarchidae*) are the most completely represented.

The database was also reviewed in relation to the relative frequency of occurrence of each of the four major types of temperature data (i.e. tolerances, preferred, growth, spawning and development). The category with the poorest (least) representation was GROWTH TEMPERATURES. This was not surprising in view of the fact that experimental determinations of temperature requirements for growth are more difficult and costly than those for survival, preference and reproduction (McCauley and Casselman 1980; Jobling 1981; Kellogg and Giff 1983). The paucity of growth data is unfortunate since changes in growth rate provide one of the few long-term indicators of species response to thermal effects (Kellogg and Giff 1983). Growth may be considered as an integrator of the mix of stresses affecting the metabolism of fish and, as such, a more sensitive index of environmental effects than mortality (Rodgers and Griffiths 1983). Recent contributions to the scientific literature have shown that growth criteria may be approximated from temperature preferenda and lethal temperatures (McCauley and Casselman 1980; Jobling 1981; Kellogg and Giff 1983).

Table 1. Great Lakes Fish Species and Types of Temperature Data.  
 Blank Space Means No Data Available.  
 Scientific and Common Names from Scott and Crossman (1973).

| Family   | Species                                 | Common Name            | Type of Temperature Data           |                        |                     |   |
|--|---|------------------------|------------------------------------|------------------------|---------------------|---|
|  |   |                        | Thermal <sup>1</sup><br>Tolerances | Preferred <sup>2</sup> | Growth <sup>3</sup> | Spawning<br>and <sup>4</sup><br>Development |
| Petromyzontidae<br>(Lampreys)                  | Petromyzon marinus                      | sea lamprey            | X                                  | X                      | X                   | X   |
| Acipenseridae<br>(Sturgeons)                   | Acipenser fulvescens                    | lake sturgeon          |                                    |                        |                     | X   |
| Lepisosteidae<br>(Gars)                        | Lepisosteus oculatus                    | spotted gar*           |                                    | X                      |                     |   |
|  | Lepisosteus osseus                      | longnose gar           |                                    | X                      | X                   |   |
| Amiidae<br>(Bowfin)                            | Amia calva                              | bowfin                 | X                                  | X                      |                     | X   |
| Clupeidae<br>(Herrings)                        | Alosa pseudoharengus                    | alewife                | X                                  | X                      | X                   | X   |
|  | Dorosoma cepedianum                     | gizzard shad           | X                                  | X                      | X                   | X   |
| Salmonidae<br>(Salmons, trouts<br>whitefishes) | Oncorhynchus gorbuscha                  | pink salmon            | X                                  | X                      | X                   | X   |
|  | Oncorhynchus kisutch                    | coho salmon            | X                                  | X                      | X                   | X   |
|  | Oncorhynchus nerka                      | kokanee salmon         | X                                  | X                      | X                   | X   |
|  | Oncorhynchus tshawytscha                | chinook salmon         | X                                  | X                      | X                   | X   |
|  | Salmo trutta                            | brown trout            | X                                  | X                      | X                   | X   |
|  | Salmo gairdneri                         | rainbow trout          | X                                  | X                      | X                   | X   |
|  | Salvelinus fontinalis                   | brook trout            | X                                  | X                      | x                   | X   |
|  | Salvelinus namaycush                    | lake trout             | X                                  | X                      | X                   | X   |
|  | Salvelinus fontinalis<br>x S. namaycush | splake                 | X                                  | X                      |                     | X   |
|  | Coregonus alpenae                       | longjaw cisco          |                                    |                        |                     |   |
|  | Coregonus artedii                       | cisco,<br>lake herring |                                    |                        | X                   |   |
|  | Coregonus hoyi                          | bloater*               | X                                  | X                      |                     | X   |
|  | Coregonus kiyi                          | kiyi*                  |                                    | X                      |                     | X   |
|  | Coregonus reighardi                     | shortnose cisco*       |                                    |                        |                     | X   |
|  | Coregonus zenithicus                    | shortjaw cisco         |                                    |                        |                     |   |
| Coregonus clupea<br>formis                     | lake whitefish                          | X                      | X                                  | X                      | X                   |   |
| Prosopium coulteri                             | pygmy whitefish*                        |                        |                                    |                        |                     |   |
| Prosopium cylindraceum                         | round whitefish                         |                        | X                                  |                        | X                   |   |
| Osmeridae<br>(Smelts)                          | Osmerus mordax                          | rainbow smelt          | X                                  | X                      | X                   | X   |
| Hiodontidae<br>(Mooneyes)                      | Hiodon tergisus                         | mooneye                |                                    | X                      |                     | X   |

Table 1. - Continued

| Family                     | Species                                       | Common Name               | Type of Temperature Data                |            |                     |  |
|----------------------------|---|---------------------------|---|------------|---------------------|--|
|                            |   |                           | Thermal <sup>1</sup><br>Toler-<br>ances | Preferred' | Growth <sup>3</sup> | Spawning<br>and <sup>4</sup><br>Develop-<br>ment |
| Umbridae<br>(Mudminnows)   | <i>Umbra limi</i>                             | central mud<br>minnow     | X                                       | X          |                     | X  |
| Esocidae<br>(Pikes)        | <i>Esox americanus</i><br><i>vermiculatus</i> | grass pickerel*           |   | X          |                     | X  |
|                            | <i>Esox lucius</i>                            | northern pike             | X                                       | X          | X                   | X  |
|                            | <i>Esox masquinongy</i>                       | muskellunge               | X                                       | X          | X                   | X  |
| Cyprinidae<br>(Minnows)    | <i>Campostoma anomalum</i>                    | stoneroller*              | X                                       | X          | X                   | X  |
|                            | <i>Chrosomus eos</i>                          | northern redbelly<br>dace | X                                       | X          |                     | X  |
|                            | <i>Chrosomus neogaeus</i>                     | finescale dace            | X                                       |            |                     | X  |
|                            | <i>Couesius plumbeus</i>                      | lake chub                 |   |            |                     | X  |
|                            | <i>Cyprinus carpio</i>                        | carp                      | X                                       | X          | X                   | X  |
|                            | <i>Exoglossum maxillingua</i>                 | cutlips minnow            |   | X          |                     | X  |
|                            | <i>Hybognathus hankinsoni</i>                 | brassy minnow             |   |            |                     | X  |
|                            | <i>Hybognathus nuchalis</i>                   | silvery minnow            |   |            |                     | X  |
|                            | <i>Hybopsis storeriana</i>                    | silver chub               |   |            |                     | X  |
|                            | <i>Nocomis biguttatus</i>                     | hornyhead chub            |   |            |                     | X  |
|                            | <i>Nocomis micropogon</i>                     | river chub                | X                                       |            |                     | X  |
|                            | <i>Notemigonus</i><br><i>crysoleucas</i>      | golden shiner             | X                                       | X          |                     | X  |
|                            | <i>Notropis anogenus</i>                      | pugnose shiner*           |   | X          |                     |  |
|                            | <i>Notropis atherinoides</i>                  | emerald shiner            | X                                       | X          | X                   | X  |
|                            | <i>Notropis bifrenatus</i>                    | bridle shiner             |   |            |                     | X  |
|                            | <i>Notropis cornutus</i>                      | common shiner             | X                                       |            |                     | X  |
|                            | <i>Notropis heterodon</i>                     | blackchin shiner          | X                                       |            |                     |  |
|                            | <i>Notropis heterolepis</i>                   | blacknose shiner          |   |            |                     |  |
|                            | <i>Notropis hudsonius</i>                     | spottail shiner           | X                                       | X          | X                   | X  |
|                            | <i>Notropis rubellus</i>                      | rosyface shiner           | X                                       | X          | X                   | X  |
|                            | <i>Notropis spilopterus</i>                   | spotfin shiner            | X                                       | X          | X                   | X  |
|                            | <i>Notropis stramineus</i>                    | sand shiner               | X                                       |            |                     |  |
|                            | <i>Notropis umbratilis</i>                    | redfin shiner             |   |            |                     |  |
|                            | <i>Notropis volucellus</i>                    | mimic shiner              |   |            |                     |  |
|                            | <i>Pimephales notatus</i>                     | bluntnose minnow          | X                                       | X          | X                   | X  |
|                            | <i>Pimephales promelas</i>                    | fathead minnow            | X                                       | X          | X                   | X  |
|                            | <i>Rhinichthys atratulus</i>                  | blacknose dace            | X                                       |            |                     | X  |
|                            | <i>Rhinichthys cataractae</i>                 | longnose dace             | X                                       | X          | X                   | X  |
|                            | <i>Semotilus</i><br><i>atromaculatus</i>      | creek chub                | X                                       |            |                     | X  |
|                            | <i>Semotilus corporalis</i>                   | fall fish                 |   | X          |                     | X  |
|                            | <i>Semotilus margarita</i>                    | pearl dace                |   |            |                     | X  |
|                            | <i>Carassius auratus</i>                      | gold fish                 | X                                       | X          | X                   | X  |
| Castostomidae<br>(Suckers) | <i>Carpoides cyprinus</i>                     | quillback                 | X                                       | X          |                     | X  |
|                            | <i>Catostomus catostomus</i>                  | longnose suckers          | X                                       | X          |                     | X  |
|                            | <i>Catostomus commersoni</i>                  | white sucker              | X                                       | X          | X                   | X  |
|                            | <i>Erimyzon sucetta</i>                       | lake chubsucker*          |   |            |                     | X  |
|                            | <i>Hypentelium nigricans</i>                  | northern hog<br>sucker    | X                                       | X          | X                   | X  |

Table 1. - Continued

| Family                                  | Species   | Common Name                        | Type of Temperature Data                |                        |                     |  |
|---|---|------------------------------------|---|------------------------|---------------------|--|
|   |   |                                    | Thermal <sup>1</sup><br>Toler-<br>ances | Preferred <sup>1</sup> | Growth <sup>3</sup> | Spawning<br>and <sup>4</sup><br>Develop-<br>ment |
| Castostomidae<br>(Suckers)              | <i>Ictiobus cyprinellus</i>                     | bigmouth buffalo*                  |   | X                      |                     | X  |
|   | <i>Minytrema melanops</i>                       | spotted sucker*                    | X                                       | X                      |                     | X  |
|   | <i>Moxostoma anisurum</i>                       | silver redhorse                    |   |                        |                     | X  |
|   | <i>Moxostoma<br/>macrolepidotum</i>             | shorthead red<br>horse             |   | X                      |                     | X  |
| Ictaluridae<br>(Catfishes)              | <i>Ictalurus melas</i>                          | black bullhead                     | X                                       | X                      |                     | X  |
|   | <i>Ictalurus natalis</i>                        | yellow bullhead                    | X                                       | X                      |                     |  |
|   | <i>Ictalurus nebulosus</i>                      | brown bullhead                     | X                                       | X                      | X                   | x  |
|   | <i>Ictalurus punctatus</i>                      | channel catfish                    | X                                       | X                      | X                   | X  |
|   | <i>Noturus flavus</i>                           | stonecat                           | X                                       | X                      |                     | X  |
|   | <i>Noturus gyrinus</i><br><i>Noturus miurus</i> | tadpole madtom<br>brindled madtom* | X                                       |                        |                     | X  |
| Anguillidae<br>(Eels)                   | <i>Anguilla rostrata</i>                        | american eel                       |   | X                      | X                   | X  |
| Cyprinodontidae<br>(Killifishes)        | <i>Fundulus diaphanus</i>                       | banded killifish                   | X                                       | X                      |                     | X  |
| Gadidae<br>(Cods)                       | <i>Lota lota</i>                                | burbot                             | X                                       | X                      | X                   | X  |
| Atherinidae<br>(Silversides)            | <i>Labiddesthes sicculus</i>                    | brook silverside                   |   | X                      |                     |  |
| Gasterosteidae<br>(Sticklebacks)        | <i>Culaea inconstans</i>                        | brook stickleback                  | X                                       |                        |                     | X  |
|   | <i>Gasterosteus aculeatus</i>                   | threespine<br>stickleback          | X                                       | X                      | X                   | X  |
|   | <i>Pungitius pungitius</i>                      | Ninespine<br>stickleback           |   | X                      |                     | X  |
| Percopsidae<br>(Trout-perches)          | <i>Percopsis omiscomaycus</i>                   | trout-perch                        | X                                       | X                      | X                   | X  |
| Percichthyidae<br>(Temperate<br>Basses) | <i>Morone americana</i>                         | white perch                        | X                                       | X                      | X                   | X  |
|   | <i>Morone chrysops</i>                          | white bass                         | X                                       | X                      | X                   | X  |
| Centrarchidae<br>(Sunfishes)            | <i>Ambloplites rupestris</i>                    | rock bass                          | X                                       | X                      | X                   | X  |
|   | <i>Lepomis cyanellus</i>                        | green sunfish*                     | X                                       | X                      | X                   | X  |
|   | <i>Lepomis gibbosus</i>                         | pumpkinseed                        | X                                       | X                      | X                   | X  |
|   | <i>Lepomis macrochirus</i>                      | bluegill                           | X                                       | X                      | X                   | X  |
|   | <i>Lepomis megalotis</i>                        | longear sunfish*                   | X                                       | X                      |                     | X  |
|   | <i>Micropterus dolomieu</i>                     | smallmouth bass                    | X                                       | X                      | X                   | X  |
|   | <i>Micropterus salmoides</i>                    | largemouth bass                    | X                                       | X                      | X                   | X  |
|   | <i>Pomoxis annularis</i>                        | white crappie                      | X                                       | X                      | X                   | X  |
|   | <i>Pomoxis nigromaculatus</i>                   | black crappie                      | X                                       | X                      | X                   | X  |

Table 1. - Continued

| Family                 | Species                           | Common Name          | Type of Temperature Data           |                        |                     |   |
|------------------------|-----------------------------------|----------------------|------------------------------------|------------------------|---------------------|---|
|                        |                                   |                      | Thermal <sup>1</sup><br>Tolerances | Preferred <sup>1</sup> | Growth <sup>3</sup> | Spawning<br>and <sup>4</sup><br>Development |
| Percidae<br>(Perches)  | <i>Perca flavescens</i>           | yellow perch         | X                                  | X                      | X                   | X   |
|                        | <i>Stizostedion canadense</i>     | sauger               | X                                  | X                      | X                   | X   |
|                        | <i>Stizostedion vitreum</i>       | walleye              | X                                  | X                      | X                   | X   |
|                        | <i>Ammocrypta pellucida</i>       | eastern sand darter* |                                    | X                      |                     |   |
|                        | <i>Etheostoma blennoides</i>      | greenside darter     | X                                  |                        |                     |   |
|                        | <i>Etheostoma caeruleum</i>       | rainbow darter       | X                                  | X                      |                     | X   |
|                        | <i>Etheostoma exile</i>           | lowa darter          |                                    | X                      |                     | X   |
|                        | <i>Etheostoma flabellare</i>      | fantail darter       | X                                  |                        |                     | X   |
|                        | <i>Etheostoma microperca</i>      | least darter*        |                                    |                        |                     | X   |
|                        | <i>Etheostoma nigrum</i>          | johnny darter        | X                                  | X                      |                     | X   |
|                        | <i>Percina caprodes</i>           | log perch            |                                    | X                      |                     | X   |
|                        | <i>Percina copelandi</i>          | channel darter*      |                                    |                        |                     | X   |
|                        | <i>Percina maculata</i>           | blackside darter     |                                    |                        |                     | X   |
| Sciaenidae<br>(Drums)  | <i>Aplodinotus grunniens</i>      | freshwater drum      | X                                  | X                      | X                   | X   |
| Cottidae<br>(Sculpins) | <i>Cottus bairdi</i>              | mottled sculpin      | X                                  | X                      |                     | X   |
|                        | <i>Cottus cognatus</i>            | slimy sculpin        | X                                  | X                      |                     | X   |
|                        | <i>Cottus ricei</i>               | Spoonhead sculpin    |                                    |                        |                     | X   |
|                        | <i>Myoxocephalus quadricornis</i> | deepwater sculpin    |                                    | X                      |                     | X   |

\* listed as rare or threatened species by McAllister et al (1985).

1. Includes: upper and lower incipient lethal; thermal resistance equations and times; critical thermal maximum.
2. Includes: final preferendum; upper and lower avoidance temperatures; preferred temperatures.
3. Includes: growth optimum and range; upper and lower thermal limits for growth: maximum weekly average temperature for growth over long term; maximum temperature for non-lethal, short-term exposure.
4. Includes: temperature optimum and range for spawning: maximum weekly average for spawning; embryo survival temperature; larval entrainment temperatures and survival levels; impingement temperatures; heat and cold shock temperatures.



TABLE 2  
ALPHABETICAL LISTING OF REVIEWED  
FISH SPECIES BY COMMON NAME

| Common Name         | Scientific Name                   | Family Name     |
|---------------------|-----------------------------------|-----------------|
| Alewife             | <i>Alosa pseudoharengus</i>       | Clupeidae       |
| American Eel        | <i>Anguilla rostrata</i>          | Anguillidae     |
| Banded Killifish    | <i>Fundulus diaphanus</i>         | Cyprinodontidae |
| Bigmouth Buffalo    | <i>Ictiobus cyprinellus</i>       | Castostomidae   |
| Black Bullhead      | <i>Ictalurus melas</i>            | Ictaluridae     |
| Black Crappie       | <i>Pomoxis nigromaculatus</i>     | Centrarchidae   |
| Blackchin Shiner    | <i>Notropis heterodon</i>         | Cyprinidae      |
| Blacknose Dace      | <i>Rhinichthys atratulus</i>      | Cyprinidae      |
| Blackside Darter    | <i>Percina maculata</i>           | Percidae        |
| Bloater             | <i>Coregonus hoyi</i>             | Salmonidae      |
| Bluegill            | <i>Lepomis macrochirus</i>        | Centrarchidae   |
| Bluntnose Minnow    | <i>Pimephales notatus</i>         | Cyprinidae      |
| Bowfin              | <i>Amia calva</i>                 | Amiidae         |
| Brassy Minnow       | <i>Hybognathus hankinsoni</i>     | Cyprinidae      |
| Bridle Shiner       | <i>Notropis bifrenatus</i>        | Cyprinidae      |
| Brindled Madtom     | <i>Noturus miurus</i>             | Ictaluridae     |
| Brook Silverside    | <i>Labidesthes sicculus</i>       | Atherinidae     |
| Brook Stickleback   | <i>Culaea inconstans</i>          | Gasterosteidae  |
| Brook Trout         | <i>Salvelinus fontinalis</i>      | Salmonidae      |
| Brown Bullhead      | <i>Ictalurus nebulosus</i>        | Ictaluridae     |
| Brown Trout         | <i>Salmo trutta</i>               | Salmonidae      |
| Burbot              | <i>Lota lota</i>                  | Gadidae         |
| Carp                | <i>Cyprinus carpio</i>            | Cyprinidae      |
| Central Mudminnow   | <i>Umbra limi</i>                 | Umbridae        |
| Channel Cat         | <i>Ictalurus punctatus</i>        | Ictaluridae     |
| Channel Darter      | <i>Percina copelandi</i>          | Percidae        |
| Chinook Salmon      | <i>Oncorhynchus tshawytscha</i>   | Salmonidae      |
| Cisco, Lake Herring | <i>Coregonus artedii</i>          | Salmonidae      |
| Coho Salmon         | <i>Oncorhynchus kisutch</i>       | Salmonidae      |
| Common Shiner       | <i>Notropis cornutus</i>          | Cyprinidae      |
| Creek Chub          | <i>Semotilus atromaculatus</i>    | Cyprinidae      |
| Cutlips Minnow      | <i>Exoglossum maxillingua</i>     | Cyprinidae      |
| Deepwater Sculpin   | <i>Myoxocephalus quadricornis</i> | Cottidae        |
| Eastern Sand Darter | <i>Ammocrypta pellucida</i>       | Percidae        |
| Emerald Shiner      | <i>Notropis atherinoides</i>      | Cyprinidae      |
| Fall Fish           | <i>Semotilus corporalis</i>       | Cyprinidae      |
| Fantail Darter      | <i>Etheostoma flabellare</i>      | Percidae        |
| Fathead Minnow      | <i>Pimephales promelas</i>        | Cyprinidae      |
| Finescale Dace      | <i>Chrosomus neogaeus</i>         | Cyprinidae      |
| Freshwater Drum     | <i>Aplodinotus grunniens</i>      | Sciaenidae      |
| Gizzard Shad        | <i>Dorosoma cepedianum</i>        | Clupeidae       |
| Golden Shiner       | <i>Notemigonus crysoleucas</i>    | Cyprinidae      |

TABLE 2 - Continued

| Common Name                  | Scientific Name                     | Family Name     |
|------------------------------|-------------------------------------|-----------------|
| Goldfish                     | <i>Carassius auratus</i>            | Cyprinidae      |
| Grass Pickerel               | <i>Esox americanus vermiculatus</i> | Esocidae        |
| Green Sunfish                | <i>Lepomis cyanellus</i>            | Centrarchidae   |
| Greenside Darter             | <i>Etheostoma blennoides</i>        | Percidae        |
| Hornyhead Chub               | <i>Nocomis biguttatus</i>           | Cyprinidae      |
| Iowa Darter                  | <i>Etheostoma exile</i>             | Percidae        |
| Johnny Darter                | <i>Etheostoma nigrum</i>            | Percidae        |
| Kiyi                         | <i>Coregonus kiyi</i>               | Salmonidae      |
| Kokanee Salmon               | <i>Oncorhynchus nerka</i>           | Salmonidae      |
| Lake Chub                    | <i>Couesius plumbeus</i>            | Cyprinidae      |
| Lake Chubsucker              | <i>Erimyzon sucetta</i>             | Castostomidae   |
| Lake Herring, Cisco          | <i>Coregonus artedii</i>            | Salmonidae      |
| Lake Sturgeon                | <i>Acipenser fulvescens</i>         | Acipenseridae   |
| Lake Trout                   | <i>Salvelinus namaycush</i>         | Salmonidae      |
| Lake Whitefish               | <i>Coregonus clupeaformis</i>       | Salmonidae      |
| Lamprey, Sea                 | <i>Petromyzon marinus</i>           | Petromyzontidae |
| Largemouth Bass              | <i>Micropterus salmoides</i>        | Centrarchidae   |
| Least Darter                 | <i>Etheostoma microperca</i>        | Percidae        |
| Log Perch -                  | <i>Percina caprodes</i>             | Percidae        |
| Longear Sunfish              | <i>Lepomis megalotis</i>            | Centrarchidae   |
| Longnose Dace                | <i>Rhinichthys cataractae</i>       | Cyprinidae      |
| longnose Gar                 | <i>Lepisosteus osseus</i>           | Lepisosteidae   |
| Longnose Sucker              | <i>Catostomus catostomus</i>        | Castostomidae   |
| Mooneye                      | <i>Hiodon tergisus</i>              | Hiodontidae     |
| Mottled Sculpin              | <i>Cottus bairdi</i>                | Cottidae        |
| Muskellunge                  | <i>Esox masquinongy</i>             | Esocidae        |
| Ninespine Stickleback        | <i>Pungitius pungitius</i>          | Gasterosteidae  |
| Northern Hogsucker           | <i>Hypentelium nigricans</i>        | Castostomidae   |
| Northern Pike                | <i>Esox lucius</i>                  | Esocidae        |
| Northern Redbelly dace       | <i>Chrosomus eos</i>                | Cyprinidae      |
| Pearl Dace                   | <i>Semotilus margarita</i>          | Cyprinidae      |
| Pink Salmon                  | <i>Oncorhynchus gorbuscha</i>       | Salmonidae      |
| Pugnose Shiner               | <i>Notropis anogenus</i>            | Cyprinidae      |
| Pumpkinseed                  | <i>Lepomis gibbosus</i>             | Centrarchidae   |
| Quillback                    | <i>Carpoides cyprinus</i>           | Cyprinidae      |
| Rainbow Darter               | <i>Etheostoma caeruleum</i>         | Percidae        |
| Rainbow Smelt                | <i>Osmerus mordax</i>               | Osmeridae       |
| Rainbow Trout                | <i>Salmo gairdneri</i>              | Salmonidae      |
| River Chub                   | <i>Nocomis micropogon</i>           | Cyprinidae      |
| Rock Bass                    | <i>Ambloplites rupestris</i>        | Centrarchidae   |
| Rosyface Shiner              | <i>Notropis rubellus</i>            | Cyprinidae      |
| Round Whitefish              | <i>Prosopium cylindraceum</i>       | Salmonidae      |
| Sand Shiner                  | <i>Notropis stramineus</i>          | Cyprinidae      |
| Sauger                       | <i>Stizostedion canadense</i>       | Percidae        |
| Sea Lamprey                  | <i>Petromyzon marinus</i>           | Petromyzontidae |
| Sheepshead (Freshwater Drum) | <i>Aplodinotus grunniens</i>        | Sciaenidae      |

TABLE 2 - Continued

| Common Name               | Scientific Name                                    | Family Name    |
|---------------------------|--|----------------|
| Shorthead Redhorse        | <i>Moxostoma macrolepidotum</i>                    | Castostomidae  |
| Silver Chub               | <i>Hybopsis storeriana</i>                         | Cyprinidae     |
| Silver Redhorse           | <i>Moxostoma anisurum</i>                          | Castostomidae  |
| Silvery Minnow            | <i>Hybognathus nuchalis</i>                        | Cyprinidae     |
| Slimy Sculpin             | <i>Cottus cognatus</i>                             | Cottidae       |
| Smallmouth Bass           | <i>Micropterus dolomieu</i>                        | Centrarchidae  |
| Spoonhead Sculpin         | <i>Cottus ricei</i>                                | Cottidae       |
| Splake                    | <i>Salvelinus fontinalis</i> x <i>S. namaycush</i> | Salmonidae     |
| Spotfin Shiner            | <i>Notropis spilopterus</i>                        | Cyprinidae     |
| Spottail Shiner           | <i>Notropis hudsonius</i>                          | Cyprinidae     |
| Spotted Gar               | <i>Lepisosteus oculatus</i>                        | Lepistosteidae |
| Spotted Sucker            | <i>Minytrema melanops</i>                          | Castostomidae  |
| Stonecat                  | <i>Noturus flavus</i>                              | Ictaluridae    |
| Stoneroller               | <i>Campostoma anomalum</i>                         | Cyprinidae     |
| Tadpole Madtom            | <i>Noturus gyrinus</i>                             | Ictaluridae    |
| Threespine Stickleback    | <i>Gasterosteus aculeatus</i>                      | Gasterosteidae |
| Trout-perch               | <i>Percopsis omiscomaycus</i>                      | Percopsidae    |
| Walleye                   | <i>Stizostedion vitreum</i>                        | Percidae       |
| White Bass                | <i>Morone chrysops</i>                             | Percichthyidae |
| White Crappie             | <i>Pomoxis annularis</i>                           | Centrarchidae  |
| White Perch               | <i>Morone americana</i>                            | Percichthyidae |
| White Sucker              | <i>Catostomus commersoni</i>                       | Castostomidae  |
| Yellow Bullhead           | <i>Ictalurus natalis</i>                           | Ictaluridae    |
| Yellow Perch              | <i>Perca flavescens</i>                            | Percidae       |
| Yellow Pickerel (Walleye) | <i>Stizostedion vitreum</i>                        | Percidae       |

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The authors are continually updating the document with plans to design a fish computer information database. Any comments, corrections or additional data and/or references are requested to be forwarded to the authors at Ontario Hydro.

## 5.0 FISH TEMPERATURE DATABASE

### 5.1 Abbreviations

#### Size

- TL = total length in millimeters. See Carlander (1977) for definition.
- FL = fork length in millimeters. See Carlander (1977) for definition. A single number or range of numbers in the size column of a database table represents FL in millimeters.
- SL = standard length in millimeters. See Carlander (1977) for definition.

g = weight in grams

in = length in inches

#### Age

d = day(s)

mo = month(s)

wk = week(s)

yr = year

YOY = young-of-the-year

egg = embryo inside egg envelope (Balon 1984)

free embryo  
(yolk-sac

larva) = hatched but uses endogenous food supply - yolk sac (Balon 1984).

embryo = endogenous feeding, not free-swimming

fry = exogenous feeding, free-swimming, rising or risen from nesting site, jerky swimming.

larval = can include fry stage, but usually implies the transition from jerky to fluent free-swimming is complete, beginning of schooling, dispersing from nest site.

juvenile = older YOY; less than or equal to one year old; younger yearlings (aged 1-1.5 year). A sub-adult is a juvenile older than 1.5 years up to the age of first maturity (McCauley and Casselman 1980).

adult = sexually mature

#### Temperature

Temperature, values in the columns of the database tables are given in degrees celsius unless otherwise indicated as degrees Fahrenheit by F symbol after the number.

Seasons

SP = Spring

Su = Summer

F = Fall

Wi or W = Winter

Day or Night

D = Day

N = Night



SPECIES: Petromyzon marinus (sea lamprey)

| Size or Age (mm)    | Acclimation Temp | Acclimation Time | Season | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time =     |    | Data Limits |       | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | THERMAL TOLERANCES: |                    |
|---------------------|------------------|------------------|--------|--------------------------|--------------------------|----------------|----|-------------|-------|---------------|-----------------------|------------------------|---------------------|--------------------|
|                     |                  |                  |        |                          |                          | a              | b  | Upper       | Lower |               |                       |                        | Location            | Reference          |
|                     |                  |                  |        |                          |                          |                |    |             |       |               |                       |                        |                     |                    |
| egg (64 cell)       | 18               |                  |        | 12                       |                          |                |    |             |       |               |                       |                        |                     | Spotila et al 1979 |
| egg (64 cell)       | 18               |                  |        | 14                       |                          |                |    |             |       |               |                       |                        |                     | Spotila et al 1979 |
| egg (64 cell)       | 18               |                  |        | 23                       |                          |                |    |             |       |               |                       |                        |                     | Spotila et al 1979 |
| egg                 | 18               |                  |        | 20                       |                          |                |    |             |       |               |                       |                        |                     | Spotila et al 1979 |
|                     |                  |                  |        | 31                       |                          |                |    |             |       |               |                       |                        |                     | Jobling 1981       |
| prolarva ammocoetes | 15120            |                  |        | > 29.5                   |                          |                |    |             |       |               |                       |                        |                     | Carlander 1969     |
|                     | 5                |                  |        | 28.5                     |                          | 17.5642-0.4680 | 34 | 29          |       |               |                       |                        | Great Lakes         | Brown 1974         |
|                     | 15               |                  |        |                          |                          |                |    |             |       |               |                       | 29.5                   |                     | Spotila et al 1979 |
|                     | 25               |                  |        |                          |                          |                |    |             |       |               |                       | 30                     |                     | Spotila et al 1979 |
|                     |                  |                  |        | 31.4                     |                          |                |    |             |       |               |                       | 31                     |                     | Spotila et al 1979 |

SPECIES: Petromyzon marinus (sea lamprey)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES: |                         | Reference                |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------|-------------------------|--------------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                |                         |                          |
| larvae           |        |              |                 | 13.6              |                 |                         |                  |                         |                         | Jobling 1981             |
| adult            |        |              |                 | 14.3              |                 |                         | 10               |                         |                         | Talmage and Coutant 1979 |
|                  | su     |              |                 | 6-15              |                 |                         |                  |                         |                         | Morman et al 1980        |
|                  | SP     |              |                 | < 6               |                 |                         |                  |                         |                         | Morman et al 1980        |
| ammocoetes       | Su     |              |                 | 10-26.1           |                 |                         |                  |                         | Streams                 | Morman et al 1980        |
| larvae           |        |              |                 | 15-20             |                 |                         |                  |                         | L. Superior tributaries | Morman et al 1980        |

SPECIES: Petromyzon marinus (sea lamprey)

| Size or Age (mm) | Optimum °C | Range | (b) ST Max |     | No Growth Limits |       | Location    | GROWTH TEMPERATURES: |                   |
|------------------|------------|-------|------------|-----|------------------|-------|-------------|----------------------|-------------------|
|                  |            |       | (a) MWAT   | Max | Upper            | Lower |             | Reference            |                   |
| 30-90 g; large   | 15         |       |            |     |                  |       | land locked |                      | Farmer et al 1977 |
| 10-30 g; small   | 20         |       |            |     |                  |       |             |                      | Farmer et al 1977 |
|                  |            |       |            |     |                  | <3    |             |                      | Farmer et al 1977 |
|                  |            |       | 20.5       | 28  |                  |       |             |                      | This study        |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: Petromyzon marinus (sea lamprey)

| Event                   | Season and/or Acclimation Temp | Optimum Temp | (a) Temp Range MWAT |           | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | (d) Median Lethal ΔT | (d) Median Lethal Final | Location                 | Reference   |
|-------------------------|--------------------------------|--------------|---------------------|-----------|--------------------------------|------------------|------------------------|------------------------|----------------------|-------------------------|--------------------------|---|
|                         |                                |              | Temp                | MWAT      |                                |                  |                        |                        |                      |                         |                          |   |
| spawning migration      |                                |              |                     | >4.4      |                                |                  |                        |                        |                      |                         |                          | Scott and Crossman 1973                                   |
| spawning onset          |                                |              |                     | 11.1-11.7 |                                |                  |                        |                        |                      |                         |                          | Scott and Crossman 1973                                   |
| spawning hatching (14d) |                                | 14.4-15.6    |                     | 11.1-24.4 |                                |                  |                        |                        |                      |                         | hatchery Cayuga L.. N.Y. | Scott and Crossman 1973                                   |
| swim-up hatching        |                                | 18.3         |                     | 13.9-18.3 |                                |                  |                        |                        |                      |                         |                          | Scott and Crossman 1973                                   |
| metamorphosis           |                                | 21.7         |                     | 15.5-21   |                                |                  |                        |                        |                      |                         | Lab                      | Scott and Crossman 1973<br>Carlander 1969<br>Cravens 1982 |
| egg incubation          | 7.5-27                         | 18.5         |                     | 7-21      |                                |                  | 21.5                   | 16                     |                      |                         |                          | Beltz et al 1974  |
| spawning                |                                | 15.5         |                     |           |                                |                  |                        |                        |                      |                         | L. Huron                 | Manion and Hanson 1980                                    |
| spawning                |                                | 14.0         |                     | 12.8-18.3 |                                |                  |                        |                        |                      |                         | Gt. Lakes                | Manion and Hanson 1980                                    |
| spawning                |                                | 15.7         |                     | 10-22.8   |                                |                  |                        |                        |                      |                         | Gt. Lakes                | Manion and Hanson 1980                                    |
| spawning                |                                | 18.2         |                     | 11.1-26.1 |                                |                  |                        |                        |                      |                         | Gt. Lakes                | Manion and Hanson 1980                                    |
| spawning                |                                |              |                     | 11-25     |                                |                  |                        |                        |                      |                         |                          | Morman et al 1980   |
| larval devel            |                                | 20-21        |                     | 10-26,1   |                                |                  |                        |                        |                      |                         |                          | Morman et al 1980   |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

| Event           | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal $\Delta T$ | (d) Median Lethal Final | Location | Reference               |
|-----------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|--------------------------|-------------------------|----------|-------------------------|
| spawning        |                                | 13-18        |            |          |                                |                  |                        |                        |                          |                         |          | Scott and Crossman 1973 |
| hatching (5-8d) |                                | 15.6-17.8    |            |          |                                |                  |                        |                        |                          |                         |          | Scott and Crossman 1973 |
| spawning        |                                |              | 12-15      |          |                                |                  |                        |                        |                          |                         | Wisc.    | Carlander 1969          |
| spawning        |                                |              | 12-19      |          |                                |                  |                        |                        |                          |                         | Ont.     | Carlander 1969          |
| spawning        |                                | 18.4         |            |          |                                |                  |                        |                        |                          |                         | Que.     | Carlander 1969          |
|                 |                                |              |            | 15.5     | 19                             |                  |                        |                        |                          |                         |          | This study              |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Lepisosteus oculatus* (spotted gar)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES:   |                       |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|---------------------------|-----------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                  | Reference             |
|                  |        |              | >35             |                   |                 |                         |                  | Colbert G.S. Tennessee R. | Beltz et al 1974      |
|                  |        |              |                 | 15-17             |                 |                         |                  | Rondeau Bay, L. Erie      | McAllister et al 1985 |

SPECIES: *Lepisosteus osseus* (longnose gar)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES:       |                       |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------------|-----------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                      | Reference             |
| large            |        |              |                 | 30-31.8           |                 |                         |                  | L. Monona, Wisc.              | Coutant 1977a         |
| large YOY        | Su     |              | 34.5            | 25.3              | 29              |                         |                  | Wabash R., Ind.               | Coutant 1977a         |
| adult            | su     |              |                 | 33.1              |                 |                         |                  | Lab                           | Coutant 1977a         |
|                  | Su     |              |                 | 30-34             |                 |                         |                  | J.M. Stuart GS, Ohio R., Ohio | Yoder and Gammon 1976 |
|                  | F      |              |                 | 24-28             |                 |                         |                  | J.M. Stuart GS, Ohio R., Ohio | Yoder and Gammon 1976 |
|                  | W      |              |                 | 12-16             |                 |                         |                  | J.M. Stuart GS, Ohio R., Ohio | Yoder and Gammon 1976 |
|                  |        |              |                 | 33-35             |                 |                         |                  | Wabash R., Ind.               | Yoder and Gammon 1976 |
|                  |        |              |                 | 34                |                 |                         |                  | White R., Ind.                | Yoder and Gammon 1976 |

SPECIES: *Lepisosteus osseus* (longnose gar)

| Size or Age (mm) | Optimum °C | Range | (a) MWAT | (b) ST Max | No Growth Upper | Limits Lower | Location | GROWTH TEMPERATURES: |      |
|------------------|------------|-------|----------|------------|-----------------|--------------|----------|----------------------|------|
|                  |            |       |          |            |                 |              |          | Reference            |      |
|                  | 26.4       |       |          |            |                 |              | Lab      | Scott and Crossman   | 1973 |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Amia calva* [bowfin]

|                  |                  |                  |        |                          |                          |                         |  |                   |                   |               |                       |                        | THERMAL TOLERANCES: |                             |
|------------------|------------------|------------------|--------|--------------------------|--------------------------|-------------------------|--|-------------------|-------------------|---------------|-----------------------|------------------------|---------------------|-----------------------------|
| Size or Age (mm) | Acclimation Temp | Acclimation Time | Season | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = a + b (temp) |  | Data Limits Upper | Data Limits Lower | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location            | Reference                   |
|                  | 23.8             |                  | su     |                          |                          |                         |  |                   |                   |               |                       | 37                     | Lab                 | Reutter and Herdendorf 1976 |

SPECIES: *Amia calva* (bowfin)

|                  |        |              |                 |                   |                 |                         |                  |          |              | PREFERRED TEMPERATURES: |  |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|----------|--------------|-------------------------|--|
| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | Location | Reference    |                         |  |
|                  |        |              |                 | 30.5              |                 |                         |                  | Lab      | Houston 1982 |                         |  |

SPECIES: *Amia calva* (bowfin)

|          |                                |              |            |          |                                |                  |                        |                        |                          |                         |          |                                       | SPAWNING AND DEVELOPMENT TEMPERATURES: |  |
|----------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|--------------------------|-------------------------|----------|---------------------------------------|--|--|
| Event    | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal $\Delta T$ | (d) Median Lethal Final | Location | Reference                             |  |  |
| spawning |                                | 16-19        |            | 17.5     | 19+                            |                  |                        |                        |                          |                         |          | Scott and Crossman 1973<br>This study |  |  |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures,

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Nor incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval **entrainment** temperatures.

SPECIES: *Alosa pseudoharengus* (alewife)

THERMAL TOLERANCES:

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Season | Upper       | Lower       | log time = |   | Data Limits |       | Exposure Time (Min) | Resistance Time (Min) | Critical Thermal (Max) | Location    | Reference                   |
|------------------|------------------|------------------|--------|-------------|-------------|------------|---|-------------|-------|---------------------|-----------------------|------------------------|-------------|-----------------------------|
|                  |                  |                  |        | Lethal Temp | Lethal Temp | a          | b | Upper       | Lower |                     |                       |                        |             |                             |
| egg              | 12-25            |                  |        | 24.5        |             |            |   |             |       |                     | 60                    |                        | Lab         | Jinks et al 1981            |
| larva            | 14-24            |                  |        | 37.1        |             |            |   |             |       |                     | 5                     |                        |             | Jinks et al 1981            |
| larva            | 14-24            |                  |        | 36.1        |             |            |   |             |       |                     | 10                    |                        |             | Jinks et al 1981            |
| larva            | 14-24            |                  |        | 34.5        |             |            |   |             |       |                     | 30                    |                        |             | Jinks et al 1981            |
| larva            | 14-24            |                  |        | 33.4        |             |            |   |             |       |                     | 60                    |                        |             | Jinks et al 1981            |
| larva            | 14-24            |                  |        | 31.4        |             |            |   |             |       |                     | 1440                  |                        |             | Jinks et al 1981            |
| 71-80; YOY       | 23-25            |                  |        | 32.9        |             |            |   |             |       |                     | 60                    |                        |             | Jinks et al 1981            |
| 71-80; YOY       | 23.25            |                  |        | 32.2        |             |            |   |             |       |                     | 1440                  |                        |             | Jinks et al 1981            |
| 71-80; YOY       | 23.25            |                  |        | 32.2        |             |            |   |             |       |                     | 5760                  |                        |             | Jinks et al 1981            |
| 28 47; YOY       | 10-12            |                  |        | 26.5        |             |            |   |             | 26.5  |                     | 150                   |                        |             | Otto et al 1976             |
| 28 47; YOY       | 18-20            |                  |        | 30.3        |             |            |   |             | 30.5  |                     | 170                   |                        |             | Otto et al 1976             |
| 28 47; YOY       | 24-26            |                  |        | 32.1        |             |            |   |             | 32.0  |                     | 520                   |                        |             | Otto et al 1976             |
| egg              | 13               |                  |        | 28          |             |            |   |             |       |                     |                       |                        |             | Jinks et al 1981            |
| juvenile         |                  |                  |        |             | 3           |            |   |             |       |                     |                       |                        |             | Richkus and Winn 1979       |
| adult            | 27               |                  |        | 28.2        |             |            |   |             | 27    |                     | 14000                 | 31-34                  | Lab         | McCauley and Binkowski 1982 |
|                  |                  |                  |        |             |             |            |   |             | 20    |                     | 13757                 |                        |             | McCauley and Binkowski 1982 |
|                  |                  |                  |        |             |             |            |   |             | 29    |                     | 8400                  |                        |             | McCauley and Binkowski 1982 |
|                  |                  |                  |        |             |             |            |   |             | 30    |                     | 3441                  |                        |             | McCauley and Binkowski 1982 |
|                  |                  |                  |        |             |             |            |   |             | 31    |                     | 377                   |                        |             | McCauley and Binkowski 1982 |
|                  |                  |                  |        |             |             |            |   |             | 32    |                     | 74                    |                        |             | McCauley and Binkowski 1982 |
|                  |                  |                  |        |             |             |            |   |             | 33    |                     | 37                    |                        |             | McCauley and Binkowski 1962 |
|                  | 17.2             |                  |        |             | 7           |            |   |             |       |                     |                       |                        |             | Spotila et al 1979          |
| adult            | 10               |                  |        | 23.5        |             |            |   |             |       |                     |                       | 28.6                   |             | Otto et al 1976             |
| adult            | 15               |                  |        | 23.5        |             |            |   |             |       |                     |                       | 30.6                   |             | Otto et al 1976             |
| adult            | 20               |                  |        | 24.5        |             |            |   |             |       |                     |                       | 32.6                   |             | Otto et al 1976             |
| YOY              | 25               |                  |        | 32.1        |             |            |   |             |       |                     |                       | 34.4                   |             | Otto et al 1976             |
| YOY              | 10               |                  |        | 26.5        |             |            |   |             |       |                     |                       | 26.3                   |             | Otto et al 1976             |
| YOY              | 20               |                  |        | 30.3        |             |            |   |             |       |                     |                       | 31.9                   |             | Otto et al 1976             |
| adult            | 21               |                  |        |             |             |            |   |             |       |                     |                       |                        | Lab         | Otto et al 1976             |
| adult            | 5.21             |                  |        |             |             |            |   |             |       |                     |                       |                        | Lab (ULILT) | Otto et al 1976             |

| Size or Age<br>(mm) | Accli-<br>mation<br>Temp | Accli-<br>mation<br>Time | Sea-<br>son | THERMAL TOLERANCES:                      |                                   |            |       |             |    |                       |                                  |                              |               | Reference                  |
|---------------------|--------------------------|--------------------------|-------------|--|-----------------------------------|------------|-------|-------------|----|-----------------------|----------------------------------|------------------------------|---------------|----------------------------|
|                     |                          |                          |             | Upper<br><b>Incip.</b><br>Lethal<br>Temp | Lower<br>Incip.<br>Lethal<br>Temp | log time = |       | Data Limits |    | Expo-<br>sure<br>Temp | Resis-<br>tance<br>Time<br>(Min) | Critical<br>Thermal<br>(Max) | Location      |                            |
|                     |                          |                          |             | a  | b                                 | Upper      | Lower |             |    |                       |                                  |                              |               |                            |
| juvenile            | 17                       |                          | SU          | 24.5                                     |                                   |            |       |             |    | 31                    | 10                               |                              | Lab           | McCauley 1331              |
| juvenile            | 17                       |                          | su          |  |                                   |            |       |             |    | 30                    | 57                               |                              | Lab           | McCauley 1981              |
| juvenile            | 17                       |                          | su          |  |                                   |            |       |             |    | 23                    | 106                              |                              | Lab           | McCauley 1381              |
| juvenile            | 17                       |                          | SU          |  |                                   |            |       |             |    | 28                    | 1060                             |                              | Lab           | McCauley 1981              |
| juvenile            | 17                       |                          | su          |  |                                   |            |       |             |    | 27                    | 1880                             |                              | Lab           | McCauley 1981              |
| juvenile            | 17                       |                          | su          |  |                                   |            |       |             |    | 26                    | 2800                             |                              | Lab           | McCauley 1981              |
| juvenile            | 17                       |                          | SU          |  |                                   |            |       |             |    | 25                    | 2150                             |                              | Lab           | McCauley 1981              |
| juvenile            | 9                        |                          | SU          | <23                                      |                                   |            |       |             |    |                       |                                  |                              | Lab           | McCauley 1981              |
| juvenile            | 20                       |                          |             | 24.5                                     |                                   |            |       |             |    |                       |                                  |                              | Lab           | McCauley 1981              |
| adult               | 17                       |                          |             | 8.5                                      |                                   |            |       |             |    |                       |                                  |                              | Lab           | McCauley 1981              |
| adult               | 15                       |                          |             | 7  |                                   |            |       |             |    |                       |                                  |                              | Lab           | McCauley 1981              |
| juvenile            |                          |                          | su          | 5-10                                     |                                   |            |       |             |    |                       |                                  |                              | Lab           | McCauley 1981              |
| adult               |                          |                          | su          |  |                                   |            |       |             | 5  | 3600                  |                                  |                              | Lab (L. Ont.) | McCauley 1981              |
| adult               |                          |                          | su          |  |                                   |            |       |             | 6  | 4980                  |                                  |                              | Lab (L. Ont.) | McCauley 1981              |
| adult               |                          |                          | su          |  |                                   |            |       |             | 7  | 9480                  |                                  |                              | Lab (L. Ont.) | McCauley 1981              |
| adult               |                          |                          | su          |  |                                   |            |       |             | 8  | 8100                  |                                  |                              | Lab (L. Ont.) | McCauley 1981              |
| adult               |                          |                          | su          |  |                                   |            |       |             | 9  | >12360                |                                  |                              | Lab (L. Ont.) | McCauley 1981              |
| adult               |                          |                          | su          |  |                                   |            |       |             | 5  | 1620                  |                                  |                              | Lab (L. Ont.) | McCauley 1981              |
| adult               |                          |                          | SU          |  |                                   |            |       |             | 6  | 2181                  |                                  |                              | Lab (L. Ont.) | McCauley 1981              |
| adult               |                          |                          | Su          |  |                                   |            |       |             |    | 2550                  |                                  |                              | Lab (L. Ont.) | McCauley 1981              |
| adult               |                          |                          | su          |  |                                   |            |       |             | 8  | 1662                  |                                  |                              | Lab (L. Ont.) | McCauley 1981              |
| adult               |                          |                          | Su          |  |                                   |            |       |             | 9  | 2250                  |                                  |                              | Lab (L. Ont.) | McCauley 1981              |
| adult               |                          |                          | su          |  |                                   |            |       |             | 10 | 6054                  |                                  |                              | Lab (L. Ont.) | McCauley 1981              |
| adult               |                          |                          |             |  |                                   |            |       |             |    |                       |                                  |                              | Lab (L. Ont.) | McCauley 1981              |
| adult               | 20                       |                          |             |  |                                   |            |       |             |    |                       |                                  |                              |               | McCauley 1981              |
| adult               |                          |                          | W           |  |                                   |            |       |             |    |                       |                                  |                              |               | McCauley 1981              |
| adult               | 0.6-19.5                 |                          |             |  |                                   |            |       |             |    |                       |                                  |                              |               | 25-32<br>McCauley 1981     |
| adult               | 16.9                     |                          |             |  |                                   |            |       |             |    |                       |                                  |                              |               | 30.5-31.8<br>McCauley 1981 |
| adult               |                          |                          |             | 31 34                                    |                                   |            |       |             |    |                       |                                  |                              |               | Cravens et al 1983         |

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| Size or Age (mm) | Acclimation Temp | Acclimation Time | Sea-son | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = |   | Data Limits Upper Lower | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | THERMAL TOLERANCES:   |                             |
|------------------|------------------|------------------|---------|--------------------------|--------------------------|------------|---|-------------------------|---------------|-----------------------|------------------------|-----------------------|-----------------------------|
|                  |                  |                  |         |                          |                          | a          | b |                         |               |                       |                        | Location              | Reference                   |
|                  | 23.9-30          |                  |         |                          |                          |            |   |                         | 33.5          | 12.5-25               |                        | Connecticut Yankee GS | Brown 1974                  |
|                  | 23.9-30          |                  |         |                          |                          |            |   |                         | 28.2          | 50-100                |                        |                       | Brown 1974                  |
| YOY              | 5                |                  |         |                          |                          |            |   |                         | 17            | 180                   |                        |                       | Brown 1974                  |
| YOY              | 5                |                  |         |                          |                          |            |   |                         | 15            | 4800                  |                        | Lab                   | Brown 1974                  |
| YOY              | 9                |                  |         |                          |                          |            |   |                         | 26            | 60                    |                        | Lab                   | Brown 1974                  |
| YOY              | 5                |                  |         | 15                       |                          |            |   |                         | 22.5          | 40                    |                        | Lab                   | Brown 1974                  |
| YOY              | 9                |                  |         | 22.6                     |                          |            |   |                         |               |                       |                        | Lab                   | Brown 1974                  |
| adult            | 10               |                  |         | > 20                     |                          |            |   |                         | 24            | 180                   |                        | Lab                   | Brown 1974                  |
| adult            | 20               |                  |         | <22.8                    |                          |            |   |                         | 24            | 4800                  |                        | Lab                   | Brown 1974                  |
| adult            | 20               |                  |         |                          |                          |            |   |                         | 28            | 300                   |                        | Lab                   | Brown 1974                  |
| adult            | 15               |                  |         | 22.8                     |                          |            |   |                         |               |                       |                        |                       | Brown 1974                  |
| adult            | 28.3             |                  |         | 33.3                     |                          |            |   |                         |               |                       |                        |                       | Brown 1974                  |
|                  |                  |                  | Su      | 31.4                     |                          |            |   |                         |               |                       |                        | Maritimes stream      | Brown 1974                  |
|                  | 20               |                  | Su      | 23.2                     |                          |            |   |                         |               |                       |                        | Lab                   | McCauley 1981               |
|                  | 18.2             |                  | Su      |                          |                          |            |   |                         |               |                       | 30.2                   | Lab                   | Reutter and Herdendorf 1976 |



SPECIES: *Alosa pseudoharengus* (alewife)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES: |                          |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------|--------------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                | Reference                |
|                  |        |              | 22              | 18.8              |                 |                         |                  | Cayuga L. N.Y.          | Coutant 1977a            |
| adult            | Sp     |              |                 | 21.3              | 8.0             |                         |                  | L. Michigan Lab         | Coutant 1977a            |
|                  |        |              | 30              | 27.8-28.3         | 10              |                         |                  |                         | Coutant 1977a            |
| adult            | su     |              |                 | 17.2              |                 | 25                      | 48h              |                         | Brown 1974               |
| young            | su     |              |                 | 17-19             |                 |                         |                  | L. Michigan             | Brown 1974               |
|                  |        |              |                 | 11-14             |                 |                         |                  | L. Michigan             | McCauley 1981            |
| adult            | F      |              |                 | 11-16             |                 |                         |                  | L. Michigan             | Talmage and Coutant 1980 |
|                  |        |              |                 | 16-21             |                 |                         |                  | L. Michigan             | Talmage and Coutant 1980 |
| YOY              |        |              |                 | 16-20             |                 |                         |                  | L. Michigan             | Talmage and Coutant 1980 |
| YOY              |        |              |                 | 24-28             |                 |                         |                  | L. Michigan             | Wyman 1981               |
| YOY              |        | D            |                 | 17-20             |                 |                         |                  | L. Michigan             | Brandt et al 1980b       |
| all sizes        |        |              |                 |                   | 3.0             |                         |                  |                         | Brandt et al 1980b       |
|                  | year   |              | 16              | 8-10              | 4               |                         |                  | L. Michigan             | Uziel 1980               |
| subadult         | F      |              |                 | 12.3-14.5         |                 |                         |                  | L. Michigan             | Michaud 1981             |
| < 140; adult     | F      |              |                 | 12.3-16.1         |                 |                         |                  | L. Huron (27-40 m)      | Argyle 1982              |
| YOY              | su     |              |                 | 31.3              |                 |                         |                  | L. Huron (27-42 m)      | Argyle 1982              |
| adult            | F      |              |                 | 19.6              |                 |                         |                  | Lab                     | Spotila et al 1979       |
| adult            | w      |              |                 | 12.0              |                 | 1-3                     |                  | Lab                     | Spotila et al 1979       |
| adult            | SP     |              |                 | 21                |                 | 7-11                    |                  | Lab                     | Otto et al 1976          |
| adult            | Su     |              |                 | 19                |                 | 10-11                   |                  | Lab                     | Otto et al 1976          |
| adult            | su     |              |                 | 16                |                 | 15-18                   |                  | Lab                     | Otto et al 1976          |
| adult            | F      |              |                 | 16                |                 | 10-12                   |                  | Lab                     | Otto et al 1976          |
| adult            | F      |              |                 | 16                |                 | 5-9                     |                  | Lab                     | Otto et al 1976          |
| adult            | w      |              |                 | 11                |                 | 1-4                     |                  | Lab                     | Otto et al 1976          |
| YOY              | su     |              |                 | 25                |                 | 15-18                   |                  | Lab (L. Michigan)       | Otto et al 1976          |
| YOY              | SU     |              |                 | 25                |                 | 24-25                   |                  | Lab (L. Michigan)       | Otto et al 1976          |
| YOY              | F      |              |                 | 24                |                 | 10-12                   |                  | Lab (L. Michigan)       | Otto et al 1976          |
| YOY              | F      |              |                 | 21                |                 | 5-9                     |                  | Lab (L. Michigan)       | Otto et al 1976          |
| YOY              | w      |              |                 | 19                |                 | 1-4                     |                  | Lab (L. Michigan)       | Otto et al 1976          |
| YOY              | F      | D            |                 | 19-20             |                 |                         |                  | L. Michigan             | Crowder et al 1981       |
| YOY              | F      | N            |                 | 17-18             |                 |                         |                  | L. Michigan             | Crowder et al 1981       |
| adult            | F      | D            |                 | 11-14             |                 |                         |                  | L. Michigan             | Crowder et al 1981       |
| adult            | F      | N            |                 | 13-16             |                 |                         |                  | L. Michigan             | Crowder et al 1981       |

SPECIES: *Alosa pseudoharengus* (alewife)

| Size or Age (mm) | Optimum °C | Range | (b) ST Max |         | No Growth Limits |         | Location | GROWTH TEMPERATURES: |                |
|------------------|------------|-------|------------|---------|------------------|---------|----------|----------------------|----------------|
|                  |            |       | (a) MWAT   | ST Max  | Upper            | Lower   |          | Reference            |                |
| YOY              |            |       |            | 34.4-35 |                  | 2.2-5.6 | L. Erie  |                      | Brown 1974     |
| age 1.2          |            |       |            |         |                  | 2.2-5.6 | L a b    |                      | Griffiths 1978 |

(a) MWAT [maximum weekly average temperature for growth] = optimum + 1/3 (upper incipient lethal temperature-optimum temp for growth)

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Alosa pseudoharengus* (alewife)

| Event             | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max          |                  | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location              | Reference               |
|-------------------|--------------------------------|--------------|------------|----------|---------------------|------------------|------------------------|------------------------|------------------|-------------------------|-----------------------|-------------------------|
|                   |                                |              |            |          | for Embryo Survival | Acclimation Time |                        |                        |                  |                         |                       |                         |
| spawning          |                                |              | 6.7        | 22.2     | 14.4                |                  |                        |                        |                  |                         |                       | Brown 1974              |
| spawning          |                                | 12.9-13.1    |            |          |                     |                  |                        |                        |                  |                         | L. Mattamuskeet, N.C. | Brown 1974              |
| spawning          |                                | 13-16        |            |          |                     |                  |                        |                        |                  |                         | Wis.                  | Brown 1974              |
| spawning          |                                | 13-21        |            |          |                     |                  |                        |                        |                  |                         | Me.                   | Brown 1974              |
| spawning          |                                | 15.6-26.7    |            |          |                     |                  |                        |                        |                  |                         | Lab                   | Brown 1974              |
| spawning          |                                | 17-19        |            |          |                     |                  |                        |                        |                  |                         | L. Hopateong, N.J.    | Brown 1974              |
| embryo devel.     |                                | 17.8         | 10-26.7    |          | 27.8                |                  |                        |                        |                  |                         | Lab                   | Brown 1974              |
|                   | 23.9-30                        |              |            |          |                     |                  | 35.5                   |                        |                  |                         |                       | Brown 1974              |
| YOY               | 16                             |              |            |          |                     | 2.5d             | 31.2                   |                        |                  |                         |                       | Brown 1974              |
| entrainment 2 0   |                                |              |            |          |                     |                  |                        |                        | 18               | 38                      |                       | Moore 1979              |
| cold shock        | 33-34                          |              |            |          |                     |                  |                        |                        | -23              | -24                     | 10                    | Coutant 1977b           |
| hatching          | 12.7-29.7                      | 20.8         |            |          |                     |                  | 29.7                   |                        |                  |                         |                       | Cravens et al 1983      |
| larvae            | 14-15                          |              |            |          |                     | 24h              | 31                     |                        |                  |                         |                       | Cravens et al 1983      |
| spawning          |                                | 22           |            |          |                     |                  |                        |                        |                  |                         |                       | Carlander 1969          |
| heat shock        | 27-28                          |              |            |          |                     |                  | 33.3                   |                        |                  |                         |                       | Carlander 1969          |
| heat shock        | 20                             |              |            |          |                     |                  |                        |                        | + 18.2           |                         | Lab (onshore)         | Fahmy and Crippen 1981  |
| heat shock        | 20                             |              |            |          |                     |                  |                        |                        | + 19.0           |                         | Lab (tempering)       | Fahmy and Crippen 19131 |
| heat shock        | 20                             |              |            |          |                     |                  |                        |                        | 3                | 18.6                    | Lab (offshore)        | Fahmy and Crippen 1981  |
| hatching          |                                | 17.7         |            |          |                     |                  |                        |                        |                  |                         |                       | Spotila et al 1979      |
| entrainment       |                                |              |            |          |                     |                  | 30-35                  |                        |                  |                         | Hudson R. powerplants | Hester 1985             |
| entrainment 14-24 |                                |              |            |          |                     |                  |                        |                        |                  | 36.1                    | Hudson R. powerplants | Hester 1985             |
| cold shock 21     |                                |              |            |          |                     |                  |                        | 6.0                    | -15.0            |                         | Lab                   | Otto et al 1976         |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Dorosoma cepedianum* (gizzard shad)

| Size or Age (mm) | Acclimation Temp. | Acclimation Time | Sea-son | THERMAL TOLERANCES:      |                          | log time =<br>a + b (temp)<br>a b | Data Limits<br>Upper Lower | Exposure Temp | Resis-tance<br>Time<br>(Min) | Critical Thermal<br>(Max) | Location                            | Reference                                |
|------------------|-------------------|------------------|---------|--------------------------|--------------------------|-----------------------------------|----------------------------|---------------|------------------------------|---------------------------|-------------------------------------|--|
|                  |                   |                  |         | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp |                                   |                            |               |                              |                           |                                     |  |
| adult            | 15.9              |                  | Fa      |                          |                          |                                   |                            |               |                              | 31.7                      | Lab                                 | Reutter and Herdendorf 1976              |
|                  | 25                |                  | su      |                          |                          |                                   |                            | 35.5          | 7-20                         |                           |                                     | Ellis 1984                               |
|                  | 25                |                  | su      |                          |                          |                                   |                            | 35            | 50                           |                           |                                     | Ellis 1984                               |
|                  | 25                |                  | su      |                          |                          |                                   |                            | 34.5          | 110                          |                           |                                     | Ellis 1984                               |
| under-yearling   | 25                |                  |         | 34-34.5                  | 10.8                     | 47.1163-1.3010                    | 35.6                       | 34.5          |                              |                           | Put-in-Bay, Ohio                    | Brown 1974                               |
|                  | 30                |                  |         | 36.0                     | 14.5                     | 38.0658-0.9694                    | 38.0                       | 36.5          |                              |                           | Put-in-Bay, Ohio                    | Brown 1974                               |
|                  | 35                |                  |         | 36.5                     | 20.0                     | 31.5434-0.7710                    | 39.0                       | 37.0          |                              |                           | Put-in-Bay, Ohio                    | Brown 1974                               |
|                  | 25                |                  |         |                          |                          | 32.1348-0.8698                    | 35.5                       | 35.0          |                              |                           | Knoxville, Tenn                     | Brown 1974                               |
|                  | 30                |                  |         |                          |                          | 44.1030-0.0547                    | 38.0                       | 36.5          |                              |                           | Knoxville, Tenn                     | Brown 1974                               |
|                  | 35                |                  |         |                          |                          | 33.2846-0.8176                    | 39.0                       | 36.5          |                              |                           | Knoxville, Tenn                     | Brown 1974                               |
|                  |                   |                  | su      | 28.5                     | 0-0.5                    |                                   |                            |               |                              |                           | L. Damadelle, Ark<br>Mississippi R. | Talmage and Coutant 1980<br>Talmage 1978 |
| juvenile         | 25                |                  |         |                          |                          |                                   |                            | 34            | 300                          |                           |                                     | Wrenn 1976                               |
| <133             |                   |                  |         |                          | 9                        |                                   |                            |               |                              |                           |                                     | Adams et al 1982                         |
| >133             |                   |                  |         |                          | 3                        |                                   |                            |               |                              |                           |                                     | Adams et al 1982                         |

SPECIES: *Dorosoma cepedianum* (gizzard shad)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES: |           | Reference              |                             |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------|-----------|------------------------|-----------------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                | Reference |                        |                             |
| adult            | Su     |              |                 | 19.0              |                 |                         |                  |                         |           | Lab                    | Ruetter and Herdendorf 1976 |
|                  | F      |              |                 | 20.5              |                 |                         |                  |                         |           | Lab                    | Ruetter and Herdendorf 1976 |
| large            |        |              | 30              |                   | 23.5            |                         |                  |                         |           | Wabash R. Ind.         | Coutant 1977a               |
| large            |        |              |                 | 23.0              |                 |                         |                  |                         |           | Norris Res. Tenn.      | Coutant 1977a               |
|                  | su     |              |                 | 26-34             |                 |                         |                  |                         |           | Nanticoke GS           | Ellis 1984                  |
|                  |        |              |                 | 10-12             |                 |                         |                  |                         |           | L. Mich                | Brown 1974                  |
|                  |        |              |                 | > 12              |                 |                         |                  |                         |           | Ottoville Quarry, Ohio | Talmage and Coutant 1980    |
| adult            |        |              | 31              |                   | 8               |                         |                  |                         |           |                        | Wyman 1981                  |
| 190              | su     |              |                 | 26-34             |                 |                         |                  |                         |           | Power plant, Ohio R.   | Yoder and Gammon 1976       |
| 190              | F      |              |                 | 10-22             |                 |                         |                  |                         |           | Power plant, Ohio R.   | Yoder and Gammon 1976       |
| 190              | W      |              |                 | 4-10              |                 |                         |                  |                         |           | Power plant, Ohio R.   | Yoder and Gammon 1976       |
| 240              | su     |              |                 | 28.5-31           |                 |                         |                  |                         |           | Lab                    | Yoder and Gammon 1976       |

SPECIES: Dorosoma cepedianum (gizzard **shad**)

| Size or Age<br>(mm) | Optimum<br>°C | Range     | (a)<br>MWAT | (b)<br>ST<br>Max | No Growth Limits |       | Location                             | GROWTH TEMPERATURES:   |  |
|---------------------|---------------|-----------|-------------|------------------|------------------|-------|--------------------------------------|------------------------|--|
|                     |               |           |             |                  | Upper            | Lower |                                      | Reference              |  |
|                     |               | 29.6-31.0 |             | >37.5            |                  | 18.3  | L. Erie,<br>White R., Wabash R. Ind. | Brown 1974             |  |
|                     | 16-18         |           |             |                  |                  |       |                                      | Brown 1974             |  |
|                     |               |           | 23.2        |                  |                  |       |                                      | Leidy and Jenkins 1977 |  |
|                     |               |           |             |                  |                  |       |                                      | This study             |  |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature. optimum temp for growth)

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: Dorosoma cepedianum (gizzard shad)

| Event               | Season<br>and/or<br>Accli-<br>mation<br>Temp | Optimum<br>Temp | Temp<br>Range | (a)<br>MWAT | (b)<br>ST Max<br>for<br>Embryo<br>Survival | Accli-<br>mation<br>Time | (c)<br>Lethal<br>Limit<br>Upper | (c)<br>Lethal<br>Limit<br>Lower | Median<br>Lethal<br>ΔT | (d)<br>Median<br>Lethal<br>Final | Location              | Reference             |
|---------------------|--|-----------------|---------------|-------------|--|--------------------------|---------------------------------|---------------------------------|------------------------|----------------------------------|-----------------------|-----------------------|
|                     |  |                 |               |             |  |                          |                                 |                                 |                        |                                  |                       |                       |
| cold shock          | W 26   | 22.2            |               |             |  |                          |                                 |                                 |                        |                                  | Lake Erie             | Brown 1974            |
| heat shock          | W  |                 |               |             |  |                          | 31.7                            |                                 |                        | - 6                              | Sandusky R. Ohio      | Brown 1974            |
| heat shock spawning | W  | 22              |               |             |  |                          | 35.7                            |                                 |                        |                                  | L. Erie               | Brown 1974            |
| cold shock          | W 27   |                 |               |             |  |                          |                                 |                                 |                        | - 18                             |                       | Carlander 1969        |
| cold shock          | 10   |                 |               |             |  |                          |                                 | 0                               |                        | - 10                             |                       | Coutant 1977b         |
| cold shock          | 15   |                 |               |             |  |                          |                                 | 3.5                             |                        | - 11.6                           |                       | Edsall and Yocum 1972 |
| cold shock          | 20   |                 |               |             |  |                          |                                 | 7.5                             |                        | - 13                             |                       | Edsall and Yocum 1972 |
| cold shock          | 25   |                 |               |             |  |                          |                                 | 11                              |                        | - 14                             |                       | Edsall and Yocum 1972 |
| cold shock          | 30   |                 |               |             |  |                          |                                 | 14.6                            |                        | - 16.6                           |                       | Edsall and Yocum 1972 |
| cold shock          | 15-20  |                 |               |             |  |                          |                                 | 6-7                             |                        |                                  |                       | Talmage, 1978         |
| cold shock          | W  |                 |               |             |  |                          |                                 |                                 | 4                      |                                  | Gt. Lakes power plant | Ellis 1994            |
|                     |  |                 |               | 22          |  | 722.2                    |                                 |                                 |                        |                                  |                       | This study            |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less then or equal to optimum. or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: Oncorhynchus gorbuscha (pink salmon)

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Sea-son | Upper              |                    | Lower |       | log time - a + b (temp) | Data Limits |       | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | THERMAL TOLERANCES: |           |                         |
|------------------|------------------|------------------|---------|--------------------|--------------------|-------|-------|-------------------------|-------------|-------|---------------|-----------------------|------------------------|---------------------|-----------|-------------------------|
|                  |                  |                  |         | Incip. Lethal Temp | Incip. Lethal Temp | Upper | Lower |                         | Upper       | Lower |               |                       |                        | Location            | Reference |                         |
| young            |                  |                  |         | 23.9               |                    |       |       |                         |             |       |               |                       |                        |                     |           | Scott and Crossman 1973 |
| 381; fry         | 5                |                  |         | 21.3               |                    |       |       | 11.1627-0.4215          | 24          | 22    |               |                       |                        | Lab, Wash.          |           | Brown 1974              |
|                  | 10               |                  |         | 22.5               |                    |       |       | 11.9021-0.3865          | 26.5        | 23    |               |                       |                        | Lab, Wash.          |           | Brown 1974              |
|                  | 15               |                  |         | 23.1               |                    |       |       | 12.6937-0.4074          | 27          | 23.5  |               |                       |                        | Lab, Wash.          |           | Brown 1974              |
|                  | 20               |                  |         | 23.9               |                    |       |       | 16.2444-0.4074          | 27.5        | 24    |               |                       |                        | Lab, Wash.          |           | Brown 1974              |
|                  | 24               |                  |         | 23.9               |                    |       |       | 14.7111-0.4459          | 27.5        | 24.5  |               |                       |                        | Lab, Wash.          |           | Brown 1974              |

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SPECIES: Oncorhynchus gorbuscha (pink salmon)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES: |                         |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------|-------------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                | Reference               |
| young            |        |              |                 | 12                | 14              |                         |                  |                         | Scott and Crossman 1973 |
| small            |        |              |                 | 11.7              |                 |                         |                  | Lab                     | Coulant 1977a           |
| newly emerged    |        |              |                 | 11.7-12.8         |                 |                         |                  | Lab                     | Coulant 1977a           |
| 50 days          |        |              |                 | 9.3               |                 |                         |                  | Lab                     | Coutant 1977a           |
|                  |        |              |                 | 11.7              |                 |                         |                  | Lab                     | Jobling 1961            |
| \$36 weeks       |        |              |                 | 10                |                 |                         |                  | Lab; L. Superior fish   | Cravens et al 1983      |

SPECIES: Oncorhynchus gorbuscha (pink salmon)

| Size or Age (mm) | Optimum °C | (b)   |          |        |                              | GROWTH TEMPERATURES: |                            |
|------------------|------------|-------|----------|--------|------------------------------|----------------------|----------------------------|
|                  |            | Range | (a) YWAT | ST Max | No Growth limits Upper Lower | -acotion             | Reference                  |
|                  | 15.5       |       | 18.3     | 21.7   |                              |                      | Jobling 1981<br>This study |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: Oncorhynchus gorbuscha (pink salmon)

| Event    | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Man for Embryo Survival | Acclimation Time | (c)                |                        |                  |                     | Location              | Reference   |
|----------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|--------------------|------------------------|------------------|---------------------|-----------------------|---|
|          |                                |              |            |          |                                |                  | Lethal Limit Upper | (d) Lethal Limit Lower | Median Lethal AT | Median Lethal Final |                       |   |
| spawning |                                | 10           | 116        |          | > 7<br>15                      |                  |                    |                        |                  |                     | Lab; L. Superior fish | Scott and Crossman 1973<br>Cravens et al 1983<br>This study |

(a) MWAT - maximum weekly average temperature during **month** of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning,

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment **temperatures**.

SPECIES: Oncorhynchus kisutch (coho salmon)

| Size or Age (mm)  | Acclimation Temp | Acclimation Time | Season | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time =     |      | Data Limits Upper | Data Limits Lower | Exposure Temp | Resistance Time (Min) | THERMAL TOLERANCES:    |             | Reference               |
|-------------------|------------------|------------------|--------|--------------------------|--------------------------|----------------|------|-------------------|-------------------|---------------|-----------------------|------------------------|-------------|-------------------------|
|                   |                  |                  |        |                          |                          | a              | b    |                   |                   |               |                       | Critical Thermal (Max) | Location    |                         |
| fry               |                  |                  |        | 25.1                     |                          |                |      |                   |                   |               |                       |                        | Lab         | Scott and Crossman 1973 |
| 478; fry          | 5                |                  |        | 22.9                     | 0.2                      | 21.3050-0.7970 | 24   | 23                | 24                | 150           |                       |                        | Lab, B.C.   | Brown 1974              |
| 478; fry          | 10               |                  |        | 23.7                     | 1.7                      | 19.5721-0.6820 | 26   | 24.5              | 26                | 90            |                       |                        | Lab, B.C.   | Brown 1974              |
| 478; fry          | 15               |                  |        | 24.3                     | 3.5                      | 20.4066-0.6858 | 27   | 24.5              | 26.5              | 155           |                       |                        | Lab, B.C.   | Brown 1974              |
| 478; fry          | 20               |                  |        | 25                       | 4.5                      | 20.4022-0.6713 | 27.5 | 25.5              | 26.5              | 90            |                       |                        | Lab, B.C.   | Brown 1974              |
| 478; fry          | 23               |                  |        | 25                       | 6.4                      | 18.9736-0.6013 | 27.5 | 25                | 27                | 500           |                       |                        | Lab, B.C.   | Brown 1974              |
| fingerling        | 2.6              |                  |        |                          | -0.1                     |                |      |                   |                   |               |                       | 26.5                   | Lab         | Brown 1974              |
|                   | 4.8              |                  |        |                          | -0.1                     |                |      |                   |                   |               |                       |                        |             | Houston 1982            |
| adult             | 17               |                  |        | 25                       |                          |                |      |                   |                   |               |                       |                        |             | Houston 1982            |
| 90-130; juvenile  | 5                |                  |        |                          |                          |                |      |                   |                   |               |                       | 25.3                   | Lab (18C/h) | Becker and Genoway 1979 |
| 90-130; juvenile  | 10               |                  |        |                          |                          |                |      |                   |                   |               |                       | 30.1                   | Lab (18C/h) | Becker and Genoway 1979 |
| 90-130; juvenile  | 15               |                  |        |                          |                          |                |      |                   |                   |               |                       | 28.7                   | Lab (18C/h) | Becker and Genoway 1979 |
| 90-130; juvenile  | 20               |                  |        |                          |                          |                |      |                   |                   |               |                       | 35.1                   | Lab (18C/h) | Becker and Genoway 1979 |
| 90-130; juvenile5 |                  |                  |        |                          |                          |                |      |                   |                   |               |                       | 27.7                   | Lab (18C/h) | Becker and Genoway 1979 |
| 90-130; juvenile  | 15               |                  |        |                          |                          |                |      |                   |                   |               |                       | 29.6                   | Lab (18C/h) | Becker and Genoway 1979 |
|                   | 12               |                  |        | 21                       |                          |                |      |                   |                   |               |                       |                        | Lab         | Cherry et al 1982       |

SPECIES: Oncorhynchus kisutch (coho salmon)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES: |                          | Reference               |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------|--------------------------|-------------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                |                          |                         |
| adult            | SP     |              |                 | 12-14             |                 |                         |                  |                         | Lab                      | Scott and Crossman 1973 |
| adult            |        |              |                 | 11.4              |                 |                         |                  |                         | Lab                      | Coutant 1977a           |
|                  |        |              |                 | 16.6              |                 |                         |                  |                         | L. Michigan              | Coutant 1977a           |
|                  |        |              |                 | 15/13             |                 |                         |                  |                         |                          | Jobling 1981            |
|                  |        |              |                 | 20                |                 |                         |                  |                         | Lab                      | Brown 1974              |
|                  |        |              |                 | >23.9             |                 |                         |                  |                         | Granby Res., Colo.       | Brown 1974              |
|                  |        |              |                 | 17                | 8/12-16         | 3                       |                  |                         | Point Beach, L. Michigan | Michaud 1981            |
|                  |        |              |                 |                   | 15.6            |                         |                  |                         | Lab                      | Cherry et al 1982       |
|                  |        |              |                 | 21                | 14.3            | 6                       | 12               |                         | Lab                      | Cherry et al 1982       |
|                  |        |              |                 | 21                | 16.6            | 12                      | 18               |                         | Lab                      | Cherry et al 1982       |

SPECIES: *Oncorhynchus kisutch* (coho salmon)

| Size or Age (mm) | Optimum °C | Range | (a) |       | No Growth Upper | Limits Lower | Location             | GROWTH TEMPERATURES: |                          |
|------------------|------------|-------|-----|-------|-----------------|--------------|----------------------|----------------------|--------------------------|
|                  |            |       | M   | W A T |                 |              |                      | ST Max               | Reference                |
| 14.8             |            |       |     | 18    |                 |              | Lab                  |                      | Jobling 1981<br>EPA 1974 |
|                  |            | 14-17 |     |       |                 |              | Field in late summer |                      | Brown 1974               |
| 17               |            |       |     | 24    |                 |              | Lab                  |                      | Brown 1974               |
|                  |            |       |     |       | <10             |              | L. Michigan          |                      | Brown 1974               |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Oncorhynchus kisutch* (coho salmon)

| Event          | Season and/or Acclimation Temp | Optimum Temp | Temp Range | lab MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location                   | Reference                      |
|----------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|------------------|-------------------------|----------------------------|--------------------------------|
|                |                                |              |            |          |                                |                  |                        |                        |                  |                         |                            |                                |
| hatching (48d) |                                | 8.9          |            |          |                                |                  |                        |                        |                  |                         | Calif.                     | Scott and Crossman 1973        |
| heat shock     | 10                             |              |            | 10       | 13                             | 3 min            |                        |                        | > + 10           |                         | Lab (physiological stress) | Spotila et al 1979<br>EPA 1974 |
| spawning       |                                |              |            |          |                                |                  |                        |                        |                  |                         |                            |                                |
| migration      |                                | <10          | 4.4-11.1   |          |                                |                  |                        |                        |                  |                         | Sand Ck., Oregon           | Brown 1974                     |
| spawning       |                                |              | 4.4-7.7    |          |                                |                  |                        |                        |                  |                         | Columbia R.,               | Brown 1974                     |
| cold shock 5   |                                |              |            |          |                                |                  |                        |                        | -4.5             |                         | Lab                        | Edsall and Yocum 1972          |
| cold shock 10  |                                |              |            |          |                                |                  |                        |                        | -8               |                         | Lab                        | Edsall and Yocum 1972          |
| cold shock 15  |                                |              |            |          |                                |                  |                        |                        | -12.5            |                         | Lab                        | Edsall and Yocum 1972          |
| cold shock 20  |                                |              |            |          |                                |                  |                        |                        | -15              |                         | Lab                        | Edsall and Yocum 1972          |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to Optimum, or middle of range of spawning temperatures

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1948).

(d) Simulated larval entrainment temperatures.



|                     |                          |                          |             |                                   |                                   |  |      |               |                 |                       | THERMAL TOLERANCES:              |                              |            |   |
|---------------------|--------------------------|--------------------------|-------------|-----------------------------------|-----------------------------------|--|------|---------------|-----------------|-----------------------|----------------------------------|------------------------------|------------|---|
| Size or Age<br>(mm) | Accli-<br>mation<br>Temp | Accli-<br>mation<br>Time | Sea-<br>son | Upper<br>Incip.<br>Lethal<br>Temp | Lower<br>Incip.<br>Lethal<br>Temp | log time =<br>$\frac{a + b(\text{temp})}{a - b}$ |      | Data<br>Upper | Limits<br>Lower | Expo-<br>sure<br>Temp | Resis-<br>tance<br>Time<br>(Min) | Critical<br>Thermal<br>(Max) | Location   | Reference                               |
| young               |                          |                          |             | 24.4<br>24.8                      |                                   |  |      |               |                 |                       |                                  |                              |            | Scott and Crossman 1973<br>Jobling 1981 |
| 449g;<br>juvenile   | 5                        |                          |             | 22.2                              | 0                                 | 17.7887-0.6623                                   | 24   | 22.5          |                 |                       |                                  |                              | Lab, Wash. | Brown 1974                              |
| 449g;<br>juvenile   | 10                       |                          |             | 23.4                              | 3.1                               | 14.7319-0.4988                                   | 26.5 | 23.5          |                 |                       |                                  |                              | Lab, Wash. | Brown 1974                              |
| 449g;<br>juvenile   | 15                       |                          |             | 24.4                              | 4.1                               | 15.8799-0.5210                                   | 27.5 | 24.5          |                 |                       |                                  |                              | Lab, Wash. | Brown 1974                              |
| 449g;<br>juvenile   | 20                       |                          |             | 24.8                              | 4.7                               | 19.3821-0.6378                                   | 27.5 | 24.5          |                 |                       |                                  |                              | Lab, Wash. | Brown 1974                              |
| 449g;<br>juvenile   | 23                       |                          |             | 24.8                              | 6.7                               | 20.0020-0.6496                                   | 26.5 | 24.5          |                 |                       |                                  |                              | Lab, Wash. | Brown 1974                              |

SPECIES: *Oncorhynchus nerka* (kokanee salmon)

|                     |        |                 |                    |                                   |                    |                            |                     |  |  |   | PREFERRED TEMPERATURES:  |  |
|---------------------|--------|-----------------|--------------------|-----------------------------------|--------------------|----------------------------|---------------------|--|--|---|--|--|
| Size or Age<br>(mm) | Season | Day or<br>Night | Upper<br>Avoidance | Final<br>Preferendum              | Lower<br>Avoidance | Acclimation<br>Temperature | Acclimation<br>Time |  |  | Location  | Reference  |  |
| adult<br>young      |        |                 |                    | 10-15<br>12-14<br>10<br>10.6-12.8 |                    |                            |                     |  |  |   | Scott and Crossman 1973<br>Scott and Crossman 1973<br>Carlander 1969 |  |
| small               |        |                 | 21                 | 14.5                              |                    |                            |                     |  |  | Horsetooth Res., Colo.<br>Okanagan R., Wash.<br>Lab | Coutant 1977a<br>Coutant 1977a<br>Coutant 1977a                      |  |

SPECIES: *Oncorhynchus nerka* (kokanee salmon)

| Size or Age<br>(mm) | Optimum<br>°C | Range | (a)  |        | (b)             |              | Location | GROWTH TEMPERATURES:  |  |
|---------------------|---------------|-------|------|--------|-----------------|--------------|----------|---|--|
|                     |               |       | MWAT | ST Max | No Growth Upper | Limits Lower |          | Reference   |  |
| juvenile            | 15            | 5-15  | 18.3 | 23     | 24              | <3           |          | Jobling 1981<br>Magnuson et al 1979<br>Cravens et al 1983<br>This study |  |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Oncorhynchus nerka* (kokanee salmon)

| Event             | Season and/or Acclimation Temp | Optimum Temp | Temp Range     | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c)                |                    |                  |                                | Location | Reference  |
|-------------------|--------------------------------|--------------|----------------|----------|--------------------------------|------------------|--------------------|--------------------|------------------|--------------------------------|----------|--|
|                   |                                |              |                |          |                                |                  | Lethal Limit Upper | Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final        |          |  |
| spawning          |                                |              | 5-10.5         |          |                                |                  |                    |                    |                  |                                |          | Scott and Crossman 1973                          |
| hatching (140d)   | 4                              |              |                |          |                                |                  |                    |                    |                  | Lab                            |          | Scott and Crossman 1973                          |
| (48d)             | 15                             |              |                |          |                                |                  |                    |                    |                  | Lab                            |          | Scott and Crossman 1973                          |
| (70-824) spawning |                                |              | 13-5.1<br>7-12 |          |                                |                  |                    |                    |                  | Lab; decreasing temp.<br>Calif |          | Scott and Crossman 1973<br>Carlander 1969        |
| egg dev.          |                                |              |                | 8.5      | 12                             |                  | 15.5<br>13.5       | 5.1                |                  | Lab                            |          | Carlander 1969<br>Beltz et al 1974<br>This study |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES Oncorhynchus tshawytscha (chinook salmon)

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Sea-son | Upper Incip. Lethal Temp |       | Lower Incip. Lethal Temp |       | log time = a + b (temp) |       | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | THERMAL TOLERANCES: |                         |
|------------------|------------------|------------------|---------|--------------------------|-------|--------------------------|-------|-------------------------|-------|---------------|-----------------------|------------------------|---------------------|-------------------------|
|                  |                  |                  |         | Upper                    | Lower | Upper                    | Lower | Upper                   | Lower |               |                       |                        | Location            | Reference               |
|                  |                  |                  |         | 25.1                     |       |                          |       |                         |       |               |                       |                        |                     |                         |
| 444; fry         | 5                |                  |         | 21.5                     |       | 9.3155-0.3107            | 25    | 22.5                    |       |               |                       |                        | Lab, Wash.          | Scott and Crossman 1973 |
| 444; fry         | 10               |                  |         | 24.3                     | 0.8   | 16.4595-0.5575           | 26.5  | 24.5                    |       |               |                       |                        | Lab, Wash.          | Brown 1974              |
| 444; fry         | 15               |                  |         | 25                       | 2.5   | 16.4454-0.5364           | 27    | 25.5                    |       |               |                       |                        | Lab, Wash.          | Brown 1974              |
| 444; fry         | 20               |                  |         | 25.1                     | 4.5   | 22.9065-0.7611           | 27.5  | 25                      |       |               |                       |                        | Lab, Wash.          | Brown 1974              |
| 444; fry         | 24               |                  |         | 25.1                     | 7.4   | 18.9940-0.5992           | 27.5  | 25                      |       |               |                       |                        | Lab, Wash.          | Brown 1974              |
| 1-2 yr           | 17               |                  |         | 22                       |       |                          |       |                         |       |               |                       | 25.1                   | Lab (UUILT)         | Spotila et al 1979      |
| adult            | 18-19            |                  |         | 21-22                    |       |                          |       |                         |       |               |                       |                        |                     | Houston 1982            |

SPECIES: Oncorhynchus tshawytscha (chinook salmon)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES: |                   |                           |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------|-------------------|---------------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                | Reference         |                           |
| small            |        |              |                 | 12-14             |                 |                         |                  |                         | Lab               | Scott and Crossman 1973   |
| adult            |        |              |                 | 11.7              |                 |                         |                  |                         | L. Michigan       | Coutant 1977a             |
|                  |        |              | 23.3            | 17.3              |                 |                         |                  |                         | Thermal discharge | Coutant 1977a             |
|                  |        |              |                 |                   |                 |                         |                  |                         | L. Michigan       | Spigarelli and Smith 1976 |
|                  |        |              |                 |                   |                 |                         |                  |                         | (max. body temp)  |                           |

SPECIES: *Oncorhynchus tshawytscha* [chinook salmon]

| Size or Age (mm) | Optimum °C | Range | (a)  |     | (b) |     | No Growth Limits Upper | Lower | Location | GROWTH TEMPERATURES: |                                |
|------------------|------------|-------|------|-----|-----|-----|------------------------|-------|----------|----------------------|--------------------------------|
|                  |            |       | MWAT | Max | ST  | Max |                        |       |          | Reference            |                                |
| fingerling       | 15.5       |       |      |     |     |     |                        |       |          |                      | Jobling 1981                   |
|                  | <12        |       |      |     |     |     |                        |       | Lab      |                      | Cravens et al 1983             |
|                  | 14.4       |       |      |     |     |     |                        |       | Lab      |                      | Beltz et al 1974<br>This study |
|                  |            |       | 18.7 | 20  |     |     |                        |       |          |                      |                                |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature-optimum temp for growth),

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Oncorhynchus tshawytscha* (chinook salmon)

| Event      | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c)                |                    | Median Lethal ΔT | (d)           |                     | Location | Reference                              |
|------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|--------------------|--------------------|------------------|---------------|---------------------|----------|--|
|            |                                |              |            |          |                                |                  | Lethal Limit Upper | lethal Limit Lower |                  | Median Lethal | Median Lethal Final |          |  |
| cold shock | 7                              |              |            |          |                                |                  |                    | 0                  | - 6              |               |                     | Lab      | Edsall and Yocum 1972                  |
| cold shock | 10                             |              |            |          |                                |                  |                    |                    | - 9              |               |                     | Lab      | Edsall and Yocum 1972                  |
| cold shock | 15                             |              |            |          |                                |                  |                    |                    | -12.5            |               |                     | Lab      | Edsall and Yocum 1972                  |
| cold shock | 20                             |              |            |          |                                |                  |                    |                    | - 15             |               |                     | Lab      | Edsall and Yocum 1972                  |
| egg dev.   |                                | 11.1         |            |          | 10                             |                  |                    | 14.9               | 5.1              |               |                     | Lab      | Cravens et al 1983<br>Beltz et al 1977 |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (19461).

(d) Simulated larval entrainment temperatures.

SPECIES: *Salmo gairdneri* (rainbow trout)

| Size or Age (mm)   | Acclimation Temp | Acclimation Time | Season | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = $\frac{a + b(\text{temp})}{a - h}$ | Data Limits |       | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | THERMAL TOLERANCES:          |                             |            |
|--------------------|------------------|------------------|--------|--------------------------|--------------------------|---|-------------|-------|---------------|-----------------------|------------------------|------------------------------|-----------------------------|------------|
|                    |                  |                  |        |                          |                          |   | Upper       | Lower |               |                       |                        | Location                     | Reference                   |            |
| fingerling         | 11               |                  |        | 24                       |                          |   |             |       |               |                       |                        | Lab (Kamloops trout)         | Scott and Crossman 1973     |            |
| adult              | 6.3              |                  | F      |                          |                          |   |             |       |               |                       | >17.5                  | Lab                          | Reutter and Herdendorf 1976 |            |
| 50-100 FL; young   | 12-24            |                  |        | 25                       |                          |   |             |       |               |                       |                        | Lab                          | Cherry et al 1977           |            |
|                    |                  |                  |        | 26.5                     |                          |   |             |       |               |                       |                        |                              | Jobling 1981                |            |
|                    |                  |                  |        | 26                       |                          |   |             |       |               |                       |                        |                              | Jobling 1981                |            |
|                    |                  |                  |        | 26.3                     |                          |   |             |       |               |                       |                        |                              | Jobling 1981                |            |
|                    |                  |                  |        |                          |                          |   |             | 30    | 0.55          |                       |                        | Lab (loss of equilibrium)    | Spotila et al 1979          |            |
|                    |                  |                  |        |                          |                          |   |             | 28    | 2             |                       |                        | Lab (loss of equilibrium)    | Spotila et al 1979          |            |
| yearling           | 20               |                  |        |                          |                          | 14.6405-0.4470                                | 29          | 27    |               |                       |                        | Lab (L. Superior, softwater) | Brown 1974                  |            |
| yearling           | 20               |                  |        |                          |                          | 15.0392-0.4561                                | 29          | 27    |               |                       |                        | Lab (L. Superior, hardwater) | Brown 1974                  |            |
| yearling           | 20               |                  |        |                          |                          | 15.1473-0.4683                                | 29          | 27    |               |                       |                        | Lab (L. Superior, softwater) | Brown 1974                  |            |
| yearling           | 20               |                  |        |                          |                          | 12.8718-0.3837                                | 29          | 27    |               |                       |                        | Lab (L. Superior, hardwater) | Brown 1974                  |            |
| 80-130; young      |                  |                  |        | 23.3-25.6                |                          |   |             |       |               |                       |                        |                              | 26.7                        | Brown 1974 |
| 37-92 TL; juvenile | 15               |                  |        | 25-26                    |                          |   |             |       |               |                       |                        | Great Lakes                  | Brown 1974                  |            |
| adult              | 16-19            |                  |        | 21-22                    |                          |   |             |       |               |                       |                        | Lab                          | Brown 1974                  |            |
| fingerling         | 5                |                  |        | 23.7                     |                          |   |             |       |               |                       |                        |                              | Houston 1982                |            |
| fingerling         | 9                |                  |        | 24.2                     |                          |   |             |       |               |                       |                        |                              | Houston 1982                |            |
| fingerling         | 13               |                  |        | 25.2                     |                          |   |             |       |               |                       |                        |                              | Houston 1982                |            |
| fingerling         | 17               |                  |        | 25.7                     |                          |   |             |       |               |                       |                        |                              | Houston 1982                |            |
| fingerling         | 21               |                  |        | 26.2                     |                          |   |             |       |               |                       |                        |                              | Houston 1982                |            |
| fingerling         | 24.5             |                  |        | 26.2                     |                          |   |             |       |               |                       | 26.2                   |                              | Houston 1982                |            |
| fingerling         | 16               |                  |        | 25.6                     |                          |   |             |       |               |                       |                        |                              | Houston 1982                |            |
| juvenile           |                  |                  |        | 25.7                     |                          |   |             |       |               |                       |                        |                              | Houston 1982                |            |
| 150-200 FL;        | 10               |                  |        |                          |                          |   |             |       |               |                       | 28.5                   | Lab mean 24-h (TL50)         | Hokanson et al 1977         |            |
| 150-200 FL:        | 20               |                  |        |                          |                          |   |             |       |               |                       | 29.4                   | Lab (Arizona; 0.02 C/min)    | Lee and Rinne 1980          |            |
|                    |                  |                  |        |                          |                          |   |             |       |               |                       |                        | Lab (Arizona; 0.02 C/min)    | Lee and Rinne 1980          |            |

SPECIES: *Salmo gairdneri* (rainbow trout)

| Size or Age<br>(mm)         | Season | Day or<br>Night | Upper<br>Avoidance | Final<br>Preferendum | Lower<br>Avoidance | Acclimation<br>Temperature | Acclimation<br>Time | PREFERRED TEMPERATURES:                          |   |
|-----------------------------|--------|-----------------|--------------------|----------------------|--------------------|----------------------------|---------------------|--|---|
|                             |        |                 |                    |                      |                    |                            |                     | Location   | Reference                                 |
| fry,<br>fingerlings         |        |                 |                    | 13-15<br>121         |                    | 10.6/12.7                  |                     | Lab  | Talmage and Coutant 1980                  |
| adult<br>red<br>fingerlings |        |                 |                    | 18.9-21.7            |                    |                            |                     | Horsetooth Res., Colo.                           | Talmage and Coutant 1980<br>Coutant 1977a |
| starved<br>fingerlings      |        | D/N             |                    | 22                   |                    |                            |                     | Lab  | Coutant 1977a                             |
| fingerlings                 |        | D/N             |                    | 18                   |                    |                            |                     | Lab  | Coutant 1977a                             |
| fingerlings                 |        |                 | 22                 | 18-19                | 14                 |                            |                     | Lab  | Coutant 1977a                             |
| adult                       |        |                 |                    | 13                   |                    |                            |                     | Lab  | Coutant 1977a                             |
| adult                       |        |                 |                    | 16.5                 |                    |                            |                     | L. Michigan                                      | Coutant 1977a                             |
| 50-100 FL;<br>young         |        |                 | 19                 | 18                   | 13                 |                            |                     | Lab  | Coutant 1977a                             |
| 50-100 FL;<br>young         |        |                 | 18                 | 14.1                 | 6                  | 12                         |                     | Lab (rising water temp.)                         | Cherry et al 1977                         |
| 50-100 FL;<br>young         |        |                 | 21                 | 17.1                 | 9                  | 15                         |                     | Lab (rising water temp.)                         | Cherry et al 1977                         |
| W-100 FL;<br>young          |        |                 | 21                 | 18.6                 | 12                 | 18                         |                     | Lab (rising water temp.)                         | Cherry et al 1977                         |
| 50-100 FL;<br>young         |        |                 | 27                 | 20.2                 | 12                 | 21                         |                     | Lab (rising water temp.)                         | Cherry et al 1977                         |
| 50-100 FL;<br>young         |        |                 | 26                 | 22.2                 | 15                 | 24                         |                     | Lab (rising water temp.)                         | Cherry et al 1977                         |
| 50-100 FL;<br>young         |        |                 |                    | 19.2                 |                    |                            |                     | Lab (rising water temp.)                         | Cherry et al 1977                         |
| adult                       |        |                 |                    | 16                   |                    |                            |                     |  | Jobling 1981                              |
|                             |        |                 |                    | 11.3                 |                    |                            |                     |  | Jobling 1981                              |
|                             |        |                 |                    | 14                   |                    |                            |                     |  | Jobling 1981                              |
|                             |        |                 |                    | 15.8                 |                    | 10                         |                     | Lab  | Spotila et al 1979                        |
|                             |        |                 |                    | 17.5                 |                    | 15                         |                     | Lab  | Spotila et al 1979                        |
|                             |        |                 |                    | 22                   |                    | 20                         |                     | Lab  | Spotila et al 1979                        |
|                             |        |                 |                    | 11.6                 |                    | 6                          |                     | Lab  | Spotila et al 1979                        |
|                             |        |                 |                    | 12.6                 |                    | 9                          |                     | Lab  | Spotila et al 1979                        |
|                             |        |                 |                    | S-17                 |                    |                            |                     | Lab  | Brown 1974                                |
|                             |        |                 | 23.5               |                      |                    |                            |                     | Thermal discharge<br>L. Michigan (max body temp) | Spigarelli and Smith 1976                 |
| 150-250g;<br>yearlings      |        |                 |                    | 16.7                 |                    |                            |                     | Lab  | McCauley and Huggins 1976                 |
| small; <1kg                 |        |                 | 23-24              | 19                   |                    |                            |                     | Point Beach NGS<br>discharge L. Michigan         | Spigarelli and Thommes 1979               |
| large; >2.5kg               |        |                 | 20-21              | 15                   |                    |                            |                     | Point Beach NGS<br>discharge L. Michigan         | Spigarelli and Thommes 1979               |
| 1-2.5 kg                    |        |                 | 22                 | 19                   |                    |                            |                     | Pt. Beach NGS, L. Mich.                          | Spigarelli and Thommes 1979               |
| < 6<br>months               |        |                 |                    | 17-21                |                    |                            |                     |  | Kwain and McCauley 1978                   |
| >1 year                     |        |                 |                    | 13                   |                    |                            |                     |  | Kwain and McCauley 1978                   |
| <6 months                   |        |                 |                    | 17-19                |                    |                            |                     | Lab  | Kwain and McCauley 1978                   |
| 7-11 months                 |        |                 |                    | 14-16.8              |                    |                            |                     | Lab  | Kwain and McCauley 1978                   |
| 1 year                      |        |                 |                    | 11.4-12.7            |                    |                            |                     | Lab  | Kwain and McCauley 1978                   |

SPECIES: *Salmo gairdneri* (rainbow trout)

| Size or Age (mm) | Optimum °C | Range | (a)     |          | No Growth Upper | Limits Lower | Location | GROWTH TEMPERATURES:        |  |
|------------------|------------|-------|---------|----------|-----------------|--------------|----------|-----------------------------|--|
|                  |            |       | M W A T | ST M a x |                 |              |          | Reference                   |  |
| juvenile         | 17.2       |       |         |          |                 |              |          | Jobling, 1981               |  |
|                  | 16.5       |       |         |          |                 |              |          | Jobling, 1981               |  |
|                  | 17         |       |         |          |                 |              |          | Jobling, 1981               |  |
|                  | 12         |       |         |          |                 |              |          | Spotila et al 1979          |  |
| fingerling       | 16.8       |       | 19      | 24       | >20             | <10          |          | McCauley and Casselman 1980 |  |
| juvenile         | 12.8       |       |         |          | 24              |              |          | EPA 1974                    |  |
|                  |            |       |         |          | 22              | 8            | Lab      | Brown 1974                  |  |
| juvenile         | 17-18.6    |       | 17      | 23       |                 |              |          | Brown 1974                  |  |
|                  |            |       |         |          |                 |              |          | Hokanson et al 1977         |  |
|                  |            |       |         |          |                 |              |          | Hokanson et al 1977         |  |

SPECIES: *Salmo gairdneri* (rainbow trout)

| Event              | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location                    | Reference                 |
|--------------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|------------------|-------------------------|-----------------------------|---------------------------|
|                    |                                |              |            |          |                                |                  |                        |                        |                  |                         |                             |                           |
| spawning           |                                |              | 10-15.5    |          |                                |                  |                        |                        |                  |                         |                             | Scott and Crossman 1973   |
| hatching (18-101d) |                                | 7-10         | 3.2-15.5   |          | <15                            |                  | >15                    | 3                      |                  |                         |                             | Spotila et al 1979        |
| heat shock         | 15                             |              |            |          |                                |                  | >29                    |                        | + 14             |                         | Lab                         | Crippen and Fahmy 1981    |
| heat shock         | 9.7                            |              |            |          |                                |                  |                        |                        | + 19.5           |                         | Lab (onshore discharge)     | Crippen and Fahmy 1981(d) |
| heat shock         | 9.7                            |              |            |          |                                |                  |                        |                        | + 20.6           |                         | Lab (tempering discharge)   | Crippen and Fahmy 1981(d) |
| heat shock         | 9.7                            |              |            |          |                                |                  |                        |                        | +18.7            |                         | Lab (offshore discharge)    | Crippen and Fahmy 1981(d) |
| spawning           |                                | 6-8          | 0.3-10     | 9        | 13                             |                  |                        |                        |                  |                         | Bothwells Ck, Ont.          | EPA 1974                  |
| spawning           |                                |              | 5.5-13     |          |                                |                  |                        |                        |                  |                         | Finger Lakes, N.Y.          | Brown 1974                |
| egg dev.           |                                | 5-7          |            |          |                                |                  |                        |                        |                  |                         |                             | Brown 1974                |
| egg dev.           |                                | 5-6-12.2     | 1.7-16.1   |          |                                |                  |                        |                        |                  |                         |                             | Brown 1974                |
| larval dev.        |                                | 12.8-18.9    |            |          |                                |                  |                        |                        |                  |                         |                             | Brown 1974                |
| heat shock         | 12.2                           |              |            |          |                                |                  |                        |                        | +11.1            |                         | Lab                         | Brown 1974                |
| heat shock         | 10                             |              |            |          |                                |                  |                        |                        | + 19             | 29                      | Lab (simulated entrainment) | Moore 1979                |
| heat shock         | 6                              |              |            |          |                                |                  | 24-30                  |                        |                  |                         | Lab                         | Cravens et al 1983        |
| heat shock (egg)   | 10                             |              |            |          |                                |                  | 36                     |                        |                  |                         | Lab                         | Thorgaard et al 1981      |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: Salmo trutta (brown trout)

| Size or Age (mm)  | Acclimation Temp | Acclimation Time | Sea-son | THERMAL TOLERANCES: |                   |                |    |               |                       |                        |          |            |              | Reference                 |                    |
|-------------------|------------------|------------------|---------|---------------------|-------------------|----------------|----|---------------|-----------------------|------------------------|----------|------------|--------------|---------------------------|--------------------|
|                   |                  |                  |         | Upper Incip. Temp   | Lower Incip. Temp | log time =     |    | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location |            |              |                           |                    |
|                   |                  |                  |         |                     |                   | a              | b  |               |                       |                        |          | Data Upper | Limits Lower |                           |                    |
| 50-100FL; young   | 12-24            |                  |         | 23                  |                   |                |    |               |                       |                        |          |            | Lab          | Cherry et al 1977         |                    |
| adult             | 14-18            |                  |         | 26.4                |                   |                |    |               |                       |                        |          |            |              | Jobling 1981              |                    |
| adult             | 26               |                  |         |                     |                   |                |    |               |                       |                        |          |            | 25           | Lab (death point)         | Spotila et al 1979 |
| fry               | 5-6              |                  |         |                     |                   |                |    |               |                       |                        |          |            | 26           | Lab (death point)         | Spotila et al 1979 |
| fry               | 20               |                  |         |                     |                   |                |    |               |                       |                        |          |            | 22.5         | Lab (death point)         | Spotila et al 1979 |
| newly hatched fry | 6                |                  |         | 22                  |                   | 12.7756-0.4010 | 28 | 20            |                       |                        |          |            | 23           | Lab (death point)         | Spotila et al 1979 |
|                   |                  |                  |         |                     |                   |                |    |               |                       |                        |          |            |              | Lab; England              | Brown 1974         |
|                   |                  |                  |         | 24.7                |                   |                |    |               |                       |                        |          |            |              | Lab                       | Brown 1974         |
|                   | 23               |                  |         | 25.3                |                   |                |    |               |                       |                        |          |            | 26.8         | N.Y. (limiting temp)      | Brown 1974         |
|                   |                  |                  |         |                     |                   |                |    |               | 26.8                  | 1440                   |          |            | 27.8         | Lab                       | Brown 1974         |
| 150-200TL;        | 10               |                  |         |                     |                   |                |    |               |                       |                        |          |            |              | Lab                       | Brown 1974         |
|                   | 20               |                  |         |                     |                   |                |    |               |                       |                        |          |            |              | Lab (Arizona; 0.02 c/min) | Lee and Rinne 1980 |
|                   |                  |                  |         |                     |                   |                |    |               |                       |                        |          |            |              | Lab (Arizona; 0.02 c/min) | Lee and Rinne 1980 |

SPECIES: Salmo trutta (brown trout)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES: |   | Reference                 |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------|---|---------------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                |   |                           |
|                  |        |              |                 | 18.3-23.9         |                 |                         |                  |                         |   | Scott and Crossman 1973   |
|                  |        |              |                 | 12                |                 |                         |                  |                         |   | Coutant 1977a             |
|                  |        |              | 20              |                   |                 |                         |                  |                         | L. Oredon, France                             | Coutant 1977a             |
| young            |        |              |                 | 17.6              |                 |                         |                  |                         | Lab   | Coutant 1977a             |
| adult            |        |              |                 | 13.8              |                 |                         |                  |                         | L. Michigan                                   | Coutant 1977a             |
| 50-100FL; young  |        |              | 15              | 11.7              | 6               | 12                      |                  |                         | Lab (rising water temps)                      | Cherry et al 1977         |
| 50-100FL; young  |        |              | 18              | 15.5              | 9               | 15                      |                  |                         | Lab (rising water temps)                      | Cherry et al 1977         |
| 50-100FL; young  |        |              | 21              | 17.9              | 12              | 18                      |                  |                         | Lab (rising water temps)                      | Cherry et al 1977         |
| 50-100FL; young  |        |              | 24              | 18.8              | 15              | 21                      |                  |                         | Lab (rising water temps)                      | Cherry et al 1977         |
| 50-100FL; young  |        |              | 25              | 18.5              | 17              | 23                      |                  |                         | Lab (rising water temps)                      | Cherry et al 1977         |
| 50-100FL; young  |        |              |                 | 17.4              |                 |                         |                  |                         | Lab (rising water temps)                      | Cherry et al 1977         |
|                  |        |              |                 | 12.2              |                 |                         |                  |                         |   | Jobling 1981              |
|                  |        |              |                 | 12.4-17.6         |                 |                         |                  |                         |   | Spotila et al 1979        |
| 44g; small       |        |              |                 | 19.9              |                 |                         |                  |                         | L. Michigan thermal discharge                 | Brown 1974                |
| 30009; large     |        |              |                 | 16.9              |                 |                         |                  |                         | L. Michigan thermal discharge                 | Brown 1974                |
|                  |        |              | 21.3            |                   |                 |                         |                  |                         | L. Michigan thermal discharge (max body temp) | Spigarelli and Smith 1976 |
|                  |        |              |                 | 12-16             |                 |                         |                  |                         | L. Michigan thermal discharge                 | Harrelson et al 1984      |



SPECIES: Salmo trutta (brown trout)

| Size or Age (mm) | Optimum °C | Range | (a)  |       | (b)   |     | Location   | GROWTH TEMPERATURES:        |              |
|------------------|------------|-------|------|-------|-------|-----|------------|-----------------------------|--------------|
|                  |            |       | M    | W A T | ST    | Max |            | No Growth Upper             | Limits Lower |
| juvenile         | 10         | 7-19  | 19.1 | 21    | <29.1 | 5   |            | Jobling 1981                |              |
|                  | 15.5       |       |      |       |       |     |            | Jobling 1981                |              |
|                  | 12         |       |      |       |       |     |            | Jobling 1981                |              |
|                  | 12.8       |       |      |       |       |     |            | Jobling 1981                |              |
|                  | 12.6       |       |      |       |       |     |            | McCauley and Casselman 1980 |              |
|                  |            |       |      |       |       |     | Brown 1974 |                             |              |
|                  |            |       |      |       |       |     | Brown 1974 |                             |              |
|                  |            |       |      |       |       |     | This study |                             |              |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

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SPECIES: Salmo trutta (brown trout)

| Event                | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST for Embryo Survival | Max | Acclimation Time | (c) Lethal Limit Upper | (c)                |    | (d) Median Lethal Final | Location           | Reference  |
|----------------------|--------------------------------|--------------|------------|----------|----------------------------|-----|------------------|------------------------|--------------------|----|-------------------------|--------------------|--|
|                      |                                |              |            |          |                            |     |                  |                        | Lethal Limit Lower | ΔT |                         |                    |  |
| spawning             |                                |              | 6.7-8.9    |          |                            |     |                  |                        |                    |    |                         | S.E. Ontario       | Scott and Crossman 1973  |
| incubation (34-148d) |                                |              | 1.9-11.2   | 12.8     |                            |     |                  | 27                     |                    |    |                         | Lab                | Brown 1974<br>Brown 1974                                       |
| embryo spawning      |                                |              | 4-11       | 7.5      | 11.2                       |     |                  | 15                     |                    |    |                         | streams SW Ontario | Cravens et al 1983<br>Witzel and MacCrimmon 1983<br>This study |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Salvelinus fontinalis* (brook trout)

|                  |                    |                  |         |                          |                          |                         |      |            |              |               |                       | THERMAL TOLERANCES:     |                             |                   |
|------------------|--------------------|------------------|---------|--------------------------|--------------------------|-------------------------|------|------------|--------------|---------------|-----------------------|-------------------------|-----------------------------|-------------------|
| Size or Age (mm) | Acclimation Temp   | Acclimation Time | Sea-son | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = a + b (temp) |      | Data Upper | Limits Lower | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max)  | Location                    | Reference         |
| 50               | 50-100FL; young    | 12-24            |         | 24                       |                          |                         |      |            |              |               |                       |                         | Lab                         | Cherry et al 1977 |
|                  |                    |                  |         | 25.3                     |                          |                         |      |            |              |               |                       |                         |                             | Jobling 1981      |
|                  |                    |                  |         | 20.1                     |                          |                         |      |            |              |               |                       |                         |                             | Jobling 1981      |
|                  | 2-25g; yearling    | 3                |         | 23.5                     |                          | 13.4325-0.4556          | 26   | 23.5       | 26           | 40            |                       |                         | Lab, Ontario                | Brown 1974        |
|                  | 2-25g; yearling    | 11               |         | 24.6                     |                          | 14.6256-0.4728          | 28   | 25         |              |               |                       |                         | Lab, Ontario                | Brown 1974        |
|                  | 2-25g; yearling    | 15               |         | 25                       |                          | 15.1846-0.4833          | 28.5 | 25.5       | 27.5         | 30            |                       |                         | Lab, Ontario                | Brown 1974        |
|                  | 2-25; yearling     | 20               |         | 25.3                     |                          | 15.0331-0.4661          | 29   | 25.5       |              |               |                       |                         | Lab, Ontario                | Brown 1974        |
|                  | 2-25g; yearling    | 22               |         | 25.5                     |                          | 17.1967-0.5367          | 29   | 26.5       |              |               |                       |                         | Lab, Ontario                | Brown 1974        |
|                  | 2-25g; yearling    | 24               |         | 25.5                     |                          | 17.8467-0.5507          | 30   | 25.5       | 28.5         | 40            |                       |                         | Lab, Ontario                | Brown 1974        |
|                  | 2-25g; yearling    | 25               |         | 25.5                     |                          | 17.8467-0.5567          | 29   | 26         |              |               |                       |                         | Lab, Ontario                | Brown 1974        |
|                  | eggs newly hatched | 12               |         | 12.7                     |                          |                         |      |            |              |               |                       |                         | Lab, Ontario                | Brown 1974        |
|                  | swim-up            | 12               |         | 20.4                     |                          |                         |      |            |              |               |                       |                         | Lab, Ontario                | Brown 1974        |
|                  | larvae juvenile    | 13               |         | 24.3                     |                          |                         |      |            |              |               |                       | 24.5                    | Lab, Ontario                | Brown 1974        |
|                  |                    | 16               |         | 20.1                     |                          |                         |      |            |              |               |                       | 25.3                    | Lab, (UUILT <sub>50</sub> ) | Brown 1974        |
|                  |                    | 19               |         | 24                       |                          |                         |      |            |              |               |                       |                         | Lab                         | Houston 1982      |
|                  | 19                 |                  | 24.9    |                          |                          |                         |      |            |              |               |                       | Lab                     | Houston 1982                |                   |
| 150-200FL;       | 10                 |                  | 25.8    |                          |                          |                         |      |            |              |               |                       | Lab                     | Houston 1982                |                   |
| 150-200FL;       | 20                 |                  |         |                          |                          |                         |      |            |              |               | 28.7                  | Lab (Arizona; 0.02 c/m) | Lee and Rinne 1980          |                   |
|                  | 20                 |                  |         |                          |                          |                         |      |            |              |               | 29.8                  | Lab (Arizona; 0.02 c/m) | Lee and Rinne 1980          |                   |

SPECIES: *Salvelinus fontinalis* (brook trout)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES:  |                          |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|--------------------------|--------------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                 | Reference                |
|                  | Su     |              |                 | <20               |                 |                         |                  |                          | Scott and Crossman 1973  |
|                  |        |              |                 | 19                |                 |                         |                  | field                    | Coutant 1977a            |
|                  |        |              |                 | 20.3              |                 |                         |                  | Moosehead L., Me.        | Coutant 1977a            |
|                  |        |              |                 | 20                |                 |                         |                  | Redrock L., Ontario      | Coutant 1977a            |
|                  |        |              | 20              |                   |                 |                         |                  | field                    | Coutant 1977a            |
| adult            |        |              |                 | 15.7              |                 |                         |                  | S. Ont. streams          | Coutant 1977a            |
| adult            |        |              |                 | 14.8              |                 |                         |                  | L. Michigan              | Coutant 1977a            |
| small            |        |              |                 | 16                |                 |                         |                  | Lab                      | Coutant 1977a            |
| small            | F      |              | 20              | 16                |                 |                         |                  | Lab                      | Coutant 1977a            |
| small            | w      |              |                 | 8-12              |                 |                         |                  | Lab                      | Coutant 1977a            |
| small            |        |              |                 | 18                |                 |                         |                  | Lab (fed)                | Coutant 1977a            |
|                  |        |              | 20              | 18                | 14              |                         |                  | Lab                      | Coutant 1977a            |
| small            |        |              |                 | 16                |                 |                         |                  | Lab (starved)            | Coutant 1977a            |
| young            |        |              |                 | 16                |                 |                         |                  | Lab                      | Coutant 1977a            |
| 50-100FL;        |        |              | 15              | 13.7              | 6               | 12                      |                  | Lab (rising water temps) | Cherry et al 1977        |
| young            |        |              |                 |                   |                 |                         |                  |                          |                          |
| 50-100FL;        |        |              | 18              | 15.2              | 9               | 15                      |                  | Lab (rising water temps) | Cherry et al 1977        |
| young            |        |              |                 |                   |                 |                         |                  |                          |                          |
| 50-100FL;        |        |              | 21              | 17.2              | 15              | 18                      |                  | Lab (rising water temps) | Cherry et al 1977        |
| young            |        |              |                 |                   |                 |                         |                  |                          |                          |
| 50-100FL;        |        |              | 24              | 18.3              | 15              | 21                      |                  | Lab (rising water temps) | Cherry et al 1977        |
| young            |        |              |                 |                   |                 |                         |                  |                          |                          |
| 50-100FL;        |        |              | 26              | 19.0              | 18              | 24                      |                  | Lab (rising water temps) | Cherry et al 1977        |
| young            |        |              |                 |                   |                 |                         |                  |                          |                          |
| 50-100FL;        |        |              |                 | 15.5              |                 |                         |                  | Lab (rising water temps) | Cherry et al 1977        |
| young            |        |              |                 |                   |                 |                         |                  |                          |                          |
|                  |        |              |                 | 14                |                 |                         |                  |                          | Jobling 1981             |
| fry              |        |              |                 | 10                |                 | 4                       |                  | Lab                      | Brown 1974               |
|                  |        |              | 21              |                   | 7               |                         |                  | Lakes N.S.               | Brown 1974               |
| fry              |        |              |                 | 9-1               | 1.5             | 10.6-12.7               |                  | Lab                      | Talmage and Coutant 1980 |
| fingerlings      |        |              |                 | 17.5              |                 | 12.1                    |                  | Lab                      | Talmage and Coutant 1980 |

SPECIES: Salvelinus fontinalis (brook trout)

| Size or Age (mm) | Optimum °C | (a) Range | (b) ST |     | No Growth Upper | Limits Lower | Location | GROWTH TEMPERATURES: |  |
|------------------|------------|-----------|--------|-----|-----------------|--------------|----------|----------------------|--|
|                  |            |           | MWAT   | Max |                 |              |          | Reference            |  |
| 13               |            |           |        |     |                 |              |          | Jobling 1981         |  |
| 14               |            |           |        |     |                 |              |          | Jobling 1981         |  |
| 16.1             |            |           | 19     | 23  |                 |              |          | Jobling 1981         |  |
| 15.4             | 9.8-17.9   |           |        |     | >20             | 8            | Lab      | EPA 1974             |  |
| IO-IS            |            |           |        |     |                 |              |          | Brown 1974           |  |
|                  |            |           |        |     |                 |              |          | Brown 1974           |  |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature-optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: Salvelinus fontinalis (brook trout)

| Event                        | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST                  |                  | (c) Lethal Upper | (c) Lethal Lower | Median Lethal AT | (d) Median Lethal Final | Location        | Reference                  |
|------------------------------|--------------------------------|--------------|------------|----------|-------------------------|------------------|------------------|------------------|------------------|-------------------------|-----------------|----------------------------|
|                              |                                |              |            |          | Max for Embryo Survival | Acclimation Time |                  |                  |                  |                         |                 |                            |
| hatching (50-100d)           |                                |              | 10-5       |          |                         |                  |                  |                  |                  |                         |                 | Scott and Crossman 1973    |
| eggs                         |                                |              |            | 9        | 13                      |                  |                  | 11.7             |                  |                         |                 | Scott and Crossman 1973    |
| spawning                     |                                | 10.7         |            |          |                         |                  |                  |                  |                  |                         | Minn.           | EPA 1974                   |
| spawning incubation (15-28d) |                                |              | 2.2-11.7   |          |                         |                  |                  |                  |                  |                         | Lab             | Brown 1974                 |
| hatching                     |                                | 6            |            |          | 14.8                    |                  |                  | 18               |                  |                         |                 | Brown 1974                 |
| spawning                     |                                |              | 4-13       |          |                         |                  |                  |                  |                  |                         | SW Ont. streams | Witzel and MacCrimmon 1983 |

(a) MWAT-c maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.



SPECIES: *Salvelinus namaycush* (lake trout)

| Size or Age<br>(mm) | Optimum<br>°C | Range | (b)<br>ST      |       | No Growth Limits |       | Location                           | GROWTH TEMPERATURES: |  |
|---------------------|---------------|-------|----------------|-------|------------------|-------|------------------------------------|----------------------|--|
|                     |               |       | (a)<br>M W A T | M a x | Upper            | Lower |                                    | Reference            |  |
| yearling            | 11.7          |       |                |       |                  |       |                                    |                      | Leidy and Jenkins 1977   |
| 1-2 yrs             | 16.5          | 4-18  | 19.4           | 21.5  |                  |       | Lake Louisa, Ont.; Cayuga L., N.Y. |                      | Leidy and Jenkins 1977<br>Leidy and Jenkins 1977<br>This study |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Salvelinus namaycush* (lake trout)

| Event                    | Season<br>and/or<br>Accli-<br>mation<br>Temp | Optimum<br>Temp | Temp<br>Range | (a)<br>M W A T | (b)<br>ST Max<br>for<br>Embryo<br>Survival | Accli-<br>mation<br>Time | SPAWNING AND DEVELOPMENT TEMPERATURES: |                                 |                        |                                  | Location                  | Reference                              |
|--------------------------|--|-----------------|---------------|----------------|--|--------------------------|--|---------------------------------|------------------------|----------------------------------|---------------------------|--|
|                          |  |                 |               |                |  |                          | (c)<br>Lethal<br>Limit<br>Upper        | (c)<br>Lethal<br>Limit<br>Lower | Median<br>Lethal<br>ST | (d)<br>Median<br>Lethal<br>Final |                           |  |
| spawning                 |  |                 | 8.9-13.9      |                |  |                          |  |                                 |                        |                                  |                           | Scott and Crossman 1973                |
| incubation<br>(15-21 wk) |  |                 | 0.3-1.0       |                |  |                          |  |                                 |                        |                                  | Algonquin Pk., Ontario    | Scott and Crossman 1973                |
| heat shock<br>spawning   | 8.8  |                 | 11-14         | a.9            |  |                          | 14.8                                   |                                 | + 6                    |                                  | Lab<br>L. Simcoe, Ontario | Wyman 1981<br>Brown 1974<br>Brown 1974 |
| incubation<br>(50-162d)  |  |                 | 1.8-10        |                | <10  |                          |  |                                 |                        |                                  | Lab                       | Brown 1974<br>Brown 1974               |
| spawning                 |  |                 | 7.1-14.4      |                |  |                          |  |                                 |                        |                                  | L. Simcoe, Ontario        | MacLean et al 1981                     |
| spawning                 |  |                 | 5.5-10        |                |  |                          |  |                                 |                        |                                  | L. Simcoe, Ontario        | MacLean et al 1981<br>This study       |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Salvelinus fontinalis* x *S. namaycush* (splake)

|                  |                  |                  |         |                          |                          |                             |      |                         |               |                       | THERMAL TOLERANCES:    |              |                        |
|------------------|------------------|------------------|---------|--------------------------|--------------------------|-----------------------------|------|-------------------------|---------------|-----------------------|------------------------|--------------|------------------------|
| Size or Age (mm) | Acclimation Temp | Acclimation Time | Sea-son | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = a t b (temp) a b |      | Data Limits Upper Lower | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location     | Reference              |
|                  | 5                |                  |         | 23.5-25.5                |                          |                             |      |                         |               |                       |                        | Lab          | Crippen and Fahmy 1981 |
|                  | 10               |                  |         | 25.5-26.7                |                          |                             |      |                         |               |                       |                        |              |                        |
|                  | 20.8             |                  |         | 27.5-28.7                |                          |                             |      |                         |               |                       |                        |              |                        |
| juvenile         | 10               |                  |         | 23.5-24                  |                          | 13.2634-0.4381              | 26.5 | 24                      |               |                       |                        | Lab, Ontario | Brown 1974             |
|                  | 15               |                  |         |                          |                          | 16.9596-0.5540              | 28   | 24.5                    |               |                       |                        | Lab, Ontario | Brown 1974             |
|                  | 20               |                  |         | 24-24.5                  |                          | 19.4449-0.6342              | 28   | 24.5                    |               |                       |                        | Lab, Ontario | Brown 1974             |

SPECIES: *Salvelinus fontinalis* x *S. namaycush* (splake)

|                  |        |              |                 |                   |                 |                         |                  |           |  |   | PREFERRED TEMPERATURES:                                    |  |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-----------|--|---|--|--|
| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time |           |  | Location                                | Reference  |  |
| young fry        |        |              |                 | 13.1<br>12        | 9-11.5          |                         |                  | 10.6-12.7 |  | Jack and Sproule L., Ont.<br>Lab<br>Lab | Coutant 1977a<br>Coutant 1977a<br>Talmage and Coutant 1980 |  |

SPECIES: *Salvelinus fontinalis* x *S. namaycush* (splake)

|               |                                |              |            |          |                                |                  |                        |                        |                   |                         | SPAWNING AND DEVELOPMENT TEMPERATURES: |                            |
|---------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|-------------------|-------------------------|--|----------------------------|
| Event         | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median $\Delta T$ | (d) Median Lethal Final | Location                               | Reference                  |
| heat shock    | 3                              |              |            |          |                                |                  |                        |                        | 20.5              |                         | Lab (onshore discharge)                | Crippen and Fahmy 1981 (d) |
| heat shock    | 3                              |              |            |          |                                |                  |                        |                        | 22.1              |                         | Lab (tempering discharge)              | Crippen and Fahmy 1981 (d) |
| heat shock    | 3                              |              |            |          |                                |                  |                        |                        | 22.4              |                         | Lab (offshore discharge)               | Crippen and Fahmy 1981 (d) |
| hatching      | 8.8                            |              |            |          |                                |                  | 14.8                   |                        | +6                |                         | Lab                                    | Wyman 1981                 |
| eggs spawning |                                | 7.8          |            |          |                                |                  |                        |                        | +10               |                         | Lab (fall spawned)                     | Griffiths 1978             |
| eggs          |                                |              |            |          |                                |                  |                        |                        | +7.8              |                         | Lab (+ ambient; TL50)                  | Griffiths 1980             |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

**SPECIES: Coregonus artedii (cisco, lake herring)**

**THERMAL TOLERANCES:**

| Size or Age<br>(mm) | Accli-<br>mation<br>Temp | Accli-<br>mation<br>Time | Sea-<br>son | Upper<br>Incip.<br>Lethal<br>Temp | Lower<br>Incip.<br>Lethal<br>Temp | log time =<br>a + b (temp)<br>a b | Data Limits<br>Upper Lower | Expo-<br>sure<br>Temp | Resis-<br>tance<br>Time<br>(Min) | Critical<br>Thermal<br>(Max) | Location    | Reference               |
|---------------------|--------------------------|--------------------------|-------------|-----------------------------------|-----------------------------------|-----------------------------------|----------------------------|-----------------------|----------------------------------|------------------------------|-------------|-------------------------|
|                     |                          |                          |             | 26                                |                                   |                                   |                            |                       |                                  |                              | Lab         | Scott and Crossman 1973 |
|                     |                          |                          |             | 19.8                              |                                   |                                   |                            |                       |                                  |                              |             | Jobling 1981            |
| larvae              |                          |                          |             | 26.2                              |                                   |                                   |                            |                       |                                  |                              |             | Jobling 1981            |
|                     |                          |                          |             | 19.7                              |                                   | 16.51X-0.6689                     | 23                         | 19                    |                                  |                              | Lab (Mich.) | Brown 1974              |
| juvenile            | 2                        | 8wk                      |             | 21.7                              |                                   | 10.2799-0.3645                    | 24                         | 20                    |                                  |                              | Lab (Mich.) | Brown 1974              |
| juvenile            | 5                        | 4wk                      |             | 24.2                              |                                   | 12.4993-0.4098                    | 28                         | 24                    |                                  |                              | Lab (Mich.) | Brown 1974              |
| juvenile            | 10                       | 2wk                      |             | 26.2                              |                                   | 17.2967-0.5333                    | 30                         | 26                    |                                  |                              | Lab (Mich.) | Brown 1974              |
| juvenile            | 20                       | 2wk                      |             | 25.7                              |                                   | 15.1204-0.4493                    | 30                         | 25                    |                                  |                              | Lab (Mich.) | Brown 1974              |
| juvenile            | 25                       | 3wk                      |             |                                   | <0.3                              |                                   |                            | 1.5                   | 0.3                              |                              | Lab (Mich.) | Brown 1974              |
| juvenile            | 2                        | 8wk                      |             |                                   | to .5                             |                                   |                            |                       | 0.5                              |                              | lab (Mich.) | Brown 1974              |
| juvenile            | 5                        | 4wk                      |             |                                   | 3.0                               | 2.7355                            | 0.3381                     | 3                     | 0.5                              |                              | Lab (Mich.) | Brown 1974              |
| juvenile            | 10                       | 2 wk                     |             |                                   | 4.7                               | 2.5090                            | 0.2685                     | 4.5                   | 0.5                              |                              | Lab (Mich.) | Brown 1974              |
| juvenile            | 20                       | 2wk                      |             |                                   | 9.7                               | 1.7154                            | 0.1652                     | 9.5                   | 0.5                              |                              | Lab (Mich.) | Brown 1974              |
| juvenile            | 25                       | 3wk                      |             |                                   |                                   |                                   |                            |                       |                                  |                              |             |                         |

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**SPECIES: Coregonus artedii (cisco, lake herring)**

**PREFERRED TEMPERATURES:**

| Size or Age<br>(mm) | Season | Day or<br>Night | Upper<br>Avoidance | Final<br>Preferendum | Lower<br>Avoidance | Acclimation<br>Temperature | Acclimation<br>Time | Location                 | Reference          |
|---------------------|--------|-----------------|--------------------|----------------------|--------------------|----------------------------|---------------------|--------------------------|--------------------|
|                     |        |                 | 15.5               | 13                   |                    |                            |                     | L. Superior              | Carlander 1969     |
|                     |        |                 | 17-20              |                      |                    |                            |                     | L. Nippissing, Ontario   | Carlander 1969     |
| large               |        |                 | 20                 | 10                   |                    |                            |                     | L. Nippissing, Ontario   | Coutant 1977a      |
| large               |        |                 |                    | 7.2                  |                    |                            |                     | Cayuga L., N.Y.          | Coutant 1977a      |
| large               |        |                 |                    | 13-18                |                    |                            |                     | Atikokan GS preop., Ont. | Spotila et al 1979 |
| larval              | SP     |                 |                    | 9-14                 |                    |                            |                     |                          | Haymes 1984        |



SPECIES: Coregonus artedii (cisco, lake herring)

| Size or Age<br>(mm) | Optimum<br>°C | Range | (b)            |             | No Growth Limits<br>Upper Lower | Location | GROWTH TEMPERATURES:     |  |
|---------------------|---------------|-------|----------------|-------------|---------------------------------|----------|--------------------------|--|
|                     |               |       | (a)<br>M W A T | ST<br>M a x |                                 |          | Reference                |  |
|                     | 18.1          |       | 17             | 25          |                                 |          | Jobling 1981<br>EPA 1974 |  |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature optimum temp for growth),  
 (b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: Coregonus artedii (cisco, lake herring)

| Event                    | Season<br>and/or<br>Accli-<br>mation<br>Temp | Optimum<br>Temp | Temp<br>Range | (a)<br>M W A T | (b)<br>ST Max<br>for<br>Embryo<br>Survival | Accli-<br>mation<br>Time | (c)                      |                              |                                |                                  | Location          | Reference               |
|--------------------------|--|-----------------|---------------|----------------|--|--------------------------|--------------------------|------------------------------|--------------------------------|----------------------------------|-------------------|-------------------------|
|                          |  |                 |               |                |  |                          | Lethal<br>Limit<br>Upper | Lethal<br>Limit<br>L o w e r | Median<br>Lethal<br>$\Delta T$ | (d)<br>Median<br>Lethal<br>Final |                   |                         |
| spawning                 |  | 3.3             | 3.3-5         |                |  |                          |                          |                              |                                |                                  | Wisc.             | Scott and Crossman 1973 |
| incubation<br>(92d)      |  | 5.6             |               |                |  |                          |                          |                              |                                |                                  | Lab               | Scott and Crossman 1973 |
| incubation               |  |                 | 0.5-5.6       |                |  |                          |                          |                              |                                |                                  | Lab               | Scott and Crossman 1973 |
| spawning                 |  |                 | 1.0-5.0       |                |  |                          |                          |                              |                                |                                  | Great Lakes       | Carlander 1969          |
| incubation<br>(111-125d) |  |                 | 2.4-3.3       |                |  |                          |                          |                              |                                |                                  | L. Mendota, Wisc. | Carlander 1969          |
| spawning                 |  | <3.8            |               |                |  |                          |                          |                              |                                |                                  |                   | Spotila et al 1979      |
| larval devel.            |  | 5.6             | 2-8           |                |  |                          |                          |                              |                                |                                  |                   | Spotila et al 1979      |
|                          |  |                 |               | 3              | ≤7<br>8                                    |                          |                          |                              |                                |                                  |                   | Spotila et al 1979      |
| incubation               |  | 6               |               |                |  |                          |                          |                              |                                |                                  | Lab               | EPA 1974                |
| cold shock 7             |  |                 |               |                |  |                          |                          |                              | - 6                            |                                  |                   | Cravens 1981            |
| cold shock 10            |  |                 |               |                |  |                          |                          |                              | - 7                            |                                  |                   |                         |
| cold shock 15            |  |                 |               |                |  |                          |                          |                              | - 12                           |                                  |                   |                         |
| cold shock 20            |  |                 |               |                |  |                          |                          |                              | -15.5                          |                                  |                   |                         |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures,  
 (b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.  
 (c) Not incipient lethal temperatures as defined by Fry et al (1946).  
 (d) Simulated larval entrainment temperatures,

SPECIES: Coregonus hoyi (bloater)

| Size or Age<br>(mm) | Accli-<br>mation<br>Temp | Accli-<br>mation<br>Time | Sea-<br>son | Upper<br>Incip.<br>Lethal<br>Temp | Lower<br>Incip.<br>Lethal<br>Temp | log time =      |    | Data Limits |       | Expo-<br>sure<br>Temp | R e s i s -<br>tance Critical<br>Time Thermal |       | Location           | Reference  |
|---------------------|--------------------------|--------------------------|-------------|-----------------------------------|-----------------------------------|-----------------|----|-------------|-------|-----------------------|---|-------|--------------------|------------|
|                     |                          |                          |             |                                   |                                   | a               | b  | Upper       | Lower |                       | (Min)   | (Max) |                    |            |
|                     |                          |                          |             |                                   |                                   |                 |    |             |       |                       |   |       |                    |            |
| 60; age 1           | 5                        |                          |             | 22.2                              |                                   | 15.8243-0.5831  | 26 | 22          |       |                       |   |       | Lab, L. Michigan   | Brown 1974 |
| 60; age 1           | 10                       |                          |             | 23.6                              |                                   | 9.0700-0.2896   | 30 | 23          |       |                       |   |       | Lab, L. Michigan   | Brown 1974 |
| 60; age 1           | 15                       |                          |             | 24.8                              |                                   | 17.1908-0.5707  | 28 | 24.5        |       |                       |   |       | Lab, L. Michigan   | Brown 1974 |
| 60; age 1           | 20                       |                          |             | 26.2                              |                                   | 28.6392-0.9458  | 29 | 25.5        |       |                       |   |       | Lab, L. Michigan   | Brown 1974 |
| 60; age 1           | 25                       |                          |             | 26.7                              |                                   | 21.351 I-0.6594 | 30 | 26.5        |       |                       |   |       | Lab, L. Michigan   | Brown 1974 |
| 60; age 1           | 8                        |                          |             |                                   |                                   |                 |    |             |       |                       | 27  |       | Lab, (death point) | Brown 1974 |
| 60; age 1           | 20                       |                          |             |                                   |                                   |                 |    |             |       |                       | 28  |       | Lab, (death point) | Brown 1974 |
| 60; age 1           | 25                       |                          |             |                                   |                                   |                 |    |             |       |                       | 29  |       | Lab, (death point) | Brown 1974 |
| age 3               | 8                        |                          |             | 26-27                             |                                   |                 |    |             |       |                       |   |       | Lab                | Brown 1974 |

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SPECIES: Coregonus hoyi (bloater)

| Size or Age<br>(mm)    | Season | Day or<br>Night | Upper<br>Avoidance | Final<br>Preferendum | Lower<br>Avoidance | Acclimation<br>Temperature | Acclimation<br>Time | PREFERRED TEMPERATURES: |  | Reference                 |
|------------------------|--------|-----------------|--------------------|----------------------|--------------------|----------------------------|---------------------|-------------------------|--|---------------------------|
|                        |        |                 |                    |                      |                    |                            |                     | Location                |  |                           |
| larval                 |        |                 | 4.8                |                      |                    |                            |                     | L. Michigan             |  | Scott and Crossman 1973   |
|                        |        |                 | >11.4              | 3.8-7                | >1.5               |                            |                     | L. Michigan             |  | Carlander 1969            |
| large                  | su     |                 | 10                 |                      | 6                  |                            |                     | L. Michigan             |  | Coutant 1977a             |
|                        |        |                 | 16                 |                      | 5                  |                            |                     | L. Michigan             |  | Cravens et al 1983        |
| 80-140 FL:<br>juvenile | SU     |                 |                    | 11-14                |                    |                            |                     | L. Michigan             |  | Crowder and Crawford 1984 |
| 150-200 FL:<br>adult   | su     |                 |                    | 7-10                 |                    |                            |                     | L. Michigan             |  | Crowder and Crawford 1984 |
| YOY                    | F      | D               |                    | 22                   |                    |                            |                     | L. Michigan             |  | Crowder and Crawford 1984 |
| YOY                    | F      | N               |                    | 7-18                 |                    |                            |                     | L. Michigan             |  | Crowder and Crawford 1984 |
| larval                 |        |                 |                    | 4.7                  |                    |                            |                     | Gt. Lakes (90-110m)     |  | McAllister et al 1985     |

SPECIES: Coregonus hoyi (bloater)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |            |          |                                |                  |                        |                        |                          |                         |             |                |
|--|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|--------------------------|-------------------------|-------------|----------------|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal $\Delta T$ | (d) Median Lethal Final | Location    | Reference      |
| larval dev.                            |                                | <4.7         |            |          |                                |                  |                        |                        |                          |                         | L. Michigan | Carlander 1969 |

SPECIES: Coregonus kiyi (kiyi)

| PREFERRED TEMPERATURES: |        |              |                 |                   |                 |                         |                  |  |  |          |                |
|-------------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|--|--|----------|----------------|
| Size or Age (mm)        | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time |  |  | Location | Reference      |
|                         |        |              |                 | 3.7-4.6           |                 |                         |                  |  |  |          | Carlander 1969 |

SPECIES: Coregonus kiyi (kiyi)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |            |          |                                |                  |                        |                        |                          |                         |             |                         |
|--|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|--------------------------|-------------------------|-------------|-------------------------|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal $\Delta T$ | (d) Median Lethal Final | Location    | Reference               |
| spawning                               |                                |              | 1.7-3.4    |          |                                |                  |                        |                        |                          |                         | Great Lakes | Scott and Crossman 1973 |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Coregonus reighardi* (shortnose cisco)

SPAWNING AND DEVELOPMENT TEMPERATURES:

| Event    | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | (d) Median Lethal $\Delta T$ | Median Lethal Final | Location    | Reference               |
|----------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|------------------------------|---------------------|-------------|-------------------------|
| spawning |                                |              | 3.8-4.7    |          |                                |                  |                        |                        |                              |                     | L. Michigan | Scott and Crossman 1973 |

SPECIES: *Coregonus clupeaformis* (lake whitefish)

THERMAL TOLERANCES:

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Sea-son | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = a + b (temp) | Data Upper | Limits Lower | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location          | Reference             |
|------------------|------------------|------------------|---------|--------------------------|--------------------------|-------------------------|------------|--------------|---------------|-----------------------|------------------------|-------------------|-----------------------|
| YOY              |                  |                  |         | 26.6                     |                          |                         |            |              |               |                       |                        |                   | Jobling 1981          |
| YOY              | 5                |                  |         | 20.6                     |                          |                         |            |              |               |                       |                        |                   | Spotila et al 1979    |
| YOY              | 10               |                  |         | 22.7                     |                          |                         |            |              |               |                       |                        |                   | Spotila et al 1979    |
| YOY              | 15               |                  |         | 25.8                     |                          |                         |            |              |               |                       |                        |                   | Spotila et al 1979    |
| YOY              | 20               |                  |         | 26.6                     |                          |                         |            |              |               |                       |                        |                   | Spotila et al 1979    |
| YOY              | 22.5             |                  |         | 26.6                     |                          |                         |            |              |               |                       |                        |                   | Spotila et al 1979    |
| YOY              | 17               |                  |         |                          |                          |                         |            |              | 27.2          | 65                    |                        | Lab (L. Michigan) | Edsall and Yocum 1972 |
| YOY              | 17               |                  |         |                          |                          |                         |            |              | 29.4          | 7                     |                        | Lab (L. Michigan) | Edsall and Yocum 1972 |
| YOY              | 17               |                  |         |                          |                          |                         |            |              | 31.7          | 0.8                   |                        | Lab (L. Michigan) | Edsall and Yocum 1972 |
| YOY              | 17               |                  |         |                          |                          |                         |            |              | 33.7          | 0.1                   |                        | Lab (L. Michigan) | Edsall and Yocum 1972 |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: Coregonus clupeaformis (lake whitefish)

| Size or Age (mm)             | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES:                           |                                     |
|------------------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|---|-------------------------------------|
|                              |        |              |                 |                   |                 |                         |                  | Location  | Reference                           |
| small; 2 yrs juvenile larvae |        |              |                 | 12.7<br>17        |                 |                         |                  | Lab<br>South Bay, Lake Huron<br>Ontario           | Coutant 1977a<br>Coutant 1977a      |
| 12.9; larvae                 |        |              |                 | 12-16             |                 |                         |                  | Lab   | Coutant 1977a                       |
| 17.8; larvae                 |        |              | 17              | 13.5              | 12              |                         |                  | Lab   | Coutant 1977a                       |
| 23.1; larvae                 |        |              | 19              | 15.5              | 14.5            |                         |                  | Lab   | Coutant 1977a                       |
| 4.2-7.2g; fingerling         |        |              |                 | 11.9              |                 |                         |                  | Moosehead L., Me.<br>Lab                          | Coutant 1977a<br>Spotila et al 1979 |
| 1.1-1.7g; young larval       |        |              |                 | 10                |                 |                         |                  | Lab   | Spotila et al 1979                  |
| YOY larval                   |        |              |                 | 17                |                 |                         |                  | L. Erie, L. Ontario<br>(surface water temp)       | Brown 1974                          |
| larval                       | Sp     |              | 14<br>12        | 4                 | 8<br>0          |                         |                  | Atikokan GS, (preop.)<br>Point Beach, L. Michigan | Haymes 1984<br>Michaud 1981         |
| adult larval                 | SP     |              |                 | <9                |                 | 0-13                    |                  | L. Michigan                                       | Cravens et al 1983                  |
| larval                       | SP     |              |                 | 6.9-9.5           |                 |                         |                  | L. Opeongo, Ontario                               | Ihssen et al 1981                   |
| larval                       | SP     |              |                 | 3.5-15            |                 |                         |                  | L. Simcoe, Ontario                                | Ihssen et al 1981                   |
| larval                       | SP     |              |                 | 4-12              |                 |                         |                  | Bay of Quinte, L. Ontario                         | Ihssen et al 1981                   |
| larval                       | SP     |              |                 | 4.5-9             |                 |                         |                  | South Bay, L. Huron                               | Ihssen et al 1981                   |

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SPECIES: Coregonus clupeaformis (lake whitefish)

| Size or Age (mm) | Optimum °C | Range | (a) M W A T |       | ST Max | (b) No Growth Limits |       | Location | GROWTH TEMPERATURES: |              |
|------------------|------------|-------|-------------|-------|--------|----------------------|-------|----------|----------------------|--------------|
|                  |            |       | Upper       | Lower |        | Upper                | Lower |          | Reference            |              |
|                  | 13.5       |       |             |       |        |                      |       |          |                      | Jobling 1981 |
|                  | 16.8       |       |             |       |        |                      |       |          |                      | Jobling 1981 |
|                  |            |       |             |       |        |                      | <10   |          |                      | Brown 1974   |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

## SPAWNING AND DEVELOPMENT TEMPERATURES:

| Event                 | Season and/or Acclimation Temp | Optimum Temp | Temp Range (a) | MWAT | (b)<br>ST Max for Embryo Survival | Acclimation Time | SPAWNING AND DEVELOPMENT TEMPERATURES: |                           |                          |                            | Location                           | Reference                |
|-----------------------|--------------------------------|--------------|----------------|------|-----------------------------------|------------------|--|---------------------------|--------------------------|----------------------------|------------------------------------|--------------------------|
|                       |                                |              |                |      |                                   |                  | (c)<br>Lethal Limit Upper              | (c)<br>Lethal Limit Lower | Median Lethal $\Delta T$ | (d)<br>Median Lethal Final |                                    |                          |
| spawning              |                                |              | ≤7.8           |      |                                   |                  |  |                           |                          |                            | L. Erie                            | Scott and Crossman 1973  |
| incubation            |                                | 0.5          | 0.5-6.1        |      |                                   |                  | 10                                     |                           |                          |                            | Lab                                | Scott and Crossman 1973  |
| spawning              |                                |              | ≤10            |      |                                   |                  |  |                           |                          |                            | Bay of Quinte, L. Ont.             | Carlander 1969           |
| spawning              |                                |              | 0.5-4.5        |      |                                   |                  |  |                           |                          |                            |                                    | Carlander 1969           |
| larval devel.         |                                | 0.5          |                |      |                                   |                  |  |                           |                          |                            | Heming L. field                    | Carlander 1969           |
| incubation (120-140d) |                                |              | 0.5-1.7        |      |                                   |                  |  |                           |                          |                            |                                    | Carlander 1969           |
| incubation (40-141d)  |                                |              | 0.5-8          |      |                                   |                  | 10                                     | 0                         |                          |                            | Lab                                | Carlander 1969           |
| spawning              |                                | 85.5         |                |      |                                   |                  |  |                           |                          |                            |                                    | Spotila et al 1979       |
| hatching              |                                | 0.5          |                |      |                                   |                  |  |                           |                          |                            |                                    | Spotila et al 1979       |
|                       |                                |              |                |      | <6.1                              |                  |  |                           |                          |                            |                                    | Spotila et al 1979       |
| incubation            |                                | 4-7.8        | 3.2-8.1        |      |                                   |                  |  |                           |                          |                            |                                    | Spotila et al 1979       |
| hatching (42d)        |                                | 10           |                |      |                                   |                  |  |                           |                          |                            |                                    | Spotila et al 1979       |
| hatching (182d)       |                                | 0.5          |                |      |                                   |                  |  |                           |                          |                            |                                    | Spotila et al 1979       |
| incubation            | 0.5-10                         |              |                |      |                                   |                  | ≤8                                     |                           |                          |                            |                                    | Wyman 1981               |
| spawning              |                                | <6.1         | 0.5-9.4        |      |                                   |                  |  |                           |                          |                            |                                    | Brown 1974               |
| hatching              |                                |              | 4.6-6.9        |      |                                   |                  |  |                           |                          |                            | L. Erie                            | Brown 1974               |
| heat shock YOY        | 18                             |              |                |      |                                   |                  | 29+                                    |                           | >+11                     |                            |                                    | Brown 1974               |
| spawning              |                                | 4            |                |      |                                   |                  |  |                           |                          |                            | Lakes Nathalie + Helene; James Bay | Talmage and Coutant 1979 |
| larval devel.         |                                | 4-6          |                |      |                                   |                  |  |                           |                          |                            | Lab                                | Griffiths 1979           |
| spawning              |                                | 4-7          |                |      |                                   |                  |  |                           |                          |                            | L. Opeongo, Ont.                   | Ihssen et al 1981        |
| spawning              |                                | 3-6          |                |      |                                   |                  |  |                           |                          |                            | L. Simcoe, Ont.                    | Ihssen et al 1981        |
| spawning              |                                | 6-8          |                |      |                                   |                  |  |                           |                          |                            | Bay of Quinte, L. Ont.             | Ihssen et al 1981        |
| spawning              |                                | 4-8          |                |      |                                   |                  |  |                           |                          |                            | South Bay, L. Huron                | Ihssen et al 1981        |
| incubation (167d)     |                                |              | 1-7            |      |                                   |                  |  |                           |                          |                            | South Bay, L. Huron                | Ihssen et al 1981        |
| incubation (160d)     |                                |              | 1-12           |      |                                   |                  |  |                           |                          |                            | Bay of Quinte., L. Ont.            | Ihssen et al 1981        |
| hatching              |                                |              | 4-12           |      |                                   |                  |  |                           |                          |                            | Bay of Quinte., L. Ont.            | Ihssen et al 1981        |
| hatching              |                                |              | 4-7            |      |                                   |                  |  |                           |                          |                            | South Bay, L. Huron                | Ihssen et al 1981        |
| heat shock (fry)      | 17.1                           |              |                |      |                                   |                  |  |                           | +11                      |                            | L. Michigan (Lab)                  | Edsall and Yocum 1972    |

## SPAWNING AND DEVELOPMENT TEMPERATURES:

| Event       | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal $\Delta T$ | (d) Median Lethal Final | Location                | Reference                    |
|-------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|--------------------------|-------------------------|-------------------------|------------------------------|
| heat shock  |                                |              |            |          |                                |                  |                        |                        | i-31                     |                         | Lab (simulated entrain) | Dunstall 1978                |
| entrainment |                                |              |            |          |                                |                  | 28.9                   |                        |                          |                         | Lab (simulated entrain) | Dunstall 1978                |
| hatching    |                                |              | 2.8-6.7    |          |                                |                  |                        |                        |                          |                         | L. Superior             | Dunstall 1978                |
| hatching    |                                | 4            | 4-8        |          |                                |                  |                        |                        |                          |                         | L. Ontario              | Dunstall 1978                |
| heat shock  |                                |              |            |          |                                |                  |                        |                        | +25                      |                         | Lab (untempered)        | Dunstall 1978 (d)            |
| 6 spawning  |                                |              | 0.5-10     |          |                                |                  |                        |                        |                          |                         |                         | Dunford 1980                 |
| egg         |                                |              |            | 7        | 10                             |                  |                        |                        | +6                       |                         | Lab (+ ambient)         | Griffiths 1980<br>This study |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryosurvival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: Prosopium cylindraceum (round whitefish)

## PREFERRED TEMPERATURES:

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | Location                  | Reference     |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|---------------------------|---------------|
|                  |        |              |                 | 17.5              |                 |                         |                  | Moosehead L. Me.          | Coutant 1977a |
|                  | W      |              |                 | 3-5.8             |                 |                         |                  | L. Ont. near Pickering GS | Carey 1982    |
|                  | F      |              |                 | 2.1-3.6           |                 |                         |                  | L. Ont. near Pickering GS | Carey 1984    |

SPECIES: Prosopium cylindraceum (round whitefish)

## SPAWNING AND DEVELOPMENT TEMPERATURES:

| Event                | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal $\Delta T$ | (d) Median Lethal Final | Location                 | Reference                    |
|----------------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|--------------------------|-------------------------|--------------------------|------------------------------|
| spawning             |                                | 4.5          |            |          |                                |                  |                        |                        |                          |                         | L. Superior              | Scott and Crossman 1973      |
| hatching (140d)      |                                | 2.2          |            |          |                                |                  |                        |                        |                          |                         |                          | Scott and Crossman 1973      |
| spawning             |                                | $\leq 3$     |            |          |                                |                  |                        |                        |                          |                         | L. Ontario               | Carey 1982                   |
| egg survival         |                                | 1-5          |            |          |                                |                  |                        |                        |                          |                         |                          | Gowans 1982                  |
| spawning             |                                | 3            | 2-4.4      |          |                                |                  |                        |                        |                          |                         | L. Ontario               | Dunford 1980                 |
| incubation           |                                | 1-2          |            |          |                                |                  |                        |                        |                          |                         |                          | Dunford 1980                 |
| incubation (37-168d) |                                |              | 1.7-10     |          | <10                            |                  |                        |                        |                          |                         |                          | Griffiths 1980               |
| egg                  |                                |              |            |          |                                |                  |                        |                        | +6                       |                         | Lab (above ambient)      | Griffiths 1980               |
| egg                  |                                |              |            | 3        | 5                              |                  |                        |                        | 4.8                      |                         | Lab (above ambient-TL50) | Griffiths 1980<br>This study |

SPECIES: *Osmerus mordax* (rainbow smelt)

|                     |                          |                          |             |                          |                          |            |   |             |       |                       |                                  | THERMAL TOLERANCES:          |                |                             |
|---------------------|--------------------------|--------------------------|-------------|--------------------------|--------------------------|------------|---|-------------|-------|-----------------------|----------------------------------|------------------------------|----------------|-----------------------------|
| Size or Age<br>(mm) | Accli-<br>mation<br>Temp | Accli-<br>mation<br>Time | Sea-<br>son | Upper                    | Lower                    | log time = |   | Data Limits |       | Expo-<br>sure<br>Temp | Resis-<br>tance<br>Time<br>(Min) | Critical<br>Thermal<br>(Max) | Location       | Reference                   |
|                     |                          |                          |             | Incip.<br>Lethal<br>Temp | Incip.<br>Lethal<br>Temp | a          | b | Upper       | Lower |                       |                                  |                              |                |                             |
|                     | <10                      |                          | W           | 19                       |                          |            |   |             |       |                       |                                  |                              |                | Ellis 1984                  |
|                     | <6                       |                          |             | >24                      |                          |            |   |             |       |                       |                                  |                              |                | Ellis 1984                  |
|                     | 15                       |                          |             |                          |                          |            |   |             |       |                       |                                  | 28.5                         |                | Ellis 1984                  |
|                     | 6                        |                          |             |                          |                          |            |   |             |       | 22                    | 51                               |                              |                | Ellis 1984                  |
|                     | 5.3-6.2                  |                          | SP          |                          |                          |            |   |             |       | 21                    | 736                              |                              | Lab (April 13) | Ellis 1984                  |
|                     |                          |                          |             |                          |                          |            |   |             |       | 23                    | 12                               |                              |                | McCauley 1981               |
|                     |                          |                          |             |                          |                          |            |   |             |       | 22                    | 51                               |                              |                | McCauley 1981               |
|                     |                          |                          |             |                          |                          |            |   |             |       | 21                    | 736                              |                              |                | McCauley 1981               |
|                     | 5.7-6.2                  |                          | SP          |                          |                          |            |   |             |       | 20                    | 1630                             |                              | Lab (April 20) | McCauley 1981               |
|                     |                          |                          |             |                          |                          |            |   |             |       | 24                    | 13                               |                              |                | McCauley 1981               |
|                     |                          |                          |             |                          |                          |            |   |             |       | 23                    | 30                               |                              |                | McCauley 1981               |
|                     |                          |                          |             |                          |                          |            |   |             |       | 22                    | 88                               |                              |                | McCauley 1981               |
|                     |                          |                          |             |                          |                          |            |   |             |       | 27                    | 854                              |                              |                | McCauley 1981               |
| 150-210:            | 6                        |                          | SP          |                          |                          |            |   |             |       |                       |                                  | 24.9                         | Lab            | Reutter and Herdendorf 1976 |
| adult               | 10.2-15                  |                          |             | 21.5-28.5                |                          |            |   |             |       |                       |                                  |                              | Lab            | Brown 1974                  |
|                     | 17                       |                          |             |                          | 8.5                      |            |   |             |       |                       |                                  |                              |                | Houston 1982                |
|                     |                          |                          | W           | 19                       |                          |            |   |             |       | 37                    | <1                               |                              |                | Teleki 1976                 |
| adult               |                          |                          | SP          | 18.9                     |                          |            |   |             |       |                       |                                  |                              |                | McCauley 1981               |
|                     | 1.0                      |                          | SP          |                          |                          |            |   |             |       |                       |                                  | 22.6                         |                | McCauley 1981               |
|                     | 1.6                      |                          | SP          |                          |                          |            |   |             |       |                       |                                  | 22.8                         |                | McCauley 1981               |
|                     | 3.1                      |                          | Sp          |                          |                          |            |   |             |       |                       |                                  | 23.3                         |                | McCauley 1981               |
|                     | 5.4                      |                          | SP          |                          |                          |            |   |             |       |                       |                                  | 24.1                         |                | McCauley 1981               |
|                     | 6.5                      |                          | SP          |                          |                          |            |   |             |       |                       |                                  | 20.1                         |                | McCauley 1981               |
|                     | 8.2                      |                          | SP          |                          |                          |            |   |             |       |                       |                                  | 25.1                         |                | McCauley 1981               |
|                     | 12.2                     |                          | Sp          |                          |                          |            |   |             |       |                       |                                  | 26.4                         |                | McCauley 1981               |



SPECIES: *Osmerus mordax* (rainbow smelt)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES: |                        |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------|------------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                | Reference              |
|                  |        |              | 14              | 6.6-8.3           | 6               |                         |                  | Cayuga L., N.Y.         | Coutant 1977a          |
|                  |        |              | 20              | 12.8              |                 |                         |                  | L. Michigan             | Coutant 1977a          |
|                  |        |              |                 | 18                |                 |                         |                  | L. Champlain, N.Y.      | Coutant 1977a          |
| adult            | su     |              | >15.6           | 7.2               |                 |                         |                  | Field                   | Ellis 1984             |
| adult            |        |              | 14              |                   | 6               |                         |                  | L. Erie                 | Ellis 1984             |
| adult            | F      | D            |                 | 6-8               |                 |                         |                  | L. Michigan             | Brown 1974             |
| adult            | F      | D            |                 | 7.8               |                 |                         |                  | L. Michigan             | Brandt et al 1980a     |
| adult            | F      | N            |                 | 11-16             |                 |                         |                  | L. Michigan             | Brandt et al 1980a     |
| young            | SU     |              |                 | >21               |                 |                         |                  | L. Erie                 | Brandt et al 1980a     |
|                  |        |              |                 | <12.8             |                 |                         |                  | L. Cayuga, N.Y.         | Brown 1974             |
| adult            |        |              |                 | <10               |                 | 0-18                    |                  | L. Michigan             | Brown 1974             |
| YOY              |        |              |                 | 13-14             |                 |                         |                  | L. Michigan             | Michaud 1976           |
| <25; larvae      | Sp/Su  |              |                 | 10.1-14           |                 |                         |                  | L. Michigan             | Tin and Jude 1983      |
|                  | s u    |              |                 | 14.1-16           |                 |                         |                  | L. Michigan             | Tin and Jude 1983      |
| adult            |        | N            | 15.5            | 7-8               |                 |                         |                  | L. Erie                 | Tin and Jude 1983      |
|                  | s u    | N            |                 | 11-16             |                 |                         |                  | L. Superior             | Heist and Swenson 1983 |
|                  |        |              |                 | 15                |                 |                         |                  | Lab                     | Heist and Swenson 1983 |
| adult            |        |              | 12              | 7.6               |                 |                         |                  | Lab                     | McCauley 1981          |
|                  | F      | N            |                 | 11-14             |                 |                         |                  | L. Michigan             | McCauley 1981          |
|                  | F      | D            |                 | 13-16             |                 |                         |                  | L. Michigan             | Crowder et al 1981     |

SPECIES: *Osmerus mordax* (rainbow smelt)

| Size or Age<br>(mm) | Optimum<br>°C | Range | (a)<br>MWAT | (b)<br>ST<br>Max | No Growth Limits |       | Location | GROWTH TEMPERATURES: |            |
|---------------------|---------------|-------|-------------|------------------|------------------|-------|----------|----------------------|------------|
|                     |               |       |             |                  | Upper            | Lower |          | Reference            |            |
|                     |               |       |             |                  | 18.3             |       | L. Erie  |                      | Brown 1974 |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature- optimum temp for growth)

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Osmerus mordax* (rainbow smelt)

| Event                 | Season<br>and/or<br>Accli-<br>mation<br>Temp | Optimum<br>Temp | Temp<br>Range | (a)<br>MWAT | (b)<br>ST Max<br>for<br>Embryo<br>Survival | Accli-<br>mation<br>Time | (c)<br>Lethal<br>Limit<br>Upper | (c)<br>Lethal<br>Limit<br>Lower | Median<br>Lethal<br>$\Delta T$ | (d)<br>Median<br>Lethal<br>Final     | Location                     | Reference |
|-----------------------|--|-----------------|---------------|-------------|--|--------------------------|---------------------------------|---------------------------------|--------------------------------|--------------------------------------|------------------------------|-----------|
|                       |  |                 |               |             |  |                          |                                 |                                 |                                |                                      |                              |           |
| spawning              |  |                 | 2.2-14.5      |             |  |                          |                                 |                                 |                                | L. Superior                          | Brown 1974                   |           |
| spawning run          |  |                 | 3.9-5.6       |             |  |                          |                                 |                                 |                                | L. Erie                              | Brown 1974                   |           |
| spawning              | 10   |                 |               |             |  |                          |                                 |                                 |                                |                                      | Brown 1974                   |           |
| incubation            |  |                 | 5-15          |             |  |                          |                                 |                                 |                                |                                      | Brown 1974                   |           |
| spawning              |  |                 | 8.9-18.3      |             |  |                          |                                 |                                 |                                | Great Lakes streams                  | Scott and Crossman 1973      |           |
| heat shock            | 8.5  |                 |               |             |  |                          |                                 | +22.2                           | 30.5                           | Lab (simulated onshore<br>discharge) | Crippen and Fahmy 1981(d)    |           |
| hatching              |  | 14              |               |             | 23   |                          |                                 |                                 |                                |                                      | McCauley 198 1<br>This study |           |
| eggs                  |  | 11-17           | 9-19          |             |  |                          |                                 |                                 |                                | Lab                                  | Griffiths 1978               |           |
| spawning              |  |                 | < 6           |             |  |                          |                                 |                                 |                                | Lennox GS, L. Ont.                   | Griffiths 1978               |           |
| embryo devel<br>(6d)  |  |                 | 22.5          |             |  |                          |                                 |                                 |                                | Lab                                  | Griffiths 1978               |           |
| embryo devel<br>(35d) |  |                 | 6             |             |  |                          |                                 |                                 |                                | Lab                                  | Griffiths 1978               |           |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Hiodon tergisus* (mooneye)

|                  |        |              |                 |                   |                 |                         |                  | PREFERRED TEMPERATURES:                           |   |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|---|---|
| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | Location  | Reference                                   |
| large larval     | su     |              | 27              | 22                | 22              |                         |                  | Wabash R., Ind.<br>Upper Mississippi R.,<br>Wisc. | Coutant 1977a<br>Holland and Sylvester 1983 |

SPECIES: *Hiodon tergisus* (mooneye)

|          |                                |              |            |          |                                |                  |                        |                        |                          |                         | SPAWNING AND DEVELOPMENT TEMPERATURES: |                            |
|----------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|--------------------------|-------------------------|--|----------------------------|
| Event    | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal $\Delta T$ | (d) Median Lethal Final | Location                               | Reference                  |
| spawning |                                | 10-13        |            | 11.5     | 13                             |                  |                        |                        |                          |                         | Assiniboine R., Man.                   | Talmage 1978<br>This study |

- (a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.
- (b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.
- (c) Not incipient lethal temperatures as defined by Fry et al (1946).
- (d) Simulated larval entrainment temperatures.

SPECIES: *Umbra limi* (central mudminnow)

|                  |                  |                  |                          |                          |                               |                         |               |                       |                        |                     | THERMAL TOLERANCES: |  |
|------------------|------------------|------------------|--------------------------|--------------------------|-------------------------------|-------------------------|---------------|-----------------------|------------------------|---------------------|---------------------|--|
| Size or Age (mm) | Acclimation Temp | Acclimation Time | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time - $\frac{a+b}{temp}$ | Data Limits Upper Lower | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location            | Reference           |  |
|                  |                  |                  |                          |                          |                               |                         |               |                       |                        | Shallow pond. Mich. | Beltz et al 1974    |  |

SPECIES: Umbra limi (central mudminnow)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES: |                         |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------|-------------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                | Reference               |
|                  | su     |              | >28.9           |                   |                 |                         |                  | Ontario                 | Scott and Crossman 1973 |
|                  | SP     |              |                 |                   | 8               |                         |                  | Ontario                 | Scott and Crossman 1973 |

SPECIES: Umbra limi (central mudminnow)

| Event    | Season and/or Acclimation Tamp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal $\Delta T$ | (d) Median Lethal Final | Location               | Reference                             |
|----------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|--------------------------|-------------------------|------------------------|---------------------------------------|
|          |                                |              |            |          |                                |                  |                        |                        |                          |                         |                        |                                       |
| spawning |                                | 13           |            |          |                                |                  |                        |                        |                          |                         | N.Y.; flood vegetation | Carlander 1969                        |
| spawning |                                | 12.8         |            |          |                                |                  |                        |                        |                          |                         | Jones Ck., Ont.        | Scott and Crossman 1973               |
| spawning |                                |              | <15.6      | 13       | 15.6                           |                  |                        |                        |                          |                         |                        | Scott and Crossman 1973<br>This study |

SPECIES: Esox americanus vermiculatus (grass pickerel)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES: |  |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------|--|
|                  |        |              |                 |                   |                 |                         |                  | Location                | Reference  |
| Small            |        |              |                 | 26                |                 |                         |                  | Lab                     | Coutant 1977a<br>Carlander 1969<br>Scott and Crossman 1973 |
|                  |        |              | 28.9            | 25.5              | 25.6            |                         |                  |                         |  |

SPECIES: Esox americanus vermiculatus (grass pickerel)

| Event    | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal $\Delta T$ | (d) Median Lethal Final | Location | Reference               |
|----------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|--------------------------|-------------------------|----------|-------------------------|
|          |                                |              |            |          |                                |                  |                        |                        |                          |                         |          |                         |
| spawning |                                | 7.2-11.7     |            | 9.5      |                                |                  |                        |                        |                          |                         |          | Scott and Crossman 1973 |
| hatching |                                | 7.8-8.9      |            |          |                                |                  |                        |                        |                          |                         |          | Scott and Crossman 1973 |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: ESOX lucius (northern pike)

|                  |                  |                  |        |                          |                          |                             |           |                            |               |                       | THERMAL TOLERANCES:    |                                  |                        |
|------------------|------------------|------------------|--------|--------------------------|--------------------------|-----------------------------|-----------|----------------------------|---------------|-----------------------|------------------------|----------------------------------|------------------------|
| Size or Age (mm) | Acclimation Temp | Acclimation Time | Season | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time =<br>a -t b (temp) |           | Data Limits<br>Upper Lower | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location                         | Reference              |
| subadult         |                  |                  |        | 29.4                     | 0.1                      |                             |           |                            |               |                       |                        | Lab                              | Casselma 1978          |
|                  | 30               |                  |        | 30                       |                          |                             |           |                            |               |                       |                        |                                  | Casselma 1978          |
|                  |                  |                  |        | 33                       |                          |                             |           |                            |               |                       |                        |                                  | Spotila et al 1979     |
|                  |                  |                  |        | 29                       |                          |                             |           |                            |               |                       |                        |                                  | Casselma 1978          |
| ≥50;<br>juvenile | 25               |                  |        | 32.25                    |                          | 17.3066-0.4523              | 34.5 32.5 | 34.5                       | >50           |                       |                        | Lab; Maple, Ont.                 | Brown 1974             |
| ≥50;<br>juvenile | 27.5             |                  |        | 32.75                    |                          | 17.4439-0.4490              | 35.0 33.0 | 35                         | 60            |                       |                        | Lab; Maple, Ont.                 | Brown 1974             |
| ≥50;<br>juvenile | 30               |                  |        | 33.25                    |                          | 17.0961-0.4319              | 35.5 33.5 | 33.5                       | >400          | 33.25                 |                        | Lab; Maple, Ont.                 | Brown 1974             |
| ≥50;<br>juvenile | 2527.5           |                  |        |                          |                          |                             |           | 32.2-33.2                  | <2000         |                       |                        |                                  | Brown 1974             |
| larval           | 17.7             |                  |        | 28.5                     |                          |                             |           |                            |               |                       |                        |                                  | Brown 1974             |
| embryo           |                  |                  |        | 18.9                     | 5                        |                             |           |                            |               |                       |                        |                                  | Brown 1974             |
| embryo           |                  |                  |        | 16.8-20.5                |                          |                             |           |                            |               |                       |                        |                                  | Brown 1974             |
| newly hatched    | 17.7             |                  |        | 25.5                     |                          |                             |           |                            |               |                       |                        |                                  | Brown 1974             |
| adult            | 25               |                  |        | 32                       |                          |                             |           |                            |               |                       |                        |                                  | Brown 1974             |
|                  |                  |                  |        | 35.6131.7                |                          |                             |           |                            |               |                       |                        | surface/bottom<br>Clear L., Iowa | Brown 1974             |
|                  |                  |                  |        | 34                       |                          |                             |           |                            |               |                       |                        |                                  | Jobling 1981           |
|                  |                  |                  |        | 28.4                     |                          |                             |           |                            |               |                       |                        |                                  | Jobling 1981           |
| larvae           | 18               |                  |        |                          | 3                        |                             |           |                            |               |                       |                        |                                  | EPA 1974               |
| juvenile         | 31-36.5          |                  |        |                          |                          |                             |           |                            |               | 30.8                  |                        |                                  | Houston 1982           |
| yolk-sac         | 14-15            | 24h              |        | 31                       |                          |                             |           |                            |               |                       |                        |                                  | Cravens et al 1983     |
| saclarvae        |                  |                  |        |                          |                          |                             |           |                            |               |                       |                        |                                  |                        |
| yolk-sac         | 17.7             |                  |        | 24.8                     |                          |                             |           |                            |               |                       |                        |                                  | Bonin and Spotila 1978 |
| larvae           |                  |                  |        |                          |                          |                             |           |                            |               |                       |                        |                                  |                        |
| eggs, 2-4 cells  |                  |                  |        | 19.8                     |                          |                             |           |                            |               |                       |                        |                                  | Spotila et al 1979     |
| eggs eyed        |                  |                  |        | 28.0                     |                          |                             |           |                            |               |                       |                        |                                  | Spotila et al 1979     |
| yolk-sac         | 11.8             |                  |        | 24.1                     |                          |                             |           |                            |               |                       |                        |                                  | Spotila et al 1979     |
| larvae           | 6.1              |                  |        | 20.6                     |                          |                             |           |                            |               |                       |                        |                                  | Spotila et al 1979     |
|                  |                  |                  | su     | 30.8                     |                          |                             |           |                            |               |                       |                        |                                  | Spotila et al 1979     |

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SPECIES: *Esox lucius* (northern pike)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES:                    |                             |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|--|-----------------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                                   | Reference                   |
| adult            |        |              | 23              | 19-20             | 6               |                         |                  | Lab  | Casselman 1978              |
| larval           |        |              |                 | -26               |                 |                         |                  |  | Casselman 1978              |
|                  |        |              |                 | 14-19             |                 |                         |                  | Wickett L., Ont.                           | Casselman 1978              |
|                  |        |              |                 | 8-24              |                 |                         |                  | SE L. Michigan                             | Brown 1974                  |
| fry              |        |              |                 | 23-24             |                 |                         |                  | Lab  | McCauley and Casselman 1980 |
|                  |        |              |                 | 9.9-11.1          |                 |                         |                  |  | Spotila et al 1979          |
|                  |        |              | 22              | 16.0              | 12.9            |                         |                  | Connecticut R., Conn.<br>(mean occurrence) | Marcy 1976a                 |

SPECIES: *Esox lucius* (northern pike)

| Size or Age (mm)      | Optimum °C | Range | (a)     |        | No Growth Upper | Limits Lower | Location                    | GROWTH TEMPERATURES:        |  |
|-----------------------|------------|-------|---------|--------|-----------------|--------------|-----------------------------|-----------------------------|--|
|                       |            |       | M W A T | ST Max |                 |              |                             | Reference                   |  |
| 283-431FL             | 19         | 10-23 |         |        | 27.5            | <4           | Lab (gain in weight)        | Casselman 1978              |  |
|                       | 21         |       |         |        | 28.2            | 4            | Lab (gain in length)        | Casselman 1978              |  |
| 2-3 yr                | 20.9       |       |         |        |                 |              | Lab                         | Casselman 1978              |  |
| 2-3 yr                | 19.8       |       |         |        |                 |              | Wickett L., Manitoulin Isl. | Casselman 1978              |  |
| larval                | 26         |       |         |        |                 |              | Lab                         | Jobling 1981                |  |
| larval                | 18-25.6    |       | 23.1    | 30     |                 |              |                             | This study                  |  |
| juvenile and subadult | 19-21      |       |         |        | 23.9            |              |                             | Brown 1974                  |  |
|                       |            |       |         |        |                 |              |                             | McCauley and Casselman 1980 |  |
| larvae                | 21         | 18-26 | 28      | 30     |                 |              |                             | EPA 1974                    |  |
| juvenile              | 26         |       |         |        |                 |              |                             | EPA 1974                    |  |
|                       |            |       |         |        |                 |              |                             | EPA 1974                    |  |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Esox lucius* (northern pike)

| Event                   | Season and/or Acclimation Temp | Optimum Temp | Temp (a)<br>Range MWAT |     | (b)<br>ST Max<br>for<br>Embryo<br>Survival | Acclimation<br>Time | SPAWNING AND DEVELOPMENT TEMPERATURES: |                                 |                                |                                  | Location                                  | Reference                 |
|-------------------------|--------------------------------|--------------|------------------------|-----|--|---------------------|--|---------------------------------|--------------------------------|----------------------------------|---|---------------------------|
|                         |                                |              |                        |     |  |                     | (c)<br>Lethal<br>Limit<br>Upper        | (c)<br>Lethal<br>Limit<br>Lower | Median<br>Lethal<br>$\Delta T$ | (d)<br>Median<br>Lethal<br>Final |   |                           |
| cold shock              | 21.8                           |              |                        |     |  |                     |  | 4.9                             | -16.9                          |                                  | L. Wabamun, Alta.                         | Casselman 1978            |
| spawning                | 12                             |              | 9.4-1                  | 4.4 |  |                     |  |                                 |                                |                                  | Ont.                                      | DeMontalembert et al 1978 |
| spawning                |                                |              | 6.7-7.8                |     |  |                     |  |                                 |                                |                                  | L. Simcoe, Ont.                           | Brown 1974                |
| spawning                |                                |              | 4.4-1                  | 1.1 |  |                     |  |                                 |                                |                                  | Canada                                    | Brown 1974                |
| incubation              |                                |              | 2.2-16.6               |     |  |                     |  |                                 |                                |                                  | Wis. Lake                                 | Scott and Crossman 1973   |
| incubation              |                                | 6.5-17.7     | 2-23                   |     |  |                     |  |                                 |                                |                                  |   | Brown 1974                |
| cold shock<br>(embryo)  | 10.5                           |              |                        |     |  |                     |  |                                 | -5.5                           |                                  |   | Brown 1974                |
| heat shock<br>(larvae)  | 16                             |              |                        |     |  |                     | 34.5                                   |                                 | +8.5                           |                                  |   | Brown 1974                |
| cold shock              | 21.8                           |              |                        |     |  |                     |  | 4.9                             | -17                            |                                  | power plant outfall,<br>L. Wabamun, Alta. | Brown 1974                |
| spawning                |                                |              |                        |     | 12   |                     |  |                                 |                                |                                  |   | EPA 1974                  |
| incubation<br>and hatch |                                |              | 4-19                   |     | 19   |                     |  |                                 |                                |                                  |   | EPA 1974                  |
| spawning                |                                | <10          |                        |     |  |                     |  |                                 |                                |                                  | Niagara R. tributaries<br>(N.Y.)          | EPA 1974                  |
| hatching                |                                | 20.8         |                        |     |  |                     |  |                                 |                                |                                  |   | Talmage and Coutant 1979  |
| hatch                   |                                | 6.4-17.7     | 5.8-21                 |     |  |                     |  |                                 |                                |                                  |   | Cravens et al 1983        |
|                         |                                |              |                        |     |  |                     |  |                                 |                                |                                  |   | Spotila et al 1979        |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures,

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Esox masquinongy* (muskellunge)

THERMAL TOLERANCES:

| Size or Age (mm)  | Acclimation Temp | Acclimation Time | Season | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = |        | Data Limits |       | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location                    | Reference              |
|-------------------|------------------|------------------|--------|--------------------------|--------------------------|------------|--------|-------------|-------|---------------|-----------------------|------------------------|-----------------------------|------------------------|
|                   |                  |                  |        |                          |                          | a          | b      | Upper       | Lower |               |                       |                        |                             |                        |
| ≥50; juvenile     | 25               |                  |        | 32.25                    |                          | 18.8879    | 0.5035 | 34.5        | 32.5  | 34.5          | >35                   |                        | Deer Lake Hatchery, Ontario | Brown 1974             |
| ≥50; juvenile     | 27.5             |                  |        | 32.75                    |                          | 20.0817    | 0.5283 | 35          | 33.0  | 35            | >40                   |                        |                             | Brown 1974             |
| ≥50; juvenile     | 30.0             |                  |        | 33.25                    |                          | 18.9506    | 0.4851 | 35.5        | 33.5  | 35.5          | 55                    |                        |                             | Brown 1974             |
| ≥50; juvenile     | 25-30            |                  |        |                          |                          |            |        |             |       | 32.5-33.5     | 500                   |                        |                             | Brown 1974             |
|                   |                  |                  |        | 29                       |                          |            |        |             |       |               |                       |                        |                             | Jobling 1981           |
|                   |                  |                  |        | 34                       |                          |            |        |             |       |               |                       |                        |                             | Jobling 1981           |
| new hatch         | 7                |                  |        |                          |                          |            |        |             |       |               |                       | 28.8                   |                             | Houston 1982           |
|                   | 15               |                  |        |                          |                          |            |        |             |       |               |                       | 31.9                   |                             | Houston 1982           |
|                   | 25               |                  |        |                          |                          |            |        |             |       |               |                       | 34.5                   |                             | Houston 1982           |
| 1-15d; post hatch | 15               |                  |        |                          |                          |            |        |             |       |               |                       | 30.3-32.4              |                             | Houston 1982           |
| 25d; post swim-up | 25               |                  |        |                          |                          |            |        |             |       |               |                       | 32.8                   |                             | Houston 1982           |
| >50 mm            | 25               |                  |        | 32.5                     |                          |            |        |             |       | 32.5          | 400                   |                        | Hatchery, N.Y.              | Bonin and Spotila 1978 |

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SPECIES: *Esox masquinongy* (muskellunge)

PREFERRED TEMPERATURES:

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | Location          | Reference                |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------|--------------------------|
| small            | sp/su  |              |                 | >25.5             |                 |                         |                  | Stony L., Ontario | Minor and Crossman 1978  |
|                  |        |              |                 | 14                |                 |                         |                  | L. St. Clair      | Haas 1978                |
|                  |        |              |                 | 24                |                 |                         |                  | Lab               | Coutant 1977a            |
|                  |        |              |                 | 25.1              |                 |                         |                  |                   | Jobling 1981             |
| 200-250          |        | D            |                 | 21.9              |                 |                         |                  | Lab               | Talmage and Coutant 1980 |
|                  |        | D            |                 | 27.3              |                 |                         |                  | Lab               | Talmage and Coutant 1980 |
|                  |        |              | 32.2            | 25.6              |                 |                         |                  |                   | Scott and Crossman 1973  |



SPECIES: *Esox masquinongy* (muskellunge)

| Size or Age (mm) | Optimum °C | Range | (a) M W A T |    | (b) ST Max |   | No Growth Limits Upper Lower | Location | GROWTH TEMPERATURES: |  |
|------------------|------------|-------|-------------|----|------------|---|------------------------------|----------|----------------------|--|
|                  |            |       | M           | W  | A          | T |                              |          | ST                   | Max  |
| fingerling       | 24-26.6    |       | 28.4        | 32 |            |   | >30                          | 10       | Niagara R., N.Y.     | Jobling 1981<br>Carlander 1969<br>This study<br>Harrison and Hadley 1979 |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 113 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Esox masquinongy* (muskellunge)

| Event                    | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) M W A T | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit |       |           |  | (d) Median Lethal Final | Location                 | Reference                |
|--------------------------|--------------------------------|--------------|------------|-------------|--------------------------------|------------------|------------------|-------|-----------|--|-------------------------|--------------------------|--------------------------|
|                          |                                |              |            |             |                                |                  | Upper            | Lower | Median ΔT |  |                         |                          |                          |
| spawning                 |                                | >10          |            |             |                                |                  |                  |       |           |  |                         | Middle Island Ck. W. Va. | Miles 1978               |
| hatching and development |                                |              | 8-19       |             |                                |                  |                  |       |           |  |                         | Lab                      | Miles 1978               |
| spawning                 |                                |              | 10.5-15.5  |             |                                |                  |                  |       |           |  |                         | Nogies Ck., Ontario      | Minor and Crossman 1978  |
| spawning                 |                                | 13           |            |             |                                |                  |                  |       |           |  |                         |                          | Haas 1978                |
| spawning                 |                                | 16-18        |            |             |                                |                  |                  |       |           |  |                         | Niagara R., N.Y.         | Talmage and Coutant 1979 |
| spawning                 |                                | 13           | 9.5-15.5   |             |                                |                  |                  |       |           |  |                         |                          | Carlander 1969           |
| spawning                 |                                | 12.8         | 9.4-15     |             |                                |                  |                  |       |           |  |                         |                          | Scott and Crossman 1973  |
| hatching                 |                                |              | 11.7-17.2  |             |                                |                  |                  |       |           |  |                         |                          | Scott and Crossman 1973  |
|                          |                                |              |            | 12.2        | 19                             |                  |                  |       |           |  |                         |                          | This study               |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: Compostoma anomalum (stone roller)

THERMAL TOLERANCES:

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Season | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time =<br>a + b (temp) |  | Data Limits Upper | Data Limits Lower | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location | Reference         |
|------------------|------------------|------------------|--------|--------------------------|--------------------------|----------------------------|--|-------------------|-------------------|---------------|-----------------------|------------------------|----------|-------------------|
|                  | 12-30            |                  |        | 31                       |                          |                            |  |                   |                   |               |                       |                        | Lab      | Cherry et al 1977 |

SPECIES: Compostoma anomalum (stone roller)

PREFERRED TEMPERATURES:

| Size or Age (mm) | Season    | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | Location                  | Reference                 |
|------------------|-----------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|---------------------------|---------------------------|
| all              |           |              | 23.8            |                   |                 |                         |                  | New R., Va.               | Coutant 1977a             |
| adult            |           |              |                 | 26.8              |                 |                         |                  | Lab                       | Coutant 1977a             |
|                  |           |              | 33              | 29                | 24              |                         |                  | Lab                       | Coutant 1977a             |
|                  |           |              |                 | 28.5              |                 |                         |                  | Lab                       | Houston 1982              |
|                  |           |              |                 | 26.2              |                 |                         |                  |                           | Houston 1982              |
|                  |           |              |                 | 19-27             |                 |                         |                  |                           | Spotila et al 1979        |
|                  |           |              |                 | 13.4              |                 |                         | 6                | Lab                       | Spotila et al 1979        |
|                  |           |              |                 | 15.2              |                 |                         | 9                | Lab                       | Spotila et al 1979        |
|                  |           |              |                 | 20.7              |                 |                         | 12               | Lab                       | Spotila et al 1979        |
|                  |           |              |                 | 21.7              |                 |                         | 15               | Lab                       | Spotila et al 1979        |
|                  |           |              |                 | 22.3              |                 |                         | 18               | Lab                       | Spotila et al 1979        |
|                  |           |              |                 | 23.6              |                 |                         | 21               | Lab                       | Spotila et al 1979        |
|                  |           |              |                 | 25.3              |                 |                         | 24               | Lab                       | Spotila et al 1979        |
|                  |           |              |                 | 28.6              |                 |                         | 27               | Lab                       | Spotila et al 1979        |
|                  | 50-100 FL |              | 21              |                   | 16.5            | 9                       | 12               |                           | Lab (rising temperatures) |
| 50-100 FL        |           | 24           |                 | 17                | 12              | 15                      |                  | Lab (rising temperatures) | Cherry et al 1977         |
| 50-100 FL        |           | 24           |                 | 21                | 15              | 18                      |                  | Lab (rising temperatures) | Cherry et al 1977         |
| 50-100 FL        |           | 27           |                 | 22.4              | 18              | 21                      |                  | Lab (rising temperatures) | Cherry et al 1977         |
| 50-100 FL        |           | 30           |                 | 25.1              | 21              | 24                      |                  | Lab (rising temperatures) | Cherry et al 1977         |
| 50-100 FL        |           | 33           |                 | 28.2              | 21              | 27                      |                  | Lab (rising temperatures) | Cherry et al 1977         |
| 50-100 FL        |           | 33           |                 | 27.4              | 21              | 30                      |                  | Lab (rising temperatures) | Cherry et al 1977         |

SPECIES: Compostoma anomalum (stone roller)

| Size or Age (mm) | Optimum °C | Range | (a)  |        | (b)                    |       | Location | GROWTH TEMPERATURES: |                            |
|------------------|------------|-------|------|--------|------------------------|-------|----------|----------------------|----------------------------|
|                  |            |       | MWAT | ST Max | No Growth Limits Upper | Lower |          | Reference            |                            |
|                  | 26.6123    |       | 27   | 30     |                        |       |          |                      | Jobling 1981<br>This study |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: Compostoma anomalum (stone roller)

| Event          | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | (d) Median Lethal ΔT | Median Lethal Final | Location       | Reference       |
|----------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|----------------------|---------------------|----------------|-----------------|
|                |                                |              |            |          |                                |                  |                        |                        |                      |                     |                |                 |
| nest building  |                                |              | 12815.6    |          |                                |                  |                        |                        |                      |                     | N.Y.           | Brown 1974      |
| spawning       |                                |              | 14.4-23.9  |          |                                |                  |                        |                        |                      |                     |                | Brown 1974      |
| nest building  |                                |              | 12         |          |                                |                  |                        |                        |                      |                     | Illinois       | Brown 1974      |
| spawning       |                                |              | 24-27      |          |                                |                  |                        |                        |                      |                     | Illinois       | Brown 1974      |
| spawning       |                                |              | 18.3-26.7  |          |                                |                  |                        |                        |                      |                     | Illinois       | Brown 1974      |
| hatching (70h) |                                | 21           |            |          |                                |                  |                        |                        |                      |                     |                | Carlander 1969  |
| (4d)           |                                | 24.3         |            |          |                                |                  |                        |                        |                      |                     | Lab (Missouri) | Carmichael 1983 |
| (6d)           |                                | 17.7         |            |          |                                |                  |                        |                        |                      |                     | Lab (Missouri) | Carmichael 1983 |
| (10d)          |                                | 13.9         |            |          |                                |                  |                        |                        |                      |                     | Lab (Missouri) | Carmichael 1983 |
|                |                                |              |            | 22.5     |                                |                  |                        |                        |                      |                     |                | This study      |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Chrosomus eos* (northern redbelly dace)

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Season | THERMAL TOLERANCES:      |                          | log time =<br>a + b (temp)<br>a b | Data Limits<br>Upper Lower | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location      | Reference      |
|------------------|------------------|------------------|--------|--------------------------|--------------------------|-----------------------------------|----------------------------|---------------|-----------------------|------------------------|---------------|----------------|
|                  |                  |                  |        | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp |                                   |                            |               |                       |                        |               |                |
|                  | 21               |                  |        |                          | 2.7                      |                                   |                            |               |                       |                        |               | Carlander 1969 |
|                  | 25-26            |                  |        | 33.1                     |                          |                                   |                            |               |                       |                        |               | Carlander 1969 |
|                  | 9                |                  |        | 28                       |                          |                                   |                            |               |                       |                        | Lab (Toronto) | Tyler 1966     |
|                  | 20               |                  |        |                          |                          |                                   |                            |               | 29                    |                        | Lab (Toronto) | Tyler 1966     |
|                  | 6                |                  | su     | 21.5                     |                          |                                   |                            |               |                       |                        | Lab (Toronto) | Tyler 1966     |
|                  | 9.5              |                  | W      | 26.5                     |                          |                                   |                            |               |                       |                        | Lab (Toronto) | Tyler 1966     |
|                  | 10               |                  | su     | 30                       |                          |                                   |                            |               |                       |                        | Lab (Toronto) | Tyler 1966     |
|                  | 15               |                  | su     | 31                       |                          |                                   |                            |               |                       |                        | Lab (Toronto) | Tyler 1966     |
|                  | 15               |                  | W      | 28                       |                          |                                   |                            |               |                       |                        | Lab (Toronto) | Tyler 1966     |
|                  | 20               |                  | SU     | 31.5                     |                          |                                   |                            |               |                       |                        | Lab (Toronto) | Tyler 1966     |
|                  | 20               |                  | W      | 29.5                     |                          |                                   |                            |               |                       |                        | Lab (Toronto) | Tyler 1966     |
|                  | 25               |                  | Su     | 32.7                     |                          |                                   |                            |               |                       |                        | Lab (Toronto) | Tyler 1966     |
|                  | 25               |                  | w      | 31                       |                          |                                   |                            |               |                       |                        | Lab (Toronto) | Tyler 1966     |

SPECIES: *Chrosomus eos* (northern redbelly dace)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES: |          | Reference    |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------|----------|--------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                | Location |              |
| adult            |        |              |                 | 25.3              |                 | 6-33                    |                  |                         |          | Cravens 1981 |

SPECIES: *Chrosomus eos* (northern redbelly dace)

| Event            | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | (c) Lethal Limit Upper | (c) Lethal Limit Lower | (d) Median AT | (d) Median Lethal Final | Location | Reference               |
|------------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------------|------------------------|---------------|-------------------------|----------|-------------------------|
|                  |                                |              |            |          |                                |                        |                        |               |                         |          |                         |
| Hatching (8-10d) |                                |              | 21.1-26.7  |          |                                |                        |                        |               |                         |          | Scott and Crossman 1973 |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Chrosomus neogaeus* (finescale dace)

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Sea-son | Upper              |                    | Lower |       | log time =<br>$\frac{a + b(\text{temp})}{a}$ | Data Limits |           | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | THERMAL TOLERANCES: |            |
|------------------|------------------|------------------|---------|--------------------|--------------------|-------|-------|--|-------------|-----------|---------------|-----------------------|------------------------|---------------------|------------|
|                  |                  |                  |         | Incip. Lethal Temp | Incip. Lethal Temp | Upper | Lower |  | Location    | Reference |               |                       |                        |                     |            |
|                  |                  |                  |         |                    |                    |       |       |  |             |           |               |                       |                        |                     |            |
| 20               |                  |                  |         |                    |                    |       |       |  |             |           |               |                       | 28.5                   | Lab (Toronto)       | Tyler 1966 |
| 9                |                  |                  | W       | 27                 |                    |       |       |  |             |           |               |                       |                        | Lab (Toronto)       | Tyler 1966 |
| 15               |                  |                  | W       | 28                 |                    |       |       |  |             |           |               |                       |                        | Lab (Toronto)       | Tyler 1966 |
| 15               |                  |                  | su      | 31                 |                    |       |       |  |             |           |               |                       |                        | Lab (Toronto)       | Tyler 1966 |
| 19               |                  |                  | W       | 30.3               |                    |       |       |  |             |           |               |                       |                        | Lab (Toronto)       | Tyler 1966 |
| 22               |                  |                  | su      | 32.2               |                    |       |       |  |             |           |               |                       |                        | Lab (Toronto)       | Tyler 1966 |
| 25               |                  |                  | W       | 31.3               |                    |       |       |  |             |           |               |                       |                        | Lab (Toronto)       | Tyler 1966 |
| 25               |                  |                  | su      | 32.2               |                    |       |       |  |             |           |               |                       |                        | Lab (Toronto)       | Tyler 1966 |

SPECIES: *Chrosomus neogaeus* (finescale dace)

| Event         | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | lb) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal $\Delta T$ | (d) Median Lethal Final | Location          | Reference    |
|---------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|--------------------------|-------------------------|-------------------|--------------|
|               |                                |              |            |          |                                |                  |                        |                        |                          |                         |                   |              |
| Spawning      |                                | > 15         |            |          |                                |                  |                        |                        |                          |                         | French Ck., Minn. | Stasiak 1978 |
| Hatching (6d) |                                | 20           |            |          |                                |                  |                        |                        |                          |                         | French Ck., Minn. | Stasiak 1978 |
| Spawning      |                                |              | 17-22      |          |                                |                  |                        |                        |                          |                         | Lab (Minn.)       | Stasiak 1978 |
|               |                                |              |            | 20       | 22                             |                  |                        |                        |                          |                         |                   | This Study   |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Couesius plumbeus* /lake chub)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |            |          |                                |                  |                        |                        |                      |                         |                                   |                                |
|--|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|----------------------|-------------------------|-----------------------------------|--------------------------------|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | (c) Median Lethal AT | (d) Median Lethal Final | Location                          | Reference                      |
| spawning migration                     |                                | 14/19        |            |          |                                |                  |                        |                        |                      |                         | Lac Saugay, Que. (tributary/lake) | Scott and Crossman 1973        |
| spawning onset                         |                                | 4            |            | 19       |                                |                  |                        |                        |                      |                         | Montreal R., Sask                 | This study<br>Brown et al 1970 |
| spawning                               |                                |              | 4-a        |          |                                |                  |                        |                        |                      |                         | Montreal R., Sask                 | Brown et al 1970               |
| spawning                               |                                |              | 10         |          |                                |                  |                        |                        |                      |                         | Lac La Ronge, Sask                | Brown et al 1970               |
| hatching (10d)                         |                                |              | 8-19       |          |                                |                  |                        |                        |                      |                         | Lab                               | Brown et al 1970               |

- (a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures,
- (b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.
- (c) Not incipient lethal temperatures as defined by Fry et al (1946).
- (d) Simulated larval entrainment temperatures.

SPECIES: *Cyprinus carpio* (carp)

| THERMAL TOLERANCES: |                  |                  |         |                          |                          |                         |                   |                   |               |                       |                        |          |   |
|---------------------|------------------|------------------|---------|--------------------------|--------------------------|-------------------------|-------------------|-------------------|---------------|-----------------------|------------------------|----------|---|
| Size or Age (mm)    | Acclimation Temp | Acclimation Time | Sea-son | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = a + b (temp) | Data Limits Upper | Data Limits Lower | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location | Reference                                       |
| small               | 20               |                  |         | 31-34                    |                          |                         |                   |                   |               |                       |                        | Lab      | Spotila et al 1979                              |
|                     | 26               |                  |         | 35.7                     |                          |                         |                   |                   |               |                       |                        |          | Spotila et al 1979                              |
| large               |                  |                  |         | 35-36                    |                          |                         |                   |                   |               |                       | 38-39                  |          | Spotila et al 1979                              |
|                     | 23.3             |                  | su      |                          |                          |                         |                   |                   |               |                       | 39.0                   | Lab      | Spotila et al 1979<br>Leidy and Jenkins 1977(a) |
| eggs                |                  |                  |         | 31-35                    | 0.7                      |                         |                   |                   |               |                       |                        |          | Brown 1974                                      |
| eggs                | 26.3             |                  |         |                          |                          |                         |                   |                   |               |                       | 40.6                   |          | Brown 1974(b)                                   |
| larval              | 25               |                  |         | 35                       |                          |                         |                   |                   | 25            | 1 0                   |                        | Lab      | Jinks et al 1981                                |
|                     | 19-27            |                  |         | 38.8                     |                          |                         |                   |                   |               |                       |                        | Lab      | Talmage 1978                                    |
|                     | 16-21            |                  |         | 36.4                     |                          |                         |                   |                   |               |                       |                        | Lab      | Talmage 1978                                    |
| late stage embryo   |                  |                  |         | 40-42.5                  |                          |                         |                   |                   |               |                       |                        | Lab      | Crippen and Fahmy 1981                          |

- (a) hybrid *C. carpio* x *Carassius auratus*
- (b) heating rate 3 c/h

SPECIES: *Cyprinus carpio* (carp)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES:                 |                          |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|---|--------------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                                | Reference                |
|                  |        |              |                 | 17                |                 |                         | 10               |   | Spotila et al 1979       |
|                  |        |              |                 | 25                |                 |                         | 15               |   | Spotila et al 1979       |
|                  |        |              |                 | 27                |                 |                         | 20               |   | Spotila et al 1979       |
|                  |        |              |                 | 31                |                 |                         | 25               |   | Spotila et al 1979       |
|                  |        |              |                 | 31                |                 |                         | 30               |   | Spotila et al 1979       |
|                  |        |              |                 | 32                |                 |                         | 35               |   | Spotila et al 1979       |
|                  |        |              |                 | 32                |                 |                         |                  |   | Spotila et al 1979       |
| adult            | SP     |              |                 | 27.4              |                 |                         |                  | Lab                                     | Spotila et al 1979       |
| adult            | su     |              |                 | 29.7              |                 |                         |                  | Lab                                     | Spotila et al 1979       |
| large            |        |              | 34.5            |                   | 27              |                         |                  | Wabash R., Ind.                         | Coutant 1977a            |
| large            |        | D            |                 | 29.3-31.9         |                 |                         |                  | L. Monona, Wis.                         | Coutant 1977a            |
| large            |        | N            |                 | 28.2-30.7         |                 |                         |                  | L. Monona, Wis.                         | Coutant 1977a            |
| young            |        |              | 35              | 32                | 28              |                         |                  | Lab                                     | Coutant 1977a            |
| young            |        | D            | 33.5            | 31.9              | 30              |                         |                  | Lab                                     | Coutant 1977a            |
| young            |        | N            | 32.3            | 32                | 29.5            |                         |                  | Lab                                     | Coutant 1977a            |
| adult            |        |              | >31             | 2 9               | 24              |                         |                  |   | LabCoutant 1977a         |
|                  |        |              |                 | 29                |                 |                         |                  |   | Jobling 1981             |
|                  |        |              |                 | 25-30             |                 |                         |                  |   | Wyman 1981               |
|                  | su     |              |                 | 26-34             |                 |                         |                  | J.M. Stuart GS, Ohio R., Ind.           | Yoder and Gammon 1976    |
|                  | F      |              |                 | 16-20             |                 |                         |                  | J.M. Stuart GS, Ohio R., Ind.           | Yoder and Gammon 1976    |
|                  | w      |              |                 | 5-16              |                 |                         |                  | J.M. Stuart GS, Ohio R., Ind.           | Yoder and Gammon 1976    |
| large            |        |              |                 | 20.7-24.8         |                 |                         |                  | Point Beach Nuclear Power Plant         | Brown 1974               |
|                  |        |              | >36.1           |                   |                 |                         |                  | Discharge effluent, White R., Ind.      | Brown 1974               |
|                  |        |              |                 | 24                |                 |                         |                  |   | Talmage and Coutant 1978 |
|                  |        |              | 39.2            | 21.6              | 5.1             |                         |                  | Connecticut R., Conn. (mean occurrence) | Marcy 1976a              |

SPECIES: *Cyprinus carpio* (carp)

| Size or Age<br>(mm) | Optimum<br>°C | Range     | (a)     |             | No Growth Limits<br>Upper | Limits<br>Lower | Location        | GROWTH TEMPERATURES:     |  |
|---------------------|---------------|-----------|---------|-------------|---------------------------|-----------------|-----------------|--------------------------|--|
|                     |               |           | M W A T | ST<br>M a x |                           |                 |                 | Reference                |  |
|                     | 27            |           |         |             |                           |                 |                 | Spotila et al 1979       |  |
|                     | 30/32         |           |         |             |                           |                 |                 | Jobling 1981             |  |
|                     | 32            |           |         |             |                           |                 |                 | Leidy and Jenkins 1977   |  |
|                     | 27            |           |         |             |                           |                 |                 | Brown 1974               |  |
|                     | 20-25         |           |         |             |                           |                 |                 | Brown 1974               |  |
|                     | 23-27         |           |         |             | 29-30                     | 10              |                 | Brown 1974               |  |
|                     |               | 23-30     |         |             |                           |                 |                 | Cravens 1981             |  |
|                     |               | 11-19     |         |             |                           |                 | Israel (winter) | Carlander 1969           |  |
| early fry           |               | 14.5-18.5 |         |             |                           | >4.5            |                 | Carlander 1969           |  |
|                     | 30            |           |         |             | >35                       |                 |                 | Talmage and Coutant 1978 |  |
|                     |               |           | 34      | 38          |                           |                 |                 | This study               |  |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature- optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.



SPECIES: Cyprinus carpio (carp)

|                       |                                |              |            |          |                                |                  |                        |                        |                          |                                 | SPAWNING AND DEVELOPMENT TEMPERATURES: |                          |
|-----------------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|--------------------------|---------------------------------|--|--------------------------|
| Event                 | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal $\Delta T$ | (d) Median Lethal Final         | Location                               | Reference                |
|                       |                                |              |            |          |                                |                  |                        |                        |                          |                                 |  |                          |
| embryo                |                                |              |            |          | 38                             |                  |                        |                        |                          |                                 |  | Spotila et al 1979       |
| larval dev.           |                                | 20-25        |            |          |                                |                  |                        |                        |                          |                                 |  | Spotila et al 1979       |
| spawning              |                                |              | 17-28      | 21       | 26                             |                  |                        |                        |                          |                                 |  | Scott and Crossman 1973  |
|                       |                                | 19-23        | 16-26      |          |                                |                  |                        |                        |                          |                                 |  | EPA 1974                 |
| incubation/hatch      |                                |              | 17-22      |          |                                |                  |                        |                        |                          |                                 |  | EPA 1974                 |
| spawning              |                                |              | 14.525     |          |                                |                  |                        |                        |                          |                                 |  | Brown 1974               |
| incubation            |                                | <22          |            |          |                                |                  |                        |                        |                          |                                 |  | Brown 1974               |
| heat shock            | 20                             |              |            |          |                                |                  | 35                     |                        | > +10                    |                                 |  | Brown 1974               |
| heat shock, larvae    | 25                             |              |            |          |                                |                  | 37-38                  |                        | +13                      | Lab                             |  | Brown 1974               |
| heat shock, larvae    |                                |              |            |          |                                |                  | 33.5                   |                        |                          | Discharge, Nuclear Plant, Conn. |  | Brown 1974               |
| heat shock            | 28.3                           |              |            |          |                                |                  | 33.3                   |                        | +5                       | Discharge (warmed)              |  | Brown 1974               |
| heat shock, larvae    |                                |              |            |          |                                |                  | 36.1                   |                        | +18.1                    | Lab; Simulated                  |  | Talmage and Coutant 1980 |
| hatching              |                                | 23.4         | 11-32      |          |                                |                  |                        |                        |                          | Entrainment                     |  | Carlander 1969           |
| heat shock, eggs      |                                |              |            |          |                                |                  | 42.5                   |                        |                          |                                 |  | Crippen and Fahmy 1981   |
| spawning              |                                | 27           | 22-27      |          |                                |                  |                        |                        |                          | Connecticut R., Conn.           |  | Marcy 1976b              |
| larval dev. (5.22 mm) |                                | 23-24.9      | 13.8-26    |          |                                |                  |                        |                        |                          | Connecticut R., Conn.           |  | Marcy 1976b              |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures,

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Exoglossum maxillingua* (cutlips minnow)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES:                                 |            |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|---|------------|
|                  |        |              |                 |                   |                 |                         |                  | Location  | Reference  |
|                  |        |              | 18.3            |                   | 8               |                         |                  | Heated discharge, Delaware R., Penn. (field occurrence) | Brown 1974 |
|                  |        |              | 19.4            |                   | 10              |                         |                  | Heated discharge, Delaware R., Penn. (field occurrence) | Brown 1974 |

SPECIES: *Exoglossum maxillingua* (cutlips minnow)

| Event    | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | SPAWNING AND DEVELOPMENT TEMPERATURES: |                        |                          |                         | Location | Reference  |
|----------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|--|------------------------|--------------------------|-------------------------|----------|------------|
|          |                                |              |            |          |                                |                  | (c) Lethal Limit Upper                 | (c) Lethal Limit Lower | Median Lethal $\Delta T$ | (d) Median Lethal Final |          |            |
| spawning |                                | <15          |            |          |                                |                  |  |                        |                          |                         |          | Brown 1974 |
| spawning |                                |              | 17-21.5    |          |                                |                  |  |                        |                          |                         |          | Brown 1974 |
|          |                                |              |            | 19       | 21.5                           |                  |  |                        |                          |                         |          | This study |

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W

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Hybognathus hankinsoni* (brassy minnow)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |                |      |                                |                  |                        |                        |                  |                         |          |                                       |
|--|--------------------------------|--------------|----------------|------|--------------------------------|------------------|------------------------|------------------------|------------------|-------------------------|----------|---------------------------------------|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp (a) Range | MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location | Reference                             |
| spawning                               |                                |              | 10-12.8        | 11.5 | 12.8                           |                  |                        |                        |                  |                         |          | Scott and Crossman 1973<br>This study |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Hybognathus nuchalis* (silvery minnow)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |                |      |                                |                  |                        |                        |                  |                         |          |                                       |
|--|--------------------------------|--------------|----------------|------|--------------------------------|------------------|------------------------|------------------------|------------------|-------------------------|----------|---------------------------------------|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp (a) Range | MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location | Reference                             |
| spawning                               |                                |              | 13-20.5        | 16.8 | 20.5                           |                  |                        |                        |                  |                         |          | Scott and Crossman 1973<br>This study |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures,

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Hybopsis storeriana* (silver chub)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |            |          |                                |                  |                        |                        |                  |                         |          |   |
|--|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|------------------|-------------------------|----------|---|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location | Reference   |
| spawning                               |                                | 21           | 18-21 t    | 21       | 21 +                           |                  |                        |                        |                  |                         | Ohio     | Scott and Crossman 1973<br>Carlander 1969<br>This study |

- (a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures,
- (b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.
- (c) Not incipient lethal temperatures as defined by Fry et al (1946).
- (d) Simulated larval entrainment temperatures.

SPECIES: *Nocomis biguttatus* (hornyhead chub)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |            |          |                                |                  |                        |                        |                          |                         |          |                                       |
|--|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|--------------------------|-------------------------|----------|---------------------------------------|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal $\Delta T$ | (d) Median Lethal Final | Location | Reference                             |
| spawning                               |                                | 23.9         |            | 23.9     |                                |                  |                        |                        |                          |                         |          | Scott and Crossman 1973<br>This study |

SPECIES: *Nocomis micropogon* (river chub)

| THERMAL TOLERANCES: |                  |                  |              |                          |                          |                             |                         |               |                        |                        |            |                     |
|---------------------|------------------|------------------|--------------|--------------------------|--------------------------|-----------------------------|-------------------------|---------------|------------------------|------------------------|------------|---------------------|
| Size or Age (mm)    | Acclimation Temp | Acclimation Time | Sea-son Temp | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | fog time = a + b (temp) a b | Data Limits Upper Lower | Exposure Temp | Resis-tance Time (Min) | Critical Thermal (Max) | Location   | Reference           |
|                     | 15               |                  |              |                          |                          |                             |                         |               |                        | 30.9                   | Lab (N.Y.) | Spotilla et al 1979 |

SPECIES: Nocomis micropogon (river chub)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |            |          |                                |                  |                        |                        |                          |                         |          |                |
|--|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|--------------------------|-------------------------|----------|----------------|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal $\Delta T$ | (d) Median Lethal Final | Location | Reference      |
| spawning nest building                 |                                |              | 19-28      |          |                                |                  |                        |                        |                          |                         | Illinois | Carlander 1969 |
| nest building                          |                                |              | 11.9-20.6  |          |                                |                  |                        |                        |                          |                         |          | Brown 1974     |
| nest building                          |                                |              | 19.4-27.8  | 23.5     | 28                             |                  |                        |                        |                          |                         | Illinois | This study     |

- (a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.
- (b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.
- (c) Not incipient lethal temperatures as defined by Fry et al (1946).
- (d) Simulated larval entrainment temperatures.



| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | Location                               | Reference                   |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|--|-----------------------------|
| adult            | W      |              |                 | 16.8              |                 |                         |                  | Lab                                    | Reutter and Herdendorf 1976 |
|                  | SP     |              |                 | 23.7              |                 |                         |                  |  | Reutter and Herdendorf 1976 |
|                  | su     |              |                 | 22.3              |                 |                         |                  |  | Reutter and Herdendorf 1976 |
|                  | F      |              |                 | 21.0              |                 |                         |                  |  | Reutter and Herdendorf 1976 |
|                  |        |              | >30             |                   |                 |                         |                  |  | Carlander 1969              |
|                  |        |              | >32.2           |                   |                 |                         |                  | Heated discharge, Delaware Ft., Penn.  | Brown 1974                  |
|                  |        |              | >37.2           | 23.9-28.9         |                 |                         |                  | Heated discharge, Delaware R., Penn.   | Brown 1974                  |
|                  |        |              | >35             |                   |                 |                         |                  | Heated discharge, Delaware R., Penn.   | Brown 1974                  |
|                  |        |              | 40              | 24                | 6.7             |                         |                  | Heated discharge, Connecticut R., Conn | Marcy 1976a                 |

SPECIES: *Notemigonus crysoleucas* (golden shiner)

SPAWNING AND DEVELOPMENT TEMPERATURES:

| Event                   | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit |       | Median AT | (d) Median Lethal |       | Location                  | Reference                |
|-------------------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------|-------|-----------|-------------------|-------|---------------------------|--------------------------|
|                         |                                |              |            |          |                                |                  | Upper            | Lower |           | Final             | Final |                           |                          |
| spawning                |                                | 20           |            |          |                                |                  |                  |       |           |                   |       |                           | Scott and Crossman 1973  |
| spawning                |                                | 20-21        |            |          |                                |                  |                  |       |           |                   |       | N.Y. ponds                | Carlander 1969           |
| hatching (1st)          |                                | 20           |            |          |                                |                  |                  |       |           |                   |       | Ponds, Alab. Field        | Carlander 1969           |
| spawning                |                                |              | 15.6-21    |          |                                |                  |                  |       |           |                   |       |                           | Carlander 1969           |
| hatching (4d)           |                                | 15.6+        |            |          |                                |                  |                  |       |           |                   |       |                           | Brown 1974               |
| heat shock (1.5-4.5 in) | 15.6                           |              |            |          |                                |                  |                  |       | +11.1     |                   |       | Lab (spring)              | Brown 1974               |
| heat shock (1.5-4.5 in) | 15.6                           |              |            |          |                                |                  |                  |       | +21.7     |                   |       | Lab (winter 5% mortality) | Brown 1974               |
| spawning                |                                | <27          |            | 20       | 25                             |                  |                  |       |           |                   |       | Lab (gonad regression)    | Talmage and Coutant 1978 |
|                         |                                |              |            |          |                                |                  |                  |       |           |                   |       |                           | This study               |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures,

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.





SPECIES: Notropis atherinoides (Emerald shiner)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES:                                |                             |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|--|-----------------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location   | Reference                   |
| adult            | w      |              |                 | 8.3               |                 |                         |                  | Lab  | Reutter and Herdendorf 1976 |
| YOY              | w      |              |                 | 10-12             |                 |                         |                  | Lab  | Reutter and Herdendorf 1976 |
| YOY              | SP     |              |                 | 13-15             |                 |                         |                  | Lab  | Reutter and Herdendorf 1976 |
| YOY              | su     |              |                 | 22-23             |                 |                         |                  | Lab  | Reutter and Herdendorf 1976 |
| YOY              | F      |              |                 | 13-14             |                 |                         |                  | Lab  | Reutter and Herdendorf 1976 |
| adult            | w      |              |                 | 5-6               |                 |                         |                  | Lab  | Reutter and Herdendorf 1976 |
|                  | SP     |              |                 | 16                |                 |                         |                  | Lab  | Reutter and Herdendorf 1976 |
|                  | SU     |              |                 | 22-24             |                 |                         |                  | Lab  | Reutter and Herdendorf 1976 |
|                  | F      |              |                 | 15-17             |                 |                         |                  | Lab  | Reutter and Herdendorf 1976 |
|                  |        |              | >28-30<br>>31.1 |                   |                 |                         |                  |  | Spotila et al 1979          |
|                  |        |              | 42              |                   | 6               |                         |                  | White R., Ind.<br>heated discharge<br>Field occurrence | Brown 1974                  |
|                  |        |              |                 | 27.8125.1         |                 |                         |                  |  | Ellis 1984                  |
|                  |        |              |                 | 25                |                 |                         |                  |  | Jobling 1981                |
|                  | su     |              |                 | 25                |                 |                         |                  | L. Simcoe, Ont.  | Brown 1974                  |
|                  | w      |              |                 | 27                |                 |                         |                  | L. Simcoe, Ont.<br>Ohio R.                             | EPA 1974<br>EPA 1974        |

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SPECIES: Notropis atherinoides (emerald shiner)

| Size or Age (mm) | Optimum °C    | Range | (a)  |        | No Growth Upper | Limits Lower | Location    | GROWTH TEMPERATURES: |                                    |
|------------------|---------------|-------|------|--------|-----------------|--------------|-------------|----------------------|------------------------------------|
|                  |               |       | MWAT | ST Max |                 |              |             | Reference            |                                    |
|                  | 24-28.9<br>27 |       |      |        |                 |              |             |                      | Spotila et al 1979<br>Jobling 1981 |
| YOY juvenile     | 29            | 24-31 |      |        |                 | 21           | L. Erie     |                      | Carlander 1969<br>Brown 1974       |
| YOY              | 28.9          | 19-29 | 30   | 31     | 29              | <19          | Lab (Minn.) |                      | EPA 1974<br>Talmage 1978           |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Notropis atherinoides* (emerald shiner)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |            |          |                                |                  |                        |                        |                     |                         |          |                         |
|--|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|---------------------|-------------------------|----------|-------------------------|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | (c) Lethal Limit AT | (d) Median Lethal Final | Location | Reference               |
| spawning                               |                                | 24           |            |          |                                |                  |                        |                        |                     |                         |          | Scott and Crossman 1973 |
| spawning                               |                                |              | 20-27      |          |                                |                  |                        |                        |                     |                         |          | Brown 1974              |
| hatch (24h)                            |                                | 23.9         |            | 23       | 27                             |                  |                        |                        |                     |                         | L. Erie  | Brown 1974              |
|  |                                |              |            |          |                                |                  |                        |                        |                     |                         |          | EPA 1974                |
| cold shock                             | 13                             |              |            |          |                                |                  | 0                      |                        | -12.5               |                         | Lab      | Edsall and Yocum 1972   |
| cold shock                             | 15                             |              |            |          |                                |                  | 1.7                    |                        | -13.5               |                         | Lab      | Edsall and Yocum 1972   |
| cold shock                             | 20                             |              |            |          |                                |                  | 5                      |                        | -15                 |                         | Lab      | Edsall and Yocum 1972   |
| cold shock                             | 25                             |              |            |          |                                |                  | 7.6                    |                        | -17.5               |                         | Lab      | Edsall and Yocum 1972   |

SPECIES: *Notropis bifrenatus* (bridle shiner)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |            |          |                                |                  |                        |                        |                     |                         |          |                              |
|--|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|---------------------|-------------------------|----------|------------------------------|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | (c) Lethal Limit AT | (d) Median Lethal Final | Location | Reference                    |
| spawning                               |                                |              | 14-27      | 20.5     | 27                             |                  |                        |                        |                     |                         | N.H.     | Carlander 1969<br>This study |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

## SPECIES: Notropis cornutus (common shiner)

| Size or Age<br>(mm)    | Accli-<br>mation<br>Temp. | Accli-<br>mation<br>Time | Sea-<br>son | Upper<br>Incip.<br>Lethal<br>Temp | Lower<br>Incip.<br>Lethal<br>Temp | log time =     |      | Expo-<br>sure<br>Temp | Resis-<br>tance<br>Time<br>(Min) | Critical<br>Thermal<br>(Max) | THERMAL TOLERANCES: |                      |            |           |
|------------------------|---------------------------|--------------------------|-------------|-----------------------------------|-----------------------------------|----------------|------|-----------------------|----------------------------------|------------------------------|---------------------|----------------------|------------|-----------|
|                        |                           |                          |             |                                   |                                   | a + b (temp)   |      |                       |                                  |                              | Upper               | Lower                | Location   | Reference |
|                        |                           |                          |             |                                   |                                   | a              | b    |                       |                                  |                              |                     |                      |            |           |
|                        |                           |                          |             | 32                                |                                   |                |      |                       |                                  |                              |                     |                      |            |           |
|                        | 15                        |                          | W           |                                   |                                   |                |      |                       |                                  | 30.6                         | Lab (Dec 15)        | Spotila et al 1979   |            |           |
|                        | 15                        |                          | SP          |                                   |                                   |                |      |                       |                                  | 31.9                         | Lab (Mar 15)        | Kowalski et al 1978  |            |           |
|                        | 5                         |                          |             | 26.7-27                           |                                   |                |      |                       |                                  |                              |                     | Carlander 1969       |            |           |
|                        | 10                        |                          |             | 28.6-29                           |                                   |                |      |                       |                                  |                              |                     | Carlander 1969       |            |           |
|                        | 15                        |                          |             | 30.3                              | 0                                 |                |      |                       |                                  |                              |                     | Carlander 1969       |            |           |
|                        | 20                        |                          |             | 31-32.3                           | 3.7-4                             |                |      |                       |                                  |                              |                     | Carlander 1969       |            |           |
|                        | 25                        |                          |             | 33.5                              | 7.8                               |                |      |                       |                                  |                              |                     | Carlander 1969       |            |           |
| 4.46 in;<br>adult      | 25-26                     |                          | Su          | 32                                |                                   |                |      |                       |                                  |                              |                     | Carlander 1969       |            |           |
|                        | 10                        |                          |             | 29                                |                                   |                | 29   | 29                    | 29                               | 50                           | Lab (Toronto, Ont.) | Brown 1974           |            |           |
|                        | 15                        |                          |             | 30.5                              |                                   | 45.4331-1.3979 | 31.5 | 31                    | 31.5                             | 28                           | Lab (Toronto, Ont.) | Brown 1974           |            |           |
|                        | 20                        |                          |             | 31                                |                                   | 34.5324-1.0116 | 33   | 31.5                  | 33                               | 17                           | Lab (Toronto, Ont.) | Brown 1974           |            |           |
|                        | 25                        |                          | w           | 31                                |                                   | 24.9620-0.6878 | 34   | 32                    | 34                               | 35                           | Lab (Toronto, Ont.) | Brown 1974           |            |           |
|                        | 25                        |                          |             | 31                                |                                   | 28.5059-0.7741 | 35.5 | 32                    | 35.5                             | 15                           | Lab (Toronto, Ont.) | Brown 1974           |            |           |
|                        | 30                        |                          |             | 31                                |                                   | 28.1261-0.7316 | 36.5 | 34                    | 36.5                             | 20                           | 31                  | Lab (Toronto, Ont.1) | Brown 1974 |           |
| 4-5 g;<br>adult (2 yr) | 5                         |                          |             | 26.7                              |                                   |                |      |                       |                                  |                              |                     | Lab (Don R., Ont.)   | Brown 1974 |           |
|                        | 10                        |                          |             | 28.6                              |                                   | 40.7738-1.3522 | 30   | 29                    |                                  |                              |                     | Lab (Don R., Ont.)   | Brown 1974 |           |
|                        | 15                        |                          |             | 30.3                              |                                   | 45.0972-1.3874 | 32   | 31                    |                                  |                              |                     | Lab (Don R., Ont.)   | Brown 1974 |           |
|                        | 20                        |                          |             | 31                                | 3.7                               | 34.5324-1.0116 | 33   | 31.5                  |                                  |                              |                     | Lab (Don R., Ont.)   | Brown 1974 |           |
|                        | 25                        |                          |             | 31                                | 7.8                               | 24.9620-0.6878 | 34   | 32                    | 31                               | 5000                         |                     | Lab (Don R., Ont.)   | Brown 1974 |           |
|                        | 7.2                       |                          | F           | 30.6                              |                                   |                |      |                       |                                  |                              |                     | Delaware R., Penn.   | Brown 1974 |           |
|                        | 11.1                      |                          |             | 31.1                              |                                   |                |      |                       |                                  |                              |                     | Delaware R., Penn.   | Brown 1974 |           |

SPECIES: *Notropis cornutus* (common shiner)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |           |      |                                   |                  |                           |                           |                                 |                            |                         |           |
|--|--------------------------------|--------------|-----------|------|-----------------------------------|------------------|---------------------------|---------------------------|---------------------------------|----------------------------|-------------------------|-----------|
| Event                                  | Season and/or Acclimation Temp | (a)          |           |      | (b)<br>ST Max for Embryo Survival | Acclimation Time | (c)<br>Lethal Limit Upper | (c)<br>Lethal Limit Lower | (d)<br>Median Lethal $\Delta T$ | (d)<br>Median Lethal Final | Location                | Reference |
|  |                                | Optimum Temp | Range     | MWAT |                                   |                  |                           |                           |                                 |                            |                         |           |
| spawning                               |                                |              | 15.6-18.3 |      |                                   |                  |                           |                           |                                 | Ithaca, N.Y.               | Scott and Crossman 1973 |           |
| spawning                               |                                |              | 28.3      |      |                                   |                  |                           |                           |                                 | L. Erie tributary          | Scott and Crossman 1973 |           |
| spawning                               |                                |              | 19-21-k   |      |                                   |                  |                           |                           |                                 |                            | Carlander 1969          |           |
| spawning initial                       |                                |              | 15-25.5   |      |                                   |                  |                           |                           |                                 |                            | Brown 1974              |           |
| spawning                               |                                |              | 13-15.6   |      |                                   |                  |                           |                           |                                 | Cayuga L., N.Y.            | Brown 1974              |           |
| spawning                               | 20                             |              | 18.9-21.1 |      |                                   |                  |                           |                           |                                 | Big Sandy L., Minn.        | Brown 1974              |           |
| spawning initial                       |                                |              | <28       |      |                                   |                  |                           |                           |                                 |                            | Brown 1974              |           |
| spawning                               |                                |              | 18        |      |                                   |                  |                           |                           |                                 | S. Michigan                | Brown 1974              |           |
| spawning                               | 17.8                           |              |           | 20   | 28                                |                  |                           |                           |                                 | Central N.Y.               | Brown 1974              |           |
| inshore migration                      |                                |              | 12-15.5   |      |                                   |                  |                           |                           |                                 |                            | This study              |           |
| spawning                               |                                |              | 13.5-18   |      |                                   |                  |                           |                           |                                 |                            | Dodson and Young 1917   |           |
|  |                                |              |           |      |                                   |                  |                           |                           |                                 |                            | Dodson and Young 1977   |           |

(a) MWAT= maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Notropis heterodon* (black chin shiner)

| THERMAL TOLERANCES: |                  |                  |         |                          |                          |            |   |             |       |               |                        |                        |               |                  |
|---------------------|------------------|------------------|---------|--------------------------|--------------------------|------------|---|-------------|-------|---------------|------------------------|------------------------|---------------|------------------|
| Size or Age (mm)    | Acclimation Temp | Acclimation Time | Sea-son | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = |   | Data Limits |       | Exposure Temp | Resis-tance Time (Min) | Critical Thermal (Max) | Location      | Reference        |
|                     |                  |                  |         |                          |                          | a          | b | Upper       | Lower |               |                        |                        |               |                  |
|                     |                  |                  |         |                          |                          |            |   |             |       |               |                        |                        | Pond Michigan | Beltz et al 1974 |

SPECIES: *Notropis hudsonius* (spottail shiner)

| Size or Age<br>(mm) | Accli-<br>mation<br>Temp | Accli-<br>mation<br>Time | Sea-<br>son | Upper                    | Lower                    | log time = |   | Data Limits |       | Expo-<br>sure<br>Temp | Resis-<br>tance<br>Time<br>(Min) | Critical<br>Thermal<br>(Max) | THERMAL TOLERANCES: |                             |
|---------------------|--------------------------|--------------------------|-------------|--------------------------|--------------------------|------------|---|-------------|-------|-----------------------|----------------------------------|------------------------------|---------------------|-----------------------------|
|                     |                          |                          |             | Incip.<br>Lethal<br>Temp | Incip.<br>Lethal<br>Temp | a          | b | Upper       | Lower |                       |                                  |                              | Location            | Reference                   |
| adult               | 21.7                     |                          | su          | >35                      |                          |            |   |             |       |                       |                                  | 32.8                         | Lab                 | Reutter and Herdendorf 1976 |
|                     | 7.2                      |                          | W           | 30.6                     |                          |            |   |             |       |                       |                                  |                              | Field (active)      | Carlander 1969              |
|                     | 11.1                     |                          |             | 31.1                     |                          |            |   |             |       |                       |                                  |                              | Lab (0.6-1.1C/h)    | Brown 1974                  |
| 13-36;<br>juvenile  | 23                       |                          |             | 37.3                     |                          |            |   |             | 37.3  | 5                     |                                  |                              | Lab                 | Jinks et al 1981            |
| 13-36;<br>juvenile  | 23                       |                          |             | 36                       |                          |            |   |             | 36    | 10                    |                                  |                              | Lab                 | Jinks et al 1981            |
| 13-36;<br>juvenile  | 23                       |                          |             | 36                       |                          |            |   |             | 36    | 30                    |                                  |                              | Lab                 | Jinks et al 1981            |
| 13-36;<br>juvenile  | 26                       |                          |             | 38.1                     |                          |            |   |             | 38.1  | 5                     |                                  |                              | Lab                 | Jinks et al 1981            |
| 13-36;<br>juvenile  | 26                       |                          |             | 37.9                     |                          |            |   |             | 37.9  | 10                    |                                  |                              | Lab                 | Jinks et al 1981            |
| juvenile            | 26                       |                          |             | 36.8                     |                          |            |   |             | 36.8  | 30                    |                                  |                              | Lab                 | Jinks et al 1981            |
| 20-65; YOY          | 9                        |                          |             | 30.5                     |                          |            |   |             | 30.5  | 60                    |                                  |                              | Lab                 | Jinks et al 1981            |
| 20-65; YOY          | 17                       |                          |             | 32.4                     |                          |            |   |             | 32.4  | 60                    |                                  |                              | Lab                 | Jinks et al 1981            |
| 20-65; YOY          | 23-24                    |                          |             | 34.3                     |                          |            |   |             | 34.3  | 60                    |                                  |                              | Lab                 | Jinks et al 1981            |
| 20-65; YOY          | 26                       |                          |             | 35.8                     |                          |            |   |             | 35.8  | 60                    |                                  |                              | Lab                 | Jinks et al 1981            |
| 21; young           | 26                       |                          |             | 34.7                     |                          |            |   |             |       |                       |                                  | 33-34                        | Lab                 | Kellogg and Gift 1983       |

**SPECIES:** *Notropis hudsonius* (spottail shiner)

|                     |        |                 |                    |                      |                    |                            |                     | PREFERRED TEMPERATURES:  |                             |
|---------------------|--------|-----------------|--------------------|----------------------|--------------------|----------------------------|---------------------|--|-----------------------------|
| Size or Age<br>(mm) | Season | Day or<br>Night | Upper<br>Avoidance | Final<br>Preferendum | Lower<br>Avoidance | Acclimation<br>Temperature | Acclimation<br>Time | Location   | Reference                   |
|                     |        | D               |                    | >13                  |                    |                            |                     | L. Michigan  | Brandt et al 1980           |
|                     |        |                 |                    | 11-16                |                    |                            |                     | L. Michigan  | Brandt et al 1980           |
|                     |        | D/N             |                    | 17-20                |                    |                            |                     | L. Michigan  | Brandt et al 1980           |
| adult               | w      |                 |                    | 9                    |                    |                            |                     | Lab  | Reutter and Herdendorf 1976 |
|                     | SP     |                 |                    | 14.3                 |                    |                            |                     | Lab  | Reutter and Herdendorf 1976 |
|                     |        |                 | >22                | 14                   | 13                 |                            |                     | L. Michigan  | Spotila et al 1979          |
| large               |        |                 | >35                |                      |                    |                            |                     | Delaware R., Penn.   | Coutant 1977a               |
| 110-116;<br>adult   |        |                 |                    | 13.9                 |                    | 15                         |                     | (6% salinity) estuary<br>heated discharge into<br>Delaware R., Penn. | Brown 1974                  |
|                     | SU     |                 | <40                |                      |                    |                            |                     |  | Brown 1974                  |
| adult               | w      |                 |                    | 10.2                 |                    |                            |                     | L. Michigan  | Houston 1982                |
|                     |        | D               |                    | 17-20                |                    |                            |                     | L. Michigan  | Talmage and Coutant 1980    |
|                     | F      | N               |                    | 19-20                | 15                 |                            |                     | L. Michigan  | Crowder et al 1981          |
|                     | F      |                 |                    | 17-18                | 11                 |                            |                     |  | Crowder et al 1981          |
| 24.4 TL;<br>young   |        |                 |                    | 28.5                 |                    | 25                         |                     | Lab (N.Y.)   | Kellogg and Gift 1983       |
| 22.9 TL;<br>young   |        |                 |                    | 29.9                 |                    | 25                         |                     | Lab (N.Y.)   | Kellogg and Gift 1983       |
| 21-30 TL;<br>young  |        |                 |                    | 29                   |                    |                            |                     | Lab (N.Y.)   | Kellogg and Gift 1983       |
|                     |        |                 | 39.2               | 20.1                 | 5.1                |                            |                     | Heated discharge into<br>Connecticut R., Conn.                       | Marcy 1976a                 |

SPECIES: *Notropis hudsonius* (spottail shiner)

| Size or Age<br>(mm) | Optimum<br>°C | (a)<br>Range | (b)           |      | No Growth Limits<br>Upper Lower | Location            | GROWTH TEMPERATURES:   |  |
|---------------------|---------------|--------------|---------------|------|---------------------------------|---------------------|------------------------|--|
|                     |               |              | ST<br>M W A T | Max  |                                 |                     | Reference              |  |
| Young               |               |              |               |      | 18                              | L. Erie             | Carlander 1969         |  |
| YOY                 |               |              |               |      | >35                             | Delaware R., Penn.  | Brown 1974             |  |
| Young               | 27.3          | 22.8-32.7    |               |      | 10                              | Lower Red L., Minn. | Brown 1974             |  |
|                     |               |              | 30            | 32.7 | 34                              | Lab (N.Y.)          | Kellogg and Gift 1983  |  |
|                     | >26           |              |               |      | <20                             | Clear L., Iowa      | This study             |  |
|                     |               |              |               |      |                                 |                     | Prince and Mengel 1981 |  |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature optimum temp for growth)

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Notropis hudsonius* (spottail shiner)

| Event      | Season<br>and/or<br>Accli-<br>mation<br>Temp | Optimum<br>Temp | Temp<br>Range | (a)<br>MWAT | (b)                                 |                          | (c)<br>Lethal<br>Limit<br>Upper | (c)<br>Lethal<br>Limit<br>Lower | (d)<br>Median<br>Lethal<br>$\Delta T$ | Median<br>Lethal<br>Final | Location                               | Reference                        |
|------------|--|-----------------|---------------|-------------|-------------------------------------|--------------------------|---------------------------------|---------------------------------|---------------------------------------|---------------------------|--|----------------------------------|
|            |  |                 |               |             | ST Max<br>for<br>Embryo<br>Survival | Accli-<br>mation<br>Time |                                 |                                 |                                       |                           |  |                                  |
| spawning   |  | 20              |               |             |                                     |                          |                                 |                                 |                                       |                           | L. Erie                                | Carlander 1969                   |
| hatching   |  | 20              |               |             |                                     |                          |                                 |                                 |                                       |                           | L. Erie                                | Brown 1974                       |
| cold shock | 21.8   |                 |               |             |                                     |                          | 4.9                             | -16.9                           |                                       |                           | L. Wabamun, Alta.<br>(30 min delta -T) | Coutant 1977b                    |
| spawning   |  | 18C             |               |             |                                     |                          |                                 |                                 |                                       |                           | L. Michigan tributary<br>Great Lakes   | Mansfield 1984<br>Mansfield 1984 |
| heat shock |  |                 | 15-20         |             |                                     |                          | 28                              |                                 |                                       |                           | Connecticut R., Conn.<br>Nuclear GS    | Talmage 1978                     |
|            |  |                 |               | 17.5        | 20                                  |                          |                                 |                                 |                                       |                           |  | This study.                      |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Notropis rubellus* (rosyface shiner)

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Sea-son | Upper Incip. Lethal Temp |      | Lower Incip. Lethal Temp |      | log time = a + b (temp) |   | Data Limits |       | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | THERMAL TOLERANCES: |                   |
|------------------|------------------|------------------|---------|--------------------------|------|--------------------------|------|-------------------------|---|-------------|-------|---------------|-----------------------|------------------------|---------------------|-------------------|
|                  |                  |                  |         | Temp                     | Temp | Temp                     | Temp | a                       | b | Upper       | Lower |               |                       |                        | Location            | Reference         |
|                  | 12-23            |                  |         | 33                       |      |                          |      |                         |   |             |       |               |                       |                        | Lab                 | Cherry et al 1977 |

SPECIES: *Notropis rubellus* (rosyface shiner)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES:         |                   |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|---------------------------------|-------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                        | Reference         |
| adult            |        |              | 31              | 26.8              | 21              |                         |                  | Lab                             | Coutant 1977a     |
| adult            |        |              |                 | 27.6              |                 |                         |                  |                                 | Houston 1982      |
| 50-100 FL; adult |        |              | 21              | 20.8              | 9               | 12                      |                  | Lab (rising water temperatures) | Cherry et al 1977 |
| 50-100 FL; adult |        |              | 24              | 21.7              | 12              | 15                      |                  | Lab (rising water temperatures) | Cherry et al 1977 |
| 50-100 FL; adult |        |              | 21              | 22.2              | 15              | 18                      |                  | Lab (rising water temperatures) | Cherry et al 1977 |
| 50-100 FL; adult |        |              | 27              | 22.5              | 15              | 21                      |                  | Lab (rising water temperatures) | Cherry et al 1977 |
| 50-100 FL; adult |        |              | 27              | 25.8              | 21              | 24                      |                  | Lab (rising water temperatures) | Cherry et al 1977 |
| 50-100 FL; adult |        |              | 33              | 28.1              | 21              | 27                      |                  | Lab (rising water temperatures) | Cherry et al 1977 |
| 50-100 FL; adult |        |              | 33              | 28.0              | 21              | 30                      |                  | Lab (rising water temperatures) | Cherry et al 1977 |
| 50-100 FL; adult |        |              | 34              | 27.7              | 24              | 33                      |                  | Lab (rising water temperatures) | Cherry et al 1977 |
| 50-100 FL; adult |        |              |                 | 26                |                 |                         |                  | Lab (rising water temperatures) | Cherry et al 1977 |

SPECIES: *Notropis rubellus* (rosyface shiner)

| Size or Age (mm) | Optimum °C | (b)       |      |        | GROWTH TEMPERATURES: |              |              |
|------------------|------------|-----------|------|--------|----------------------|--------------|--------------|
|                  |            | (a) Range | MWAT | ST Max | No Growth Upper      | Limits Lower | Location     |
|                  | 25.7/25.3  |           |      |        |                      |              | Jobling 1981 |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.



SPECIES: *Notropis rubellus* (rosyface shiner)

SPAWNING AND DEVELOPMENT TEMPERATURES:

| Event          | Season and/or Acclimation Temp | Optimum Temp | (a)        |      | (b)<br>ST Max for Embryo Survival | Acclimation Time | (c)                |                    | (d)                      |                     | Location | Reference                |
|----------------|--------------------------------|--------------|------------|------|-----------------------------------|------------------|--------------------|--------------------|--------------------------|---------------------|----------|--------------------------|
|                |                                |              | Temp Range | MWAT |                                   |                  | Lethal Limit Upper | Lethal Limit Lower | Median Lethal $\Delta T$ | Median Lethal Final |          |                          |
| spawning       |                                |              | 26.1-28.9  |      |                                   |                  |                    |                    |                          |                     | N.Y.     | Scott and Crossman 1973  |
| spawning       |                                |              | 20-22.2    |      |                                   |                  |                    |                    |                          |                     | Penn.    | Scott and Crossman 1973  |
| hatching (59h) |                                | 21.1         |            |      |                                   |                  |                    |                    |                          |                     | Penn.    | Scott and Crossman 1973  |
| spawning       |                                | >21.1        |            |      |                                   |                  |                    |                    |                          |                     | N.Y.     | Carlander 1969           |
| spawning       |                                | >20          |            |      | 24.5                              | 28               |                    |                    |                          |                     |          | Brown 1974<br>This study |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

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SPECIES: *Notropis spilopterus* (spotfin shiner)

THERMAL TOLERANCES:

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Sea-son | Upper       | Lower       | log time = |   | Data Limits |       | Exposure Temp | Resis-tance Time (Min) | Critical Thermal (Max) | Location | Reference         |
|------------------|------------------|------------------|---------|-------------|-------------|------------|---|-------------|-------|---------------|------------------------|------------------------|----------|-------------------|
|                  |                  |                  |         | Lethal Temp | Lethal Temp | a          | b | Upper       | Lower |               |                        |                        |          |                   |
|                  | 12-36            |                  |         | 36          |             |            |   |             |       |               |                        |                        | Lab      | Cherry et al 1977 |

SPECIES: *Notropis spilopterus* (spotfin shiner)

| Size or Age (mm)    | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES:                 |                            |
|---------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|---|----------------------------|
|                     |        |              |                 |                   |                 |                         |                  | Location                                | Reference                  |
| adult               |        |              | 35              | 29.5              | 26              |                         |                  | Lab                                     | Coutant 1977a              |
| adult               |        |              | >31.1           | 29.4              |                 |                         |                  | Lab<br>White R., heated discharge, Ind. | Jobling 1981<br>Brown 1974 |
| 50-100 FL;<br>adult |        |              | 27              | 21.4              | 9               | 12                      |                  | Lab (rising water temperatures)         | Cherry et al 1977          |
|                     |        |              | 24              | 21.8              | 12              | 15                      |                  | Lab (rising water temperatures)         | Cherry et al 1977          |
|                     |        |              | 27              | 24.1              | 15              | 18                      |                  | Lab (rising water temperatures)         | Cherry et al 1977          |
|                     |        |              | 27              | 26.4              | 18              | 21                      |                  | Lab (rising water temperatures)         | Cherry et al 1977          |
|                     |        |              | 30              | 27.3              | 21              | 24                      |                  | Lab (rising water temperatures)         | Cherry et al 1977          |
|                     |        |              | 33              | 30.6              | 21              | 27                      |                  | Lab (rising water temperatures)         | Cherry et al 1977          |
|                     |        |              | 36              | 31.8              | 24              | 30                      |                  | Lab (rising water temperatures)         | Cherry et al 1977          |
|                     |        |              | 36              | 31                | 24              | 33                      |                  | Lab (rising water temperatures)         | Cherry et al 1977          |
|                     |        |              | 38              | 29.2              | 27              | 36                      |                  | Lab (rising water temperatures)         | Cherry et al 1977          |
|                     |        |              |                 | 31                |                 |                         |                  | Lab (rising water temperatures)         | Cherry et al 1977          |

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SPECIES: *Notropis spilopterus* (spotfin shiner)

| Size or Age (mm) | Optimum °C | Range | (b) ST |       | No Growth Limits |       | Location | GROWTH TEMPERATURES: |                            |
|------------------|------------|-------|--------|-------|------------------|-------|----------|----------------------|----------------------------|
|                  |            |       | la) M  | W A T | Max              | Upper |          | Lower                | Reference                  |
|                  | 28.6/29.2  |       | 31.3   |       | 35               |       |          |                      | Jobling 1981<br>This study |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Notropis spilopterus* (spotfin shiner)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |            |          |                                |                  |                        |                        |                          |                         |          |              |
|--|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|--------------------------|-------------------------|----------|--------------|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal $\Delta T$ | (4) Median Lethal Final | Location | Reference    |
| heat shock 22                          |                                |              |            |          |                                |                  | >33                    |                        | >11                      |                         | Lab      | Talmage 1978 |
| cold shock 33                          |                                |              |            |          |                                |                  |                        | <22                    | <11                      |                         | Lab      | Talmage 1978 |

- (a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.
- (b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.
- (c) Not incipient lethal temperatures as defined by Fry et al (1946).
- (d) Simulated larval entrainment temperatures.

SPECIES: *Notropis stramineus* (sand shiner)

| THERMAL TOLERANCES: |                  |                  |         |                          |                          |   |                         |               |                       |                        |                   |                     |
|---------------------|------------------|------------------|---------|--------------------------|--------------------------|---|-------------------------|---------------|-----------------------|------------------------|-------------------|---------------------|
| Size or Age (mm)    | Acclimation Temp | Acclimation Time | Sea-son | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = $\frac{a + b(\text{temp})}{a - b}$ | Data Limits Upper Lower | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location          | Reference           |
|                     | 15               |                  | w       |                          |                          |   |                         |               |                       | 32.3                   | Lab (Dec 15) N.Y. | Kowalski et al 1978 |
|                     | 15               |                  | w       |                          |                          |   |                         |               |                       | 32.3                   | Lab (Jan 15) N.Y. | Kowalski et al 1978 |
|                     | 15               |                  | SP      |                          |                          |   |                         |               |                       | 33.0                   | Lab (Mar 15) N.Y. | Kowalski et al 1978 |

SPECIES: Pimephales notatus (bluntnose minnow)

| Size or Age<br>(mm)    | Accli-<br>mation<br>Temp | Accli-<br>mation<br>Time | Sea-<br>son | Upper<br>Incip.<br>Lethal<br>Temp | Lower<br>Incip.<br>Lethal<br>Temp | log time =      |      | Data Limits |       | Expo-<br>sure<br>Temp | Resis-<br>tance<br>Time<br>(Min) | Critical<br>Thermal<br>(Max) | THERMAL TOLERANCES:                     |  |
|------------------------|--------------------------|--------------------------|-------------|-----------------------------------|-----------------------------------|-----------------|------|-------------|-------|-----------------------|----------------------------------|------------------------------|---|--|
|                        |                          |                          |             |                                   |                                   | a               | b    | Upper       | Lower |                       |                                  |                              | Location                                | Reference  |
| adult                  | 6.0<br>15                |                          | SP          |                                   |                                   |                 |      |             |       |                       |                                  | 27.8<br>31.9<br>34.8         | Lab<br>Lab (N.Y.)<br>Lab (1C/h)<br>Lab  | Reutter and Herdendorf 1976<br>Spotila et al 1979<br>Spotila et al 1979<br>Cherry et al 1977 |
|                        | 12-30                    |                          |             | 32                                |                                   |                 |      |             |       |                       |                                  |                              |   |  |
| 0-2 g;<br>adult (1 yr) | 5                        |                          |             | 26                                |                                   | 24.6417-0.8602  | 27   | 26.5        | 27    | 25                    |                                  |                              | Etobicoke Ck., Ont.                     | Brown 1974   |
| 0-2 g;<br>adult (1 yr) | 10                       |                          |             | 28.3                              |                                   | 55.8357-1.8588  | 29.5 | 29          | 29.5  | 10                    |                                  |                              | Etobicoke Ck., Ont.                     | Brown 1974   |
| 0-2 g;<br>adult (1 yr) | 15                       |                          |             | 30.6                              | 10                                | 28.0377-0.8337  | 32   | 32          | 32    | 20                    |                                  |                              | Etobicoke Ck., Ont.                     | Brown 1974   |
| 0-2 g;<br>adult (1 yr) | 20                       |                          |             | 31.7                              | 4.2                               | 34.3240-0.96882 | 34   | 32.5        | 34    | 15                    |                                  |                              | Etobicoke Ck., Ont.                     | Brown 1974   |
| 0-2 g;<br>adult (1 yr) | 25                       |                          |             | 33.3                              | 7.5                               | 50.8212-1.4181  | 35   | 34          | 35    | 21<br>38              |                                  |                              | Etobicoke Ck., Ont.<br>S. Michigan pond | Brown 1974<br>Brown 1974   |
| 17-23; young<br>adult  |                          |                          |             | 38                                |                                   |                 |      |             |       |                       |                                  |                              | S. Michigan pond<br>(one fish)          | Brown 1974   |

SPECIES: Pimephales notatus (bluntnose minnow)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES:                                    |                    |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|--|--------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location   | Reference          |
|                  |        |              |                 | 23-29.5           |                 |                         |                  | F i e l d  | Spotila et al 1979 |
|                  |        |              |                 | 15.7              |                 | 6                       |                  | Lab  | Spotila et al 1979 |
|                  |        |              |                 | 17.2              |                 | 9                       |                  | Lab  | Spotila et al 1979 |
|                  |        |              |                 | 20.5              |                 | 12                      |                  | Lab  | Spotila et al 1979 |
|                  |        |              |                 | 20.4              |                 | 15                      |                  | Lab  | Spotila et al 1979 |
|                  |        |              |                 | 21.5              |                 | 18                      |                  | Lab  | Spotila et al 1979 |
|                  |        |              |                 | 22.8              |                 | 21                      |                  | Lab  | Spotila et al 1979 |
|                  |        |              |                 | 25.7              |                 | 24                      |                  | Lab  | Spotila et al 1979 |
|                  |        |              |                 | 28.9              |                 | 27                      |                  | Lab  | Spotila et al 1979 |
| adult            |        | 31           |                 | 29                | 21              |                         |                  | Lab  | Coutant 1977a      |
|                  |        | >31.1        |                 |                   |                 |                         |                  | (max temp of occurrence in field) discharge White R., Ind. | Brown 1974         |
|                  |        |              |                 | 28.4              |                 |                         |                  | Lab  | Houston 1982       |
|                  |        |              |                 | 28.1              |                 |                         |                  | Lab  | Houston 1982       |
| 50-100 FL;       |        | 21           |                 | 19.3              | 9               | 12                      |                  | Lab (rising water temperatures)                            | Cherry et al 1977  |
| 50-100 FL;       |        | 24           |                 | 20.9              | 12              | 15                      |                  | Lab (rising water temperatures)                            | Cherry et al 1977  |
| 50-100 FL;       |        | 27           |                 | 21.9              | 15              | 18                      |                  | Lab (rising water temperatures)                            | Cherry et al 1977  |
| 50-100 FL;       |        | 27           |                 | 23.2              | 18              | 21                      |                  | Lab (rising water temperatures)                            | Cherry et al 1977  |
| 50-100 FL;       |        | 27           |                 | 26.4              | 21              | 24                      |                  | Lab (rising water temperatures)                            | Cherry et al 1977  |
| 50-100 FL;       |        | 30           |                 | 27.9              | 21              | 27                      |                  | Lab (rising water temperatures)                            | Cherry et al 1977  |
| 50-100 FL;       |        | 33           |                 | 29                | 24              | 30                      |                  | Lab (rising water temperatures)                            | Cherry et al 1977  |
|                  |        |              |                 | 28.1              |                 |                         |                  |  |                    |

SPECIES: Pimephales notatus (bluntnose minnow)

| Size or Age (mm) | Optimum °C | Range | (a)  |     | (b) |     | No Growth Upper | Limits Lower | Location | GROWTH TEMPERATURES: |  |
|------------------|------------|-------|------|-----|-----|-----|-----------------|--------------|----------|----------------------|--|
|                  |            |       | MWAT | Max | ST  | Max |                 |              |          | Reference            |  |
|                  | 27.2124    |       |      |     |     |     |                 |              |          | Jobling 1981         |  |
|                  |            |       | 27.9 | 31  |     |     |                 |              |          | This study           |  |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: Pimephales notatus (bluntnose minnow)

SPAWNING AND DEVELOPMENT TEMPERATURES:

| Event    | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal $\Delta T$ | (4) Median Lethal Final | Location                      | Reference               |
|----------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|--------------------------|-------------------------|-------------------------------|-------------------------|
| spawning |                                |              | $\geq 20$  |          |                                |                  |                        |                        |                          |                         |                               | Scott and Crossman 1973 |
| spawning |                                |              | 21.1-26.1  |          |                                |                  |                        |                        |                          |                         | Illinois                      | Carlander 1969          |
| spawning |                                |              | >21        |          |                                |                  |                        |                        |                          |                         | Michigan                      | Carlander 1969          |
| spawning |                                |              | 19-31      |          |                                |                  |                        |                        |                          |                         | Outdoor spawning pools, Penn. | Gale 1983               |
|          |                                |              |            | 25       | 31                             |                  |                        |                        |                          |                         |                               | This study              |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.



SPECIES: Pimephales promelas (fathead minnow)

| Size or Age (mm) | Optimum °C | Range | (a) M W A T |     | No Growth Upper | Limits Lower | Location                    | GROWTH TEMPERATURES:   |  |
|------------------|------------|-------|-------------|-----|-----------------|--------------|-----------------------------|--|--|
|                  |            |       | M           | A T |                 |              |                             | Reference  |  |
|                  | 26/25.5    |       | 28          | 33  | 32              | <2-7         | experiment Alabama (winter) | Jobling 1981<br>Carlander 1969<br>Beltz et al 1974<br>This study |  |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: Pimephales promelas (fathead minnow)

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| Event                  | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) M W A T | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location                       | Reference  |
|------------------------|--------------------------------|--------------|------------|-------------|--------------------------------|------------------|------------------------|------------------------|------------------|-------------------------|--------------------------------|--|
|                        |                                |              |            |             |                                |                  |                        |                        |                  |                         |                                |  |
| spawning hatching (5d) |                                | 25           | 15.6-17.8  |             |                                |                  |                        |                        |                  |                         | Lake, Que. (minimum temp)      | Scott and Crossman 1973<br>Scott and Crossman 1973     |
| spawning onset         | SP                             | 15.6         |            |             |                                |                  |                        |                        |                  |                         |                                | Carlander 1969   |
| spawning cessation     | F                              |              | 15.6-18.4  |             |                                |                  |                        |                        |                  |                         |                                | Carlander 1969<br>Carlander 1969                       |
| spawning               | Su                             | >27          |            |             |                                |                  |                        |                        |                  |                         | Outdoor exptal pool, Penn. Lab | Gale and Buynak 1982<br>Beltz et al 1974<br>This study |
| spawning               |                                | <23.5        | <32        | 23          | 28                             |                  |                        |                        |                  |                         |                                |  |

(a) MWAT - maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.



SPECIES: *Rhinichthys atratulus* (blacknose dace)

| Size or Age<br>(mm) | Accli-<br>mation<br>Temp | Accli-<br>mation<br>Time | Sea-<br>son | Upper                    | Lower                    | log time =     |             |       | Expo-<br>sure<br>Temp | Resis-<br>tance<br>Time<br>(Min) | Critical<br>Thermal<br>(Max) | THERMAL TOLERANCES: |                          |              |
|---------------------|--------------------------|--------------------------|-------------|--------------------------|--------------------------|----------------|-------------|-------|-----------------------|----------------------------------|------------------------------|---------------------|--------------------------|--------------|
|                     |                          |                          |             | Incip.<br>Lethal<br>Temp | Incip.<br>Lethal<br>Temp | a + b (temp)   | Data Limits |       |                       |                                  |                              | Location            | Reference                |              |
|                     |                          |                          |             |                          |                          | a              | b           | Upper |                       |                                  |                              |                     |                          | Lower        |
|                     | 5                        |                          |             | 25                       |                          |                |             |       |                       |                                  |                              |                     | Carlander 1969           |              |
|                     | 10                       |                          |             | 27                       |                          |                |             |       |                       |                                  |                              |                     | Carlander 1969           |              |
|                     | 20                       |                          |             | 29.3                     | 1                        |                |             |       |                       |                                  |                              |                     | Carlander 1969           |              |
| adult               | 5                        |                          |             | 27                       |                          |                |             |       |                       |                                  |                              |                     |                          |              |
| adult               | 15                       |                          |             | 29.3                     |                          | 19.8158-0.5771 | 31.5        | 30    |                       |                                  |                              | Lab (Toronto, Ont.) | Brown 1974               |              |
| adult               | 20                       |                          |             | 29.3                     |                          | 24.5749-0.7061 | 33          | 30    |                       |                                  |                              | Lab (Toronto, Ont.) | Brown 1974               |              |
| adult               | 25                       |                          |             | 29.3                     |                          | 20.1840-0.5389 | 35          | 32    |                       |                                  |                              | Lab (Toronto, Ont.) | Brown 1974               |              |
| Z-3.9; adult        | 5                        |                          |             | 26.5                     |                          | 77.1877-2.7959 | 27.5        | 27    |                       |                                  |                              | Lab (Don. R., Ont.) | Brown 1974               |              |
| 2-3.9; adult        | 10                       |                          |             | 28.8                     |                          | 49.1469-1.6021 | 30.5        | 29.5  |                       |                                  |                              | Lab (Don. R., Ont.) | Brown 1974               |              |
| 2-3.9; adult        | 15                       |                          |             | 29.6                     |                          | 19.6975-0.5734 | 31.5        | 30    |                       |                                  |                              | Lab (Don. R., Ont.) | Brown 1974               |              |
| 2-3.9; adult        | 20                       |                          |             | 29.3                     | 2.2                      | 26.5952-0.7719 | 33.5        | 29.5  |                       |                                  |                              | Lab (Don. R., Ont.) | Brown 1974               |              |
| 2-3.9; adult        | 25                       |                          |             | 29.3                     | 5                        | 23.5765-0.6629 | 34          | 30    |                       |                                  | 29.5                         | Lab (Don. R., Ont.) | Brown 1974               |              |
|                     | 5                        |                          | W           |                          |                          |                |             |       | 27                    | 50                               |                              | Lab (Toronto, Ont.) | Brown 1974               |              |
|                     | 10                       |                          | W           |                          |                          |                |             |       | 30                    | 40                               |                              | Lab (Toronto, Ont.) | Brown 1974               |              |
|                     | 15                       |                          | W           |                          |                          |                |             |       | 31.5                  | 50                               |                              | Lab (Toronto, Ont.) | Brown 1974               |              |
|                     | 20                       |                          | W           |                          |                          |                |             |       | 33                    | 20                               |                              | Lab (Toronto, Ont.) | Brown 1974               |              |
|                     | 25                       |                          | W           |                          |                          |                |             |       | 34                    | 20                               |                              | Lab (Toronto, Ont.) | Brown 1974               |              |
|                     | 28                       |                          | W           |                          |                          |                |             |       | 35.5                  | 15                               |                              | Lab (Toronto, Ont.) | Brown 1974               |              |
|                     | 7.2                      |                          |             | 31.7                     |                          |                |             |       |                       |                                  |                              | Lab (2 F/h) Penn.   | Brown 1974               |              |
| adult               |                          |                          |             |                          |                          |                |             |       |                       |                                  | 29.3                         |                     | Houston 1982             |              |
|                     | 20                       |                          |             | 29.9                     |                          |                |             |       |                       |                                  |                              |                     | Lab (16 h day/8 h night) | Houston 1982 |
|                     | 20                       |                          |             | 28.8                     |                          |                |             |       |                       |                                  |                              |                     | Lab (8 h day/16 h night) | Houston 1982 |
|                     | 20                       |                          |             | 30                       |                          |                |             |       |                       |                                  |                              |                     | Lab (24 h day/O h night) | Houston 1982 |
|                     |                          |                          |             |                          |                          |                |             |       |                       |                                  | 31.9                         |                     |                          |              |

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SPECIES: *Rhinichthys atratulus* (blacknose dace)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |            |          |                                |                  |                        |                        |           |                         |                          |                            |
|--|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|-----------|-------------------------|--------------------------|----------------------------|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median AT | (d) Median Lethal Final | Location                 | Reference                  |
| spawning                               |                                | 21.1         |            |          |                                |                  |                        |                        |           |                         | Upstate N.Y.             | Scott and Crossman 1973    |
| spawning                               |                                |              | 16-22.2    |          |                                |                  |                        |                        |           |                         |                          | Brown 1974                 |
| spawning                               |                                |              | 15.6-17.8  |          |                                |                  |                        |                        |           |                         | W. Va.                   | Brown 1974                 |
| spawning                               |                                | 22.2         |            |          |                                |                  |                        |                        |           |                         | N.Y.                     |                            |
| spawning onset                         |                                | 19           |            | 21       | 22.2                           |                  |                        |                        |           |                         | Mink R.; Valley R., Man. | This study<br>Bartnik 1970 |

(a) MWAT - maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Rhinichthys cataractae* (longnose dace)

| THERMAL TOLERANCES: |                  |                  |                          |                          |   |                   |                   |               |                       |                        |            |                    |
|---------------------|------------------|------------------|--------------------------|--------------------------|---|-------------------|-------------------|---------------|-----------------------|------------------------|------------|--------------------|
| Size or Age (mm)    | Acclimation Temp | Acclimation Time | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = $\frac{a + b(\text{temp})}{a - b}$ | Data Limits Upper | Data Limits Lower | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location   | Reference          |
| 15                  |                  |                  |                          |                          |   |                   |                   |               |                       | 31.4                   | Lab (N.Y.) | Spotila et al 1979 |

SPECIES: *Rhinichthys cataractae* (longnose dace)

| PREFERRED TEMPERATURES: |        |              |                 |                   |                 |                         |                  |  |  |  |                  |
|-------------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|--|--|--|------------------|
| Size or Age (mm)        | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time |  |  | Location                                 | Reference        |
|                         | W      |              |                 | 10-19.7           |                 |                         |                  |  |  | heated discharge into Delaware R., Penn. | Brown 1974       |
| 95-134;                 | S      | P            |                 | 8-14              | 5.2             |                         |                  |  |  | L. Michigan (nearshore occurrence)       | Brazo et al 1978 |
| 51-104;                 | su     |              |                 | 10-22.7           |                 |                         |                  |  |  | L. Michigan (nearshore occurrence)       | Brazo et al 1978 |
| 32-116;                 | F      |              |                 | 7.2-14.7          |                 |                         |                  |  |  | L. Michigan (nearshore occurrence)       | Brazo et al 1978 |

SPECIES: *Rhinichthys cataractae* (longnose dace)

| Size or Age<br>(mm) | Optimum<br>°C | Range | (b)            |             | No Growth<br>Upper | Limits<br>Lower | Location                                     | GROWTH TEMPERATURES: |  |
|---------------------|---------------|-------|----------------|-------------|--------------------|-----------------|--|----------------------|--|
|                     |               |       | (a)<br>M W A T | ST<br>M a x |                    |                 |  | Reference            |  |
|                     |               |       |                |             | (1.2               |                 | L. Michigan (fall nearshore last occurrence) | Brazo et al 1978     |  |

- (a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).  
 (b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Rhinichthys cataractae* (longnose dace)

| Event                    | Season<br>and/or<br>Accli-<br>mation<br>Temp | Optimum<br>Temp | Temp<br>Range | (a)<br>M W A T | (b)<br>ST Max<br>for<br>Embryo<br>Survival | Accli-<br>mation<br>Time | (c)<br>Lethal<br>Limit<br>Upper | (c)<br>Lethal<br>Limit<br>Lower | Median<br>Lethal<br>AT | (4)<br>Median<br>Lethal<br>Final | Location    | Reference                           |
|--------------------------|--|-----------------|---------------|----------------|--|--------------------------|---------------------------------|---------------------------------|------------------------|----------------------------------|-------------|-------------------------------------|
|                          |  |                 |               |                |  |                          |                                 |                                 |                        |                                  |             |                                     |
| hatching<br>(7-10d)      |  | 15.6            |               |                |  |                          |                                 |                                 |                        |                                  | Manitoba    | Scott and Crossman 1973             |
| spawning<br>migration Sp |  | > 8             |               |                |  |                          |                                 |                                 |                        |                                  | L. Michigan | Brazo et al 1978                    |
| spawning                 |  | 15              | 14-19         |                |  |                          |                                 |                                 |                        |                                  | L. Michigan | Brazo et al 1978                    |
| spawning                 |  |                 |               | 15             | 20   |                          |                                 |                                 |                        |                                  | L. Winnipeg | Brazo et al 1978                    |
| spawning                 |  |                 | 15.5-20       |                |  |                          |                                 |                                 |                        |                                  | L. Winnipeg | This study<br>Gee and Machniak 1972 |

- (a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.  
 (b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.  
 (c) Not incipient lethal temperatures as defined by Fry et al (1946).  
 (d) Simulated larval entrainment temperatures.

SPECIES: *Semotilus atromaculatus* (creek chub)

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Sea-son | THERMAL TOLERANCES:      |                          |                           |      |                         |      |               |                        |                        |   | Reference |                                    |
|------------------|------------------|------------------|---------|--------------------------|--------------------------|---------------------------|------|-------------------------|------|---------------|------------------------|------------------------|---|-----------|------------------------------------|
|                  |                  |                  |         | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = a + b (temp) b |      | Data Limits Upper Lower |      | Exposure Temp | Resis-tance Time (Min) | Critical Thermal (Max) | Location  |           |                                    |
|                  |                  |                  |         | Temp                     | Temp                     |                           |      |                         |      |               |                        |                        |   |           |                                    |
|                  | 5                |                  |         | 24.7                     |                          |                           |      |                         |      |               |                        |                        |   |           | Carlander 1969                     |
|                  | 10               |                  |         | 27                       |                          |                           |      |                         |      |               |                        |                        |   |           | Carlander 1969                     |
|                  | 17.1-17.5        |                  |         | 30.1-30.5                |                          |                           |      |                         |      |               |                        |                        |   |           | Carlander 1969                     |
|                  | 20               |                  |         | 30                       | 1.0                      |                           |      |                         |      |               |                        |                        |   |           | Carlander 1969                     |
|                  | 21-21.9          |                  |         | 31.8                     | 1.7                      |                           |      |                         |      |               |                        |                        |   |           | Carlander 1969                     |
|                  | 22.8             |                  |         | 32.1                     |                          |                           |      |                         |      |               |                        |                        |   |           | Carlander 1969                     |
|                  | 25-26            |                  |         | 32.6                     |                          |                           |      |                         |      |               |                        |                        |   |           | Carlander 1969                     |
| 2-3.9 g; adult   | 5                |                  |         | 24.7                     |                          | 42.1859-1.6021            | 26   | 25                      |      |               |                        | 30.3                   | Don Ft., Thornhill, Ont.                          |           | Brown 1974                         |
|                  | 10               |                  |         | 27.3                     |                          | 31.0755-1.0414            | 29   | 28                      |      |               |                        |                        | Don R., Thornhill, Ont.                           |           | Brown 1974                         |
|                  | 15               |                  |         | 29.3                     |                          | 20.8055-0.6226            | 31   | 30                      |      |               |                        |                        | Don R., Thornhill, Ont.                           |           | Brown 1974                         |
| 20               |                  |                  |         | 30.3                     | 0.7                      | 21.0274-0.5933            | 33.5 | 30.5                    |      |               |                        |                        | Don R., Thornhill, Ont.                           |           | Brown 1974                         |
|                  | 25               |                  |         | 30.3                     | 4.5                      | 16.8951-0.4499            | 35   | 31                      |      |               |                        |                        | Don R., Thornhill, Ont.                           |           | Brown 1974                         |
|                  | 10               |                  |         | 27.5                     |                          |                           | 29   | 28                      | 29   | 55            | 31.5                   |                        | Toronto, Ont.; Knoxville, Tenn.                   |           | Brown 1974                         |
|                  | 15               |                  |         | 29                       |                          | 20.8055-0.6226            | 31   | 30                      | 31   | 35            |                        |                        | Toronto, Ont.; Knoxville, Tenn.                   |           | Brown 1974                         |
|                  | 20               |                  |         | 30.5                     |                          | 19.1315-0.5328            | 33   | 30.5                    | 33   | 30            |                        |                        | Toronto, Ont.; Knoxville, Tenn.                   |           | Brown 1974                         |
|                  | 25               |                  |         | 31.5                     |                          | 19.3186-0.4717            | 36   | 32                      | 35.5 | 50            |                        |                        | Toronto, Ont.; Knoxville, Tenn.                   |           | Brown 1974                         |
|                  | 30               |                  |         | 31.5                     |                          | 22.8982-0.5844            | 37   | 33                      | 37   | 20            |                        |                        | Toronto, Ont.; Knoxville, Tenn.                   |           | Brown 1974                         |
|                  | 7.2              |                  |         | 31.1                     |                          |                           |      |                         |      |               |                        | 32.3                   | Lab (Delaware R; 2F/h)<br>Lab (Savannah R., 4C/h) |           | Brown 1974<br>McFarlane et al 1976 |

SPECIES: *Semotilus atromaculatus* (creek chub)

| Event          | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | SPAWNING AND DEVELOPMENT TEMPERATURES: |                        |                        |                         |          |  |  |  |          |  | Reference                |
|----------------|--------------------------------|--------------|------------|----------|--|------------------------|------------------------|-------------------------|----------|--|--|--|----------|--|--------------------------|
|                |                                |              |            |          | (b) ST Max for Embryo Survival         | (c) Lethal Limit Upper | (c) Lethal Limit Lower | (d) Median Lethal Final | Location |  |  |  |          |  |                          |
|                |                                |              |            |          | Temp                                   | Temp                   | Temp                   | Temp                    |          |  |  |  |          |  |                          |
| spawning onset |                                | 12.8         |            |          |  |                        |                        |                         |          |  |  |  |          |  | Scott and Crossman 1973  |
| spawning       |                                |              | 12.8-26.7  |          |  |                        |                        |                         |          |  |  |  | Illinois |  | Brown 1974               |
| spawning       |                                | > 14         |            | 19.8     | 27                                     |                        |                        |                         |          |  |  |  | Manitoba |  | Brown 1974<br>This study |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Semotilus corporalis* (fall fish)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES: |                         |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------|-------------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                | Reference               |
|                  |        |              | 28              |                   |                 |                         |                  | Eastern U.S.            | Scott and Crossman 1973 |

SPECIES: *Semotilus corporalis* (fall fish)

| Event         | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | (d) Median Lethal AT | (d) Median Lethal Final | Location       | Reference                             |
|---------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|----------------------|-------------------------|----------------|---------------------------------------|
|               |                                |              |            |          |                                |                  |                        |                        |                      |                         |                |                                       |
| nest building |                                | 12           |            |          |                                |                  |                        |                        |                      |                         | Brome L., Que. | Scott and Crossman 1973               |
| spawning      |                                | 16.6         |            | 16.6     | 28                             |                  |                        |                        |                      |                         | Brome L., Que. | Scott and Crossman 1973<br>This study |

- (a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.
- (b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.
- (c) Not incipient lethal temperatures as defined by Fry et al (1946).
- (d) Simulated larval entrainment temperatures.

SPECIES: *Semotilus margarita* (pearl dace)

| Event    | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (d) Lethal Limit Lower | (d) Median Lethal AT | (d) Median Lethal Final | Location            | Reference                             |
|----------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|----------------------|-------------------------|---------------------|---------------------------------------|
|          |                                |              |            |          |                                |                  |                        |                        |                      |                         |                     |                                       |
| spawning |                                | 17.2         |            |          |                                |                  |                        |                        |                      |                         | Pentwater R., Mich. | Scott and Crossman 1983               |
| spawning |                                | 18.3         |            | 17.2     | >18.3                          |                  |                        |                        |                      |                         | Pine Ck., Mich.     | Scott and Crossman 1983<br>This study |

- (a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.
- (b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.
- (c) Not incipient lethal temperatures as defined by Fry et al (1946).
- (d) Simulated larval entrainment temperatures.

SPECIES: *Carassius auratus* (goldfish)

| THERMAL TOLERANCES: |                  |                  |        |                          |                          |                         |  |                              |  |          |                       |                        |          |                                |
|---------------------|------------------|------------------|--------|--------------------------|--------------------------|-------------------------|--|------------------------------|--|----------|-----------------------|------------------------|----------|--------------------------------|
| Size or Age (mm)    | Acclimation Temp | Acclimation Time | Season | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time - a + b (temp) |  | Data Limits Upper Lower Temp |  | Exposure | Resistance Time (Min) | Critical Thermal (Max) | Location | Reference                      |
| Juvenile            | 5-30             |                  |        | 38.6                     |                          |                         |  |                              |  |          |                       |                        |          | Jobing 1981                    |
|                     | 5-40             |                  |        | 40                       |                          |                         |  |                              |  |          |                       | 36.6                   |          | Jobing 1981                    |
|                     | 23.9             |                  |        | 29-38.6                  |                          |                         |  |                              |  |          |                       |                        |          | Spotila et al 1979             |
|                     | 19               |                  |        | 29.9-41                  |                          |                         |  |                              |  |          |                       | >35                    | Lab      | Spotila et al 1979             |
|                     | 24               |                  |        |                          | 1.0                      |                         |  |                              |  |          |                       |                        |          | Reutter and Herdendorf 1976    |
|                     | 38               |                  |        |                          | 5.0                      |                         |  |                              |  |          |                       |                        |          | Houston 1982                   |
|                     | 1-2              |                  |        |                          | 15.5                     |                         |  |                              |  |          |                       |                        |          | Houston 1982                   |
|                     | 9.3              |                  | F      | 28                       |                          |                         |  |                              |  |          |                       | 41                     |          | Houston 1982                   |
|                     | 10               |                  |        |                          |                          |                         |  |                              |  |          |                       | >25.3                  | Lab      | Reutter and Herdendorf 1976(a) |
|                     | 35               |                  |        | 40.5                     | 0                        |                         |  |                              |  |          |                       |                        |          | Leidy and Jenkins 1977         |
| larval              | 32               |                  |        |                          |                          |                         |  |                              |  |          |                       |                        |          | Leidy and Jenkins 1977         |
|                     | 38               |                  |        |                          |                          |                         |  |                              |  |          |                       |                        |          | Brown 1974                     |
|                     | 21-23            |                  |        |                          |                          |                         |  |                              |  |          |                       |                        |          | Brown 1974                     |
|                     |                  |                  |        | 39.3                     |                          |                         |  |                              |  |          |                       |                        |          | Jinks et al 1981               |
|                     |                  |                  |        | 38.5                     |                          |                         |  |                              |  |          |                       |                        |          | Jinks et al 1981               |
|                     |                  |                  |        | 37.5                     |                          |                         |  |                              |  |          |                       |                        |          | Jinks et al 1981               |
|                     | 25               |                  |        |                          |                          |                         |  |                              |  |          |                       |                        | Lab      | Jinks et al 1981               |
|                     | 5                |                  |        |                          |                          |                         |  |                              |  |          |                       | 37.6                   | Lab      | Talmage and Countant 1979      |
|                     |                  |                  |        |                          |                          |                         |  |                              |  |          |                       | 32                     | Lab      | Talmage and Countant 1979      |

(a) hybrid *C. carpio* x *Carassius auratus*

SPECIES: *Carassius auratus* (goldfish)

| PREFERRED TEMPERATURES: |        |              |                 |                   |                 |                         |                  |          |                          |
|-------------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|----------|--------------------------|
| Size or Age (mm)        | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | Location | Reference                |
| small                   |        |              | 33              | 30                |                 |                         |                  | Lab      | Coutant 1977a            |
| small                   |        |              |                 | 28.1              |                 |                         |                  | Lab      | Coutant 1977a            |
| adult                   | w      |              |                 | 24.2              |                 |                         |                  | Lab      | Coutant 1977a            |
| adult                   | SP     |              |                 | 25.3              |                 |                         |                  | Lab      | Coutant 1977a            |
| adult                   | su     |              |                 | 27.0              |                 |                         |                  | Lab      | Coutant 1977a            |
| adult                   | F      |              |                 | 24.0              |                 |                         |                  | Lab      | Coutant 1977a            |
| medium                  |        |              |                 | 27.9              |                 |                         |                  | Lab      | Coutant 1977a            |
|                         |        |              |                 | 29.7              |                 |                         | 26-30            | Lab      | Talmage and Coutant 1979 |
| 80-100 mm               |        |              |                 | 19.2              |                 |                         | 15               |          | Talmage and Coutant 1980 |
|                         |        |              |                 | 26                |                 |                         | 25               |          | Talmage and Coutant 1980 |
|                         |        |              |                 | 28                |                 |                         |                  |          | Talmage and Coutant 1980 |

SPECIES: Carassius auratus (goldfish)

| Size or Age<br>(mm) | Optimum<br>°C | Range | (b)            |             | No Growth Limits<br>Upper | Limits<br>Lower | Location | GROWTH TEMPERATURES:                                |  |
|---------------------|---------------|-------|----------------|-------------|---------------------------|-----------------|----------|---|--|
|                     |               |       | (a)<br>M W A T | ST<br>M a x |                           |                 |          | Reference   |  |
| Juvenile            | 25<br>28.1    |       | 30.4           | 32          |                           |                 |          | Jobing 1981<br>Leidy and Jenkins 1977<br>This study |  |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: Carassius auratus (goldfish)

| Event        | Season<br>and/or<br>Accli-<br>mation<br>Temp | Optimum<br>Temp | (a)       |       | (b)<br>ST Max<br>for<br>Embryo<br>Survival | Accli-<br>mation<br>Time | (c)<br>Lethal<br>Limit<br>Upper | (4)<br>Lethal<br>Limit<br>L o w e r | (d)<br>Median<br>Lethal<br>$\Delta T$ | Median<br>Lethal<br>Final | Location | Reference                              |
|--------------|--|-----------------|-----------|-------|--|--------------------------|---------------------------------|-------------------------------------|---------------------------------------|---------------------------|----------|--|
|              |  |                 | Temp      | Range |  |                          |                                 |                                     |                                       |                           |          |  |
| incubation   |  |                 | 18.5-29.5 |       |  |                          |                                 |                                     |                                       |                           |          | Scott and Crossman 1973                |
| spawning     |  |                 | 18.4-24.9 |       |  |                          |                                 |                                     |                                       |                           |          | Scott and Crossman 1973                |
| 1st hatching |  |                 | 15.5-18.4 |       |  |                          |                                 |                                     |                                       |                           |          | Carlander 1969                         |
| spawning     |  |                 | 17-24     | 24    | 29.5                                       |                          |                                 |                                     |                                       |                           |          | Talmage and Coutant 1978<br>This Study |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Carpoides cyprinus* (quillback)

| THERMAL TOLERANCES: |                  |                  |         |                          |                          |                             |             |       |               |                       |                        |          |           |
|---------------------|------------------|------------------|---------|--------------------------|--------------------------|-----------------------------|-------------|-------|---------------|-----------------------|------------------------|----------|-----------|
| Size or Age (mm)    | Acclimation Temp | Acclimation Time | Sea-son | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = $a + b_{(temp)}$ | Data Limits |       | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location | Reference |
|                     |                  |                  |         |                          |                          | a                           | Upper       | Lower |               |                       |                        |          |           |

|  |      |  |  |  |  |  |  |  |  |  |      |     |                    |
|--|------|--|--|--|--|--|--|--|--|--|------|-----|--------------------|
|  | 23.3 |  |  |  |  |  |  |  |  |  | 37.2 | Lab | Spotila et al 1979 |
|--|------|--|--|--|--|--|--|--|--|--|------|-----|--------------------|

SPECIES: *Carpoides cyprinus* (quillback)

| PREFERRED TEMPERATURES: |        |              |                 |                   |                 |                         |                  |          |           |
|-------------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|----------|-----------|
| Size or Age (mm)        | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | Location | Reference |

|             |    |  |      |       |      |  |  |                                |                       |
|-------------|----|--|------|-------|------|--|--|--------------------------------|-----------------------|
| adult large | F  |  | 34.5 | 22.1  | 27.0 |  |  | Lab Wabash, R., Ind.           | Coutant 1977a         |
|             | su |  |      | 26.32 |      |  |  | J.M. Stuart, GS, Ohio R., Ind. | Yoder and Gammon 1976 |
|             | W  |  |      | 10-16 |      |  |  | J.M. Stuart, GS, Ohio R., Ind. | Yoder and Gammon 1976 |

SPECIES: *Carpoides cyprinus* (quillback)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |            |          |                                |                  |                        |                        |           |                         |          |           |
|--|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|-----------|-------------------------|----------|-----------|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median AT | (d) Median Lethal Final | Location | Reference |

|          |  |  |       |      |    |  |  |  |  |  |                     |                            |
|----------|--|--|-------|------|----|--|--|--|--|--|---------------------|----------------------------|
| spawning |  |  | 19-28 | 23.5 | 28 |  |  |  |  |  | Four Mile Ck., Ohio | Talmage 1978<br>This study |
|----------|--|--|-------|------|----|--|--|--|--|--|---------------------|----------------------------|

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.



SPECIES: *Catostomus catostomus* (longnose sucker)

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Sea-son | THERMAL TOLERANCES:      |                          | log time = $\frac{a+b}{temp}$ | Data Limits |       | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location | Reference               |
|------------------|------------------|------------------|---------|--------------------------|--------------------------|-------------------------------|-------------|-------|---------------|-----------------------|------------------------|----------|-------------------------|
|                  |                  |                  |         | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp |                               | Upper       | Lower |               |                       |                        |          |                         |
| 44 g;            | 14               |                  |         | 26.5                     |                          |                               |             |       |               |                       |                        |          | Scott and Crossman 1973 |
| 44 g;            | 11.5             |                  |         | 27                       |                          |                               |             |       |               |                       |                        |          | Carlander 1969          |

SPECIES: *Catostomus catostomus* (longnose sucker)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES: |       | Location               | Reference     |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------|-------|------------------------|---------------|
|                  |        |              |                 |                   |                 |                         |                  | Upper                   | Lower |                        |               |
|                  |        |              |                 | 11-11.6           |                 |                         |                  |                         |       | Moosehead L., Me.      | Coutant 1977a |
|                  |        |              |                 | 8-17              |                 |                         |                  |                         |       | Pt. Beach, L. Michigan | Michaud 1981  |
|                  |        |              |                 | 8                 |                 |                         |                  |                         |       | Escanaba, L. Michigan  | Michaud 1981  |

SPECIES: *Catostomus catostomus* (longnose sucker)

| Event            | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | SPAWNING AND DEVELOPMENT TEMPERATURES: |                        |                      |                         | Location         | Reference               |
|------------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|--|------------------------|----------------------|-------------------------|------------------|-------------------------|
|                  |                                |              |            |          |                                |                  | (c) Lethal Limit Upper                 | (c) Lethal Limit Lower | (d) Median Lethal AT | (d) Median Lethal Final |                  |                         |
| spawning run     |                                | 5            |            |          |                                |                  |  |                        |                      |                         | B.C.             | Scott and Crossman 1973 |
| hatching (8-11d) |                                |              | 10-15      |          |                                |                  |  |                        |                      |                         | B.C.             | Scott and Crossman 1973 |
| migration        |                                |              | 11-14      |          |                                |                  |  |                        |                      |                         | Pyramid L., Sask | Brown 1974              |
| spawning         |                                | > 15         |            |          |                                |                  |  |                        |                      |                         | Gt. Slave Lake   | Brown 1974              |
| spawning         |                                | 5            |            |          |                                |                  |  |                        |                      |                         | Stream           | Fuiman and Witman 1979  |
|                  |                                |              |            | 5-10     | 13                             |                  |  |                        |                      |                         |                  | This study              |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Catostomus commersoni* (white sucker)

THERMAL TOLERANCES:

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Season | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time -- |         | Data Limits |       | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location                             | Reference                                  |
|------------------|------------------|------------------|--------|--------------------------|--------------------------|-------------|---------|-------------|-------|---------------|-----------------------|------------------------|--------------------------------------|--|
|                  |                  |                  |        |                          |                          | a           | b       | Upper       | Lower |               |                       |                        |                                      |  |
| adult            | 19               |                  | SP     |                          |                          |             |         |             |       |               |                       | 31.6                   | Lab                                  | Reutter and Herdendorf 1976                |
| Juvenile         | 5                |                  |        | 26                       |                          |             |         |             |       | 26            | 310                   |                        |                                      | Brown 1974                                 |
| larvae/ Juvenile | 10               |                  |        | 28                       |                          |             |         |             |       | 28            | 310                   |                        |                                      | Brown 1974                                 |
| larvae           | 15               |                  |        | 31                       |                          |             |         |             |       |               |                       |                        |                                      | EPA 1974                                   |
| Juvenile         | 15               |                  |        | 29                       |                          |             |         |             |       |               |                       |                        |                                      | EPA 1974                                   |
| Juvenile         | 20               |                  |        | 29                       | 2-3                      |             |         |             |       | 29            | 2000                  |                        |                                      | Brown 1974                                 |
| larvae           | 21               |                  |        | 30                       | 6                        |             |         |             |       |               |                       |                        |                                      | EPA 1974                                   |
| Juvenile         | 25               |                  |        | 29                       | 6                        |             |         |             |       | 29            | 8000                  |                        |                                      | Brown 1974                                 |
| Juvenile         | 25-26            |                  |        | 31                       |                          |             |         |             |       | 31            | 720                   |                        |                                      | Brown 1974                                 |
| 1-2 yr           | 5                |                  |        | 26.3                     |                          | 33.6957     | -1.1797 | 27.5        | 27    |               |                       |                        |                                      | Brown 1974                                 |
|                  | 10               |                  |        | 27.7                     |                          | 19.9890     | -0.6410 | 29          | 29    |               |                       |                        |                                      | Brown 1974                                 |
|                  | 15               |                  |        | 29.3                     |                          | 31.9007     | -1.0036 | 30          | 29.5  |               |                       |                        |                                      | Brown 1974                                 |
|                  | 20               |                  |        | 29.3                     | 2.5                      | 27.0023     | -0.8068 | 31.5        | 30    |               |                       |                        |                                      | Brown 1974                                 |
|                  | 25               |                  |        | 28.3                     | 6.6                      | 22.2209     | -0.6277 | 32.5        | 29.5  |               |                       |                        |                                      | Brown 1974                                 |
| 120 Juvenile     |                  |                  |        | 31.4                     |                          |             |         |             |       |               |                       | 35.1-36.1              |                                      | Brown 1974                                 |
|                  |                  |                  |        | 30-33.3                  |                          |             |         |             |       |               |                       |                        | Nova Scotia R. Power plant discharge | Brown 1974                                 |
|                  | 32.2             |                  |        | 35                       |                          |             |         |             |       | 35            | 600                   |                        |                                      | Brown 1974                                 |
|                  | 7.2              |                  |        | 30                       |                          |             |         |             |       | 30            | 600                   |                        |                                      | Brown 1974                                 |
|                  | 11.1             |                  |        | 31                       |                          |             |         |             |       | 31            | 2160                  |                        |                                      | Brown 1974                                 |
| larval           | 9-10             |                  |        | 28.3-28.8                |                          |             |         |             |       |               |                       |                        |                                      | Jinks et al 1981                           |
|                  | 15-16            |                  |        | 30-31.1                  |                          |             |         |             |       |               |                       |                        |                                      | Jinks et al 1981                           |
| newly hatched    | 21               |                  |        | 30.5-31.7                |                          |             |         |             |       |               |                       |                        |                                      | Jinks et al 1981                           |
| swim-up          | 21.2             | 7d               |        | >28.2                    | 4.8                      |             |         |             |       |               |                       |                        | Lab                                  | McCormick et al 1977                       |
|                  | 21.1             | 7d               |        | 30.5                     | 6.1                      |             |         |             |       |               |                       |                        | Lab                                  | McCormick et al 1977                       |
|                  | 15.8             | 7d               |        | 30.7                     |                          |             |         |             |       |               |                       |                        | Lab                                  | McCormick et al 1977                       |
|                  | 10.0             | 7d               |        | 28.1                     |                          |             |         |             |       |               |                       |                        | Lab                                  | McCormick et al 1977                       |
| newly hatched    | 15.2             | 7d               |        | 30.0                     | 4.8                      |             |         |             |       |               |                       |                        | Lab                                  | McCormick et al 1977                       |
|                  | 8.9              | 7d               |        | 28.6                     |                          |             |         |             |       |               |                       |                        | Lab                                  | McCormick et al 1977                       |
| larvae           |                  |                  |        | 30.2                     |                          |             |         |             |       |               |                       | 32.7                   | Lab (temp. incr. 1 c/h)              | Crippen & Fahmy 1981<br>Spotila et al 1979 |

SPECIES: *Catostomus commersoni* (white sucker)

| Size or Age (mm) | Season                      | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES:  |                             |                       |
|------------------|-----------------------------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|--|-----------------------------|-----------------------|
|                  |                             |              |                 |                   |                 |                         |                  | Location   | Reference                   |                       |
| large adult      | F                           |              |                 | 20.6              |                 |                         |                  | Wisconsin lakes<br>Moosehead L. Me.<br>Horse tooth Res., Colo<br>Lab   | Coutant 1977a               |                       |
|                  |                             |              |                 | 18.3              |                 |                         |                  |  | Coutant 1977a               |                       |
|                  |                             |              |                 | 18.9-21.1         |                 |                         |                  |  |                             | Coutant 1977a         |
|                  |                             |              |                 | 22.4              |                 |                         |                  |  |                             | Coutant 1977a         |
|                  |                             |              |                 | 14.1-18.3         | < 5             |                         |                  |  |                             | Brown 1974            |
| adult            | SP<br>su<br>Year<br>su<br>F |              | 20.6            |                   | 11.8            |                         |                  | Discharge<br><br>Point Beach L Mich.<br>Ohio R.<br>Ohio R.   | Brown 1974                  |                       |
|                  |                             |              | >29.4           | 23.9              |                 | 17.2                    |                  |  | Brown 1974                  |                       |
|                  |                             |              | 20              |                   | 14              |                         |                  |  | Haymes 1984                 |                       |
|                  |                             |              | 17              |                   | 8               |                         |                  |  | Michaud 1981                |                       |
|                  |                             |              |                 | 25-27             |                 |                         |                  |  |                             | Yoder and Gammon 1976 |
| adult            |                             |              |                 | 16-19             |                 |                         |                  | Oswego or Pickering GS<br>L. Ontario<br>Lab<br>New River, Va.<br>Connecticut R., Conn.<br>(mean field occurrence)<br>Jack L., Ont. | Yoder and Gammon 1976       |                       |
|                  |                             |              | 31.2            | 24                |                 |                         |                  |  | EPA 1978a                   |                       |
|                  |                             |              |                 | 19-21             |                 |                         |                  |  |                             | McCormick et al 1977  |
|                  |                             |              |                 | 26.1              | 24.1            | 22.8                    |                  |  |                             | Wyman 1981            |
| Larval           |                             |              |                 | 26.7              |                 |                         |                  |  | Reynolds and Casterlin 1978 |                       |
|                  |                             |              | 19.9            | 14.4              | 10              |                         |                  |  | Reynolds and Casterlin 1978 |                       |
|                  |                             |              | 30              |                   |                 |                         |                  |  | Marcy 1976a                 |                       |
|                  |                             |              |                 |                   |                 |                         |                  |  | Corbett and Powles 1983     |                       |

SPECIES: *Catostomus commersoni* (white sucker)

| Size or Age (mm) | Optimum °C | Range     | (a) |       | No Growth Upper | Limits Lower | Location     | GROWTH TEMPERATURES: |                          |
|------------------|------------|-----------|-----|-------|-----------------|--------------|--------------|----------------------|--------------------------|
|                  |            |           | M   | W A T |                 |              |              | ST Max               | Reference                |
| larvae           | 27         | 24-27     | 28  | 30    |                 |              |              |                      | EPA 1974                 |
| 100; juvenile    | 24         | 12-29     |     |       |                 | <12          | Lab          |                      | EPA 1974                 |
| 4-5 mg; larva    | 26.9       |           |     |       |                 |              | Lab          |                      | EPA 1974                 |
| 100; juvenile    | 26         |           |     |       |                 |              | Lab (summer) |                      | EPA 1978b                |
| juvenile         | 24         |           |     |       |                 |              | Lab (winter) |                      | EPA 1978b                |
| larvae           | 26.9       | 15.7-26.9 |     |       | 29.7            | 10           | Lab          |                      | McCormick et al 1977     |
| adult            | 24         |           |     |       |                 |              | Lab          |                      | Smagula and Adelman 1982 |
| 104; age I       | 24         | 12-30     |     |       |                 |              | Lab          |                      | Adelman 1980             |
| 263; age II      | 24         | 12-30     |     |       |                 |              | Lab          |                      | Adelman 1980             |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Catostomus commersoni* (white sucker)

| Event                       | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max far Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (4) Lethal Limit Lower | SPAWNING AND DEVELOPMENT TEMPERATURES: |                         | Location                           | Reference               |
|-----------------------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|--|-------------------------|------------------------------------|-------------------------|
|                             |                                |              |            |          |                                |                  |                        |                        | Median Lethal AT                       | (4) Median Lethal Final |                                    |                         |
| spawning                    |                                | 10           | 4-18       | 10       | 21                             |                  |                        |                        |  |                         |                                    | EPA 1974                |
| incubation/hatch            |                                | 15           | 8-21       |          |                                |                  |                        |                        |  |                         |                                    | EPA 1974                |
| spawning                    |                                |              | 10-20      |          |                                |                  |                        |                        |  |                         |                                    | Brown 1974              |
| heat shock incubation/hatch | 12                             |              |            |          |                                |                  |                        |                        | 20                                     | 32                      | Lab                                | Moore 1979(d)           |
| incubation/hatch            | 6.2-42.1                       | 15.2         | 9-17.2     |          |                                |                  | 24.1                   | 6.2                    |  |                         | Lab                                | McCormick et al 1977    |
| spawning                    |                                | 17.8         | 27.2       |          | <24.1                          |                  |                        |                        |  |                         |                                    | McCormick et al 1977    |
| cold shock                  | 16                             |              |            |          |                                |                  |                        | 0                      | -16                                    |                         | Lab                                | Edsall and Yocum 1972   |
| cold shock                  | 20                             |              |            |          |                                |                  |                        | 3                      | -17                                    |                         | Lab                                | Edsall and Yocum 1972   |
| cold shock                  | 25                             |              |            |          |                                |                  |                        | 6                      | -19                                    |                         | Lab                                | Edsall and Yocum 1972   |
| cold shock                  | 33-34                          |              |            |          |                                |                  |                        | 10                     | -13                                    |                         | Sandusky, R. (L. Erie)             | Coutant 1977b           |
| cold shock                  | 27                             |              |            |          |                                |                  |                        | 2                      | -25                                    |                         | Susquehanna R.                     | Coutant 1977b           |
| heat shock                  | 12.2                           |              |            |          |                                |                  |                        |                        | +20.6                                  |                         | Lab, simulated onshore discharge   | Crippen and Fahmy 1981  |
|                             | 12.2                           |              |            |          |                                |                  |                        |                        | +23.5                                  |                         | Lab, simulated tempering discharge | Crippen and Fahmy 1981  |
|                             | 12.2                           |              |            |          |                                |                  |                        |                        | i-23.3                                 |                         | Lab, simulated offshore discharge  | Crippen and Fahmy 1981  |
| spawning                    |                                | 11.16        |            |          |                                |                  |                        |                        |  |                         | N.Y. and Penn.                     | Fuiman 1979             |
| spawning                    |                                | 23.4         | 12.2-24    |          |                                |                  |                        |                        |  |                         | Connecticut R., Conn.              | Marcy 1976b             |
| larval dev.                 |                                | 23.8         | 14.0-24    |          |                                |                  |                        |                        |  |                         | Connecticut R., Conn.              | Marcy 1976b             |
| spawning migration          |                                | 211.8        | 3-16.5     |          |                                |                  |                        |                        |  |                         | Jack L., Ont.                      | Corbett and Powles 1983 |
| spawning                    |                                | 16.8         | 10-16.9-k  |          |                                |                  |                        |                        |  |                         | Jack L., Ont.                      | Corbett and Powles 1983 |
| larval dev. (9-11 mm TL)    |                                |              | 6-16.8     |          |                                |                  |                        |                        |  |                         | Jack L., Ont.                      | Corbett and Powles 1983 |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: Erimyzon sucetta (lake chubsucker)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |            |          |                                |                  |                        |                        |                  |                         |                              |                         |
|--|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|------------------|-------------------------|------------------------------|-------------------------|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location                     | Reference               |
| hatching (6.7d)                        |                                |              | 22-29.5    |          |                                |                  |                        |                        |                  |                         |                              | Scott and Crossman 1973 |
| spawning                               |                                |              | 15-22      |          |                                |                  |                        |                        |                  |                         | N.Y. and Penn. (E. oblongus) | Fuiman 1979             |
|  |                                |              |            | 18.5     | 22                             |                  |                        |                        |                  |                         |                              | This study              |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

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SPECIES: Hypentelium nigricans (northern hog sucker)

| THERMAL TOLERANCES: |                  |                  |         |                          |                          |                             |                   |                     |                        |                        |          |                     |
|---------------------|------------------|------------------|---------|--------------------------|--------------------------|-----------------------------|-------------------|---------------------|------------------------|------------------------|----------|---------------------|
| Size or Age (mm)    | Acclimation Temp | Acclimation Time | Sea-son | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = a + b (temp) a b | Data Limits Upper | Exposure Lower Temp | Resis-tance Time (Min) | Critical Thermal (Max) | Location | Reference           |
| 15                  |                  |                  |         |                          |                          |                             |                   |                     |                        | 30.8                   |          | Kowalski et al 1978 |
| 18-33               |                  |                  |         | 33                       |                          |                             |                   |                     |                        |                        | Lab      | Cherry et al 1977   |
| 18                  |                  |                  |         | 27                       |                          |                             |                   |                     |                        |                        |          | Cherry et al 1977   |
| 21                  |                  |                  |         | 30                       |                          |                             |                   |                     |                        |                        |          | Cherry et al 1977   |
| 24                  |                  |                  |         | 33                       |                          |                             |                   |                     |                        |                        |          | Cherry et al 1977   |
| 27                  |                  |                  |         | 33                       |                          |                             |                   |                     |                        |                        |          | Cherry et al 1977   |
| 30                  |                  |                  |         | 33                       |                          |                             |                   |                     |                        |                        |          | Cherry et al 1977   |
| 33                  |                  |                  |         | 34                       |                          |                             |                   |                     |                        |                        |          | Cherry et al 1977   |

SPECIES: *Hypentelium nigricans* (northern hog sucker)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES:         |                   |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|---------------------------------|-------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                        | Reference         |
|                  |        |              |                 | 26.6              |                 |                         |                  |                                 | Jobling 1981      |
| 50-100 FL;       |        |              |                 | 15.3              |                 | 12                      |                  | Lab (rising water temperatures) | Cherry et al 1977 |
| 50-100 FL;       |        |              |                 | 20.2              |                 | 15                      |                  | Lab (rising water temperatures) | Cherry et al 1977 |
| 50-100 FL;       |        |              |                 | 16.9              |                 | 18                      |                  | Lab (rising water temperatures) | Cherry et al 1977 |
| 50-100 FL;       |        |              |                 | 23                |                 | 21                      |                  | Lab (rising water temperatures) | Cherry et al 1977 |
| 50-100 FL;       |        |              |                 | 27                |                 | 24                      |                  | Lab (rising water temperatures) | Cherry et al 1977 |
| 50-100 FL;       |        |              |                 | 28.7              |                 | 27                      |                  | Lab (rising water temperatures) | Cherry et al 1977 |
| 50-100 FL;       |        |              |                 | 29.4              |                 | 30                      |                  | Lab (rising water temperatures) | Cherry et al 1977 |
| 50-100 FL;       |        |              |                 | 28.8              |                 | 33                      |                  | Lab (rising water temperatures) | Cherry et al 1977 |
| 50-100 FL;       |        |              |                 | 28.6              |                 |                         |                  | Lab (rising water temperatures) | Cherry et al 1977 |
|                  |        |              |                 | 29.2              |                 |                         |                  |                                 | Cherry et al 1977 |
|                  |        |              |                 | 25.2              |                 |                         |                  | Wabash Ft., Ind.                | Brown 1974        |

SPECIES: *Hypentelium nigricans* (northern hog sucker)

| Size or Age (mm) | Optimum °C | (a) Range | (b) ST Max |     | No Growth Limits Upper | Lower | Location          | GROWTH TEMPERATURES:    |           |
|------------------|------------|-----------|------------|-----|------------------------|-------|-------------------|-------------------------|-----------|
|                  |            |           | MWAT       | Max |                        |       |                   | Reference               | Reference |
|                  |            | 13.3-15.5 |            |     |                        |       | Annulus formation | Scott and Crossman 1973 |           |
|                  | 25.8/25.3  |           |            |     |                        | 3 1 0 |                   | Scott and Crossman 1973 |           |
|                  |            |           | 28.1       | 30  |                        |       |                   | Jobling 1981            |           |
|                  |            |           |            |     |                        |       |                   | This study              |           |

(a) MWAT (maximum weekly average temperature for growth) = Optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Hypentelium nigricans* (northern hog sucker)

| Event          | Season and/or Acclimation Temp | Optimum Temp | (a) Temp Range | (b) ST Max for Embryo Survival | (c) Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | (d) Median Lethal AT | Median Lethal Final | Location       | Reference                 |
|----------------|--------------------------------|--------------|----------------|--------------------------------|----------------------|------------------------|------------------------|----------------------|---------------------|----------------|---------------------------|
|                |                                |              |                |                                |                      |                        |                        |                      |                     |                |                           |
| spawning       |                                |              | > 15.6         |                                |                      |                        |                        |                      |                     |                | Scott and Crossman 1973   |
| spawning       |                                |              | 12-23          |                                |                      |                        |                        |                      |                     | N.Y. and Penn. | Fuiman 1979               |
| hatching (10d) |                                |              | 17.4           |                                |                      |                        |                        |                      |                     | Lab            | Buynak and Mohr, Jr. 1978 |
|                |                                |              |                | 17.5                           | 23                   |                        |                        |                      |                     |                | This study                |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: Ictiobus cyprinellus (bigmouth buffalo)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES:                    |                       |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|--|-----------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                                   | Reference             |
| Large            |        |              | 34.5            |                   | 27              |                         |                  | Wabash R., Ind. (buffalo sp.)              | Coutant 1977a         |
|                  | W      |              |                 | 6-24              |                 |                         |                  | J.M. Stuart GS, Ohio R., Ohio (I. bubalus) | Yoder and Gammon 1976 |
|                  | F      |              |                 | 18-26             |                 |                         |                  | J.M. Stuart GS, Ohio R., Ohio (I. bubalus) | Yoder and Gammon 1987 |
|                  | su     |              |                 | 22-23             |                 |                         |                  | J.M. Stuart GS, Ohio R., Ohio (I. bubalus) | Yoder and Gammon 1976 |

SPECIES: Ictiobus cyprinellus (bigmouth buffalo)

| Event    | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | SPAWNING AND DEVELOPMENT TEMPERATURES: |                        |                  |                         | Location | Reference                  |
|----------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|--|------------------------|------------------|-------------------------|----------|----------------------------|
|          |                                |              |            |          |                                |                  | (c) Lethal Limit Upper                 | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final |          |                            |
| spawning |                                | 15.5-18.3    |            |          |                                |                  |  |                        |                  |                         |          | Scott and Crossman 1973    |
| spawning |                                |              | 14.4-26.7  |          |                                |                  |  |                        |                  |                         |          | Carlander 1969<br>EPA 1974 |
| spawning |                                |              |            | 17       | 27                             |                  |  |                        |                  |                         |          |                            |
| spawning |                                | 17           |            |          |                                |                  |  |                        |                  |                         |          | EPA 1974                   |
| hatching |                                |              | 14-27      |          |                                |                  |  |                        |                  |                         |          | EPA 1974                   |
|          |                                |              |            | 17       | 26.7                           |                  |  |                        |                  |                         |          | This study                 |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Minytrema melanops* (spotted sucker)

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Sea-son | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time =<br>a + b (temp)<br>a b | Data Limits |       | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | THERMAL TOLERANCES: |                             |
|------------------|------------------|------------------|---------|--------------------------|--------------------------|-----------------------------------|-------------|-------|---------------|-----------------------|------------------------|---------------------|-----------------------------|
|                  |                  |                  |         |                          |                          |                                   | Upper       | Lower |               |                       |                        | Location            | Reference                   |
|                  | 20               |                  | SU      |                          |                          |                                   |             |       |               |                       | >31                    | Lab                 | Reutter and Herdendorf 1976 |

SPECIES: *Minytrema melanops* (spotted sucker)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES:   |                       |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|---------------------------|-----------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                  | Reference             |
|                  | SU     |              |                 | 25-27             |                 |                         |                  | J.M. Stuart, GS, Ohio R., | Yoder and Gammon 1976 |
|                  | F      |              |                 | 16-19             |                 |                         |                  | J.M. Stuart, GS, Ohio R., | Yoder and Gammon 1976 |

SPECIES: *Minytrema melanops* (spotted sucker)

| Event    | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | SPAWNING AND DEVELOPMENT TEMPERATURES: |                        |                          |                         |          |           |                                       |
|----------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|--|------------------------|--------------------------|-------------------------|----------|-----------|---------------------------------------|
|          |                                |              |            |          |                                |                  | (c) Lethal Limit Upper                 | (c) Lethal Limit Lower | Median Lethal $\Delta T$ | (d) Median Lethal Final | Location | Reference |                                       |
| spawning |                                |              | 15-17.8    | 16.4     | 17.8                           |                  |  |                        |                          |                         |          | Oklahoma  | Scott and Crossman 1973<br>This study |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.



SPECIES: *Moxostoma anisurum* (silver redhorse)

SPAWNING AND DEVELOPMENT TEMPERATURES:

| Event    | Season and/or Acclimation Temp | Optimum Temp | Temp Range (a) | MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location | Reference               |
|----------|--------------------------------|--------------|----------------|------|--------------------------------|------------------|------------------------|------------------------|------------------|-------------------------|----------|-------------------------|
| spawning |                                | 13.3         |                |      |                                |                  |                        |                        |                  |                         |          | Scott and Crossman 1973 |
| spawning |                                | 13.5         |                |      |                                |                  |                        |                        |                  |                         |          | Carlander 1969          |
|          |                                |              |                | 13.5 |                                |                  |                        |                        |                  |                         |          | This study              |

SPECIES: *Moxostoma macrolepidotum* (shorthead redhorse)

PREFERRED TEMPERATURES:

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | Location                                   | Reference                               |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|--|---|
| large            |        |              | 37.2<br>26      |                   | 22              |                         |                  | Wabash R., Ind.<br>( <i>Moxostoma</i> sp.) | Scott and Crossman 1973<br>Coutant 1977 |
|                  |        |              |                 | 26-27.5           |                 |                         |                  |  | Yoder and Gammon 1976                   |

SPECIES: *Moxostoma macrolepidotum* (shorthead redhorse)

SPAWNING AND DEVELOPMENT TEMPERATURES:

| Event         | Season and/or Acclimation Temp | Optimum Temp | Temp Range (a) | MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location              | Reference                 |
|---------------|--------------------------------|--------------|----------------|------|--------------------------------|------------------|------------------------|------------------------|------------------|-------------------------|-----------------------|---------------------------|
| spawning      |                                | 11           |                |      |                                |                  |                        |                        |                  |                         | Iowa                  | Scott and Crossman 1973   |
| spawning      |                                | 16           |                |      |                                |                  |                        |                        |                  |                         | Big Rock Ck, Ill.     | Talmage and Coutant 1978  |
| spawning      |                                | 12           |                |      |                                |                  |                        |                        |                  |                         | Susquehanna R., Penn. | Buynak and Mohr, Jr. 1979 |
| hatching (8d) |                                | 15.6         |                |      |                                |                  |                        |                        |                  |                         | Lab                   | Buynak and Mohr, Jr. 1979 |
|               |                                |              |                | 13.5 | 16+                            |                  |                        |                        |                  |                         |                       | This study                |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Ictalurus melas* (black bullhead)

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Season | THERMAL TOLERANCES:      |                          | log time =<br>a + b (temp)<br>a b | Data Limits<br>Upper Lower | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location       | Reference                         |
|------------------|------------------|------------------|--------|--------------------------|--------------------------|-----------------------------------|----------------------------|---------------|-----------------------|------------------------|----------------|-----------------------------------|
|                  |                  |                  |        | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp |                                   |                            |               |                       |                        |                |                                   |
| YOY              | 23               |                  | su     | 35                       |                          |                                   |                            |               |                       |                        |                | Carlander 1969                    |
| YOY              | 33-37            |                  | SU     | 35.7                     |                          |                                   |                            | 35.7          | 2880                  |                        | Lab            | Spotila et al 1979                |
| YOY              |                  |                  | su     | 35.7                     |                          |                                   |                            |               |                       | 37.5                   | Mississippi R. | Jinkes et al 1981<br>Talmage 1978 |

SPECIES: *Ictalurus melas* (black bullhead)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES:             |          | Reference        |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------------------|----------|------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                            | Location |                  |
| juvenile         | su     |              | 35              |                   |                 |                         |                  | Discharge L. Monona Steam GS, Wisc. |          | Beltz et al 1974 |
|                  | W      |              | 14              |                   |                 |                         |                  | Discharge L. Monona Steam GS, Wisc. |          | Beltz et al 1974 |

SPECIES: *Ictalurus melas* (black bullhead)

| Event    | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median AT | (d) Median Lethal Final | Location | Reference                             |
|----------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|-----------|-------------------------|----------|---------------------------------------|
|          |                                |              |            |          |                                |                  |                        |                        |           |                         |          |                                       |
| spawning |                                | 21           |            |          |                                |                  |                        |                        |           |                         |          | Scott and Crossman 1973<br>This study |

- (a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.
- (b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.
- (c) Not incipient lethal temperatures as defined by Fry et al (1946).
- (d) Simulated larval entrainment temperatures.

SPECIES: *Ictalurus natalis* (yellow bullhead)

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Sea-son | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = |   | Data Limits |       | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | THERMAL TOLERANCES: |                    |
|------------------|------------------|------------------|---------|--------------------------|--------------------------|------------|---|-------------|-------|---------------|-----------------------|------------------------|---------------------|--------------------|
|                  |                  |                  |         |                          |                          | a          | b | Upper       | Lower |               |                       |                        | Location            | Reference          |
|                  | 22.2             |                  | su      |                          |                          |            |   |             |       |               |                       | 36.4                   |                     | Spotila et al 1979 |

SPECIES: *Ictalurus natalis* (yellow bullhead)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES: |               |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------|---------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                | Reference     |
| adult            | su     |              |                 | 28.3              |                 |                         |                  | Lab                     | Coutant 1977a |
| juvenile         |        |              |                 | 28.8              |                 |                         |                  |                         | Coutant 1977a |
| adult            |        |              |                 | 27.6              |                 |                         |                  |                         | Coutant 1977a |

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## THERMAL TOLERANCES:

| Size or Age<br>(mm) | Acclimation<br>Temp | Acclimation<br>Time | Season | Upper          | Lower          | log time =     |          | Data Limits |       | Exposure<br>Temp | Resistance<br>Time<br>(Min) | Critical<br>Thermal<br>(Max) | Location                         | Reference               |
|---------------------|---------------------|---------------------|--------|----------------|----------------|----------------|----------|-------------|-------|------------------|-----------------------------|------------------------------|----------------------------------|-------------------------|
|                     |                     |                     |        | Lethal<br>Temp | Lethal<br>Temp | a              | b (temp) | Upper       | Lower |                  |                             |                              |                                  |                         |
|                     |                     |                     |        | 36.1           |                |                |          |             |       |                  |                             |                              |                                  | Scott and Crossman 1973 |
| 5-6                 |                     |                     |        | 28.6-29        |                |                |          |             |       |                  |                             |                              |                                  | Carlander 1969          |
| 10                  |                     |                     |        | 30-30.2        |                |                |          |             |       |                  |                             |                              |                                  | Carlander 1969          |
| 20                  |                     |                     |        | 33-33.4        | -1/+1          |                |          |             |       |                  |                             |                              |                                  | Carlander 1969          |
| 25                  |                     |                     |        | 35.5           | 1.3            |                |          |             |       |                  |                             |                              |                                  | Carlander 1969          |
| 30                  |                     |                     |        | 36.5-37        | 3.7            |                |          |             |       |                  |                             |                              |                                  | Carlander 1969          |
| 36                  |                     |                     |        | 37.5           | 7.0            |                |          |             |       |                  |                             |                              |                                  | Carlander 1969          |
| 37-38               |                     |                     |        | 37.2           |                |                |          |             |       |                  |                             |                              |                                  | Carlander 1969          |
| 10                  |                     |                     |        | 29             |                |                |          |             |       |                  |                             |                              |                                  | Spotila et al 1979      |
| 20                  |                     |                     |        | 32.3           |                |                |          |             |       |                  |                             |                              |                                  | Spotila et al 1979      |
| 25                  |                     |                     |        | 33.7           |                |                |          |             |       |                  |                             |                              |                                  | Spotila et al 1979      |
| 30                  |                     |                     |        | 34.7           |                |                |          |             |       |                  |                             |                              |                                  | Spotila et al 1979      |
| 5                   |                     |                     |        | 29.9           |                |                |          |             |       |                  |                             |                              |                                  | Spotila et al 1979      |
| 10                  |                     |                     |        | 31.5           |                |                |          |             |       |                  |                             |                              |                                  | Spotila et al 1979      |
| 15                  |                     |                     |        | 33             |                |                |          |             |       |                  |                             |                              |                                  | Spotila et al 1979      |
| 20                  |                     |                     |        | 35             |                |                |          |             |       |                  |                             |                              |                                  | Spotila et al 1979      |
| 25                  |                     |                     |        | 37.5           |                |                |          |             |       |                  |                             |                              |                                  | Spotila et al 1979      |
| 30                  |                     |                     |        | 39             |                |                |          |             |       |                  |                             |                              |                                  | Spotila et al 1979      |
| 35                  |                     |                     |        | 41             |                |                |          |             |       |                  |                             |                              |                                  | Spotila et al 1979      |
| 40                  |                     |                     |        | 41             |                |                |          |             |       |                  |                             |                              |                                  | Spotila et al 1979      |
|                     |                     |                     | SU     | 35.5           |                |                |          |             |       |                  |                             |                              |                                  | Spotila et al 1979      |
|                     |                     |                     | w      | 29.0           |                |                |          |             |       |                  |                             |                              |                                  | Spotila et al 1979      |
|                     |                     |                     | SP     | 29.1-32.6      |                |                |          |             |       |                  |                             |                              | Algonquin Pk., stream Ont.       | Spotila et al 1979      |
|                     |                     |                     | su     | 33.2-35.5      |                |                |          |             |       |                  |                             |                              |                                  | Spotila et al 1979      |
|                     |                     |                     | F      | 32.9           |                |                |          |             |       |                  |                             |                              |                                  | Spotila et al 1979      |
| 23                  |                     |                     | su     |                |                |                |          |             |       |                  | 37.8                        |                              |                                  | Spotila et al 1979      |
| 5                   |                     |                     |        | 27.8           |                | 14.6802-0.4539 | 29.5     | 28.0        |       |                  |                             |                              | Florida to Ontario<br>(combined) | Brown 1974              |
| 10                  |                     |                     |        | 29             |                | 16.4227-0.4842 | 31.5     | 29.5        |       |                  |                             |                              | Florida to Ontario<br>(combined) | Brown 1974              |
| 15                  |                     |                     |        | 31             |                | 28.3281-0-8239 | 33       | 32.5        |       |                  |                             |                              | Florida to Ontario<br>(combined) | Brown 1974              |
| 20                  |                     |                     |        | 32.5           | 0.5            | 23.9586-0.6473 | 35       | 32.5        |       |                  |                             |                              | Florida to Ontario<br>(combined) | Brown 1974              |
| 25                  |                     |                     |        | 33.8           | 4.0            | 22.4970-0.5732 | 37       | 34          |       |                  |                             |                              | Florida to Ontario<br>(combined) | Brown 1974              |
| 30                  |                     |                     |        | 34.8           | 6.8            | 24.2203-0.5917 | 38.5     | 35.5        |       |                  |                             |                              | Florida to Ontario<br>(combined) | Brown 1974              |
| 34                  |                     |                     |        | 34.8           |                | 19.3194-0.4500 | 37.5     | 36.0        |       |                  |                             |                              | Florida to Ontario<br>(combined) | Brown 1974              |
|                     |                     |                     |        |                |                |                |          |             |       |                  | ≅38                         |                              | S. Michigan pond                 | Brown 1974              |
|                     |                     |                     | SP     | 28             |                |                |          |             |       |                  |                             |                              | L. Opeongo                       | Brown 1974              |
|                     |                     |                     | su     | 34.8           |                |                |          |             |       |                  |                             |                              | L. Opeongo                       | Brown 1974              |

| Size or Age<br>(mm) | Accli-<br>mation<br>Temp. | Accli-<br>mation<br>Time | Sea-<br>son | THERMAL TOLERANCES:               |                                   |                            |  |                       |                                  |                              |          |     |                  | Reference |
|---------------------|---------------------------|--------------------------|-------------|-----------------------------------|-----------------------------------|----------------------------|--|-----------------------|----------------------------------|------------------------------|----------|-----|------------------|-----------|
|                     |                           |                          |             | Upper<br>Incip.<br>Lethal<br>Temp | Lower<br>Incip.<br>Lethal<br>Temp | log time =<br>a + b (temp) |  | Expo-<br>sure<br>Temp | Resis-<br>tance<br>Time<br>(Min) | Critical<br>Thermal<br>(Max) | Location |     |                  |           |
|                     |                           |                          |             | Data Limits<br>Upper Lower        | a                                 | b                          |  |                       |                                  |                              |          |     |                  |           |
| larval              | 25                        |                          |             | 38.2                              |                                   |                            |  | 38.2                  | IO                               |                              |          | Lab | Jinks et al 1981 |           |
|                     |                           |                          |             | 36.4                              |                                   |                            |  | 36.4                  | 30                               |                              |          | Lab | Jinks et al 1981 |           |
|                     |                           |                          |             | 36.4                              |                                   |                            |  | 36.4                  | 60                               |                              |          | Lab | Jinks et al 1981 |           |
| early<br>juvenile   | 26                        |                          |             | 37.6                              |                                   |                            |  | 37.6                  | IO                               |                              |          | Lab | Jinks et al 1981 |           |
|                     |                           |                          |             | 36.5                              |                                   |                            |  | 36.5                  | 30                               |                              |          | Lab | Jinks et al 1981 |           |
| 44; YOY             | 24                        |                          |             | 35.9                              |                                   |                            |  | 35.9                  | 60                               |                              |          | Lab | Jinks et al 1981 |           |
| 44; YOY             | 24                        |                          |             | 35.6                              |                                   |                            |  | 35.6                  | 1440                             |                              |          | Lab | Jinks et al 1981 |           |
| 44; YOY             | 24                        |                          |             | 35.7                              |                                   |                            |  | 35.7                  | 5760                             |                              |          | Lab | Jinks et al 1981 |           |

SPECIES: Ictalurus nebulosus (brown bullhead)

| Size or Age<br>(mm) | Season | Day or<br>Night | Upper<br>Avoidance | Final<br>Preferendum | Lower<br>Avoidance | Acclimation<br>Temperature | Acclimation<br>Time | PREFERRED TEMPERATURES:                         |  | Reference                   |
|---------------------|--------|-----------------|--------------------|----------------------|--------------------|----------------------------|---------------------|---|--|-----------------------------|
|                     |        |                 |                    |                      |                    |                            |                     | Location  |  |                             |
|                     |        |                 | 40                 |                      |                    |                            |                     | Delaware R., discharge<br>power plant           |  | Brown 1974                  |
| adult               | w      |                 |                    | 11.9                 |                    |                            |                     | Lab   |  | Coutant 1977a               |
| adult               | SP     |                 |                    | 23.5                 |                    |                            |                     | Lab   |  | Coutant 1977a               |
| adult               | su     |                 |                    | 24.9                 |                    |                            |                     | Lab   |  | Coutant 1977a               |
| adult               | F      |                 |                    | 23.6                 |                    |                            |                     | Lab   |  | Coutant 1977a               |
| adult               |        |                 |                    | 29-31                |                    |                            |                     | Lab   |  | Coutant 1977a               |
| 93-1 93             |        |                 |                    | 27.3                 |                    |                            |                     | Lab   |  | Coutant 1977a               |
|                     |        |                 |                    | 26                   |                    |                            |                     | Lab   |  | Spotila et al 1979          |
|                     | w      |                 |                    | 10.9                 |                    |                            |                     | Lab   |  | Reutter and Hendendorf 1976 |
|                     | SP     |                 |                    | 22.4                 |                    |                            |                     | Lab   |  | Reutter and Hendendorf 1976 |
|                     |        |                 |                    | 29-31                |                    |                            |                     |   |  | Jobling 1981                |
| young               |        |                 |                    | 31                   |                    |                            |                     |   |  | Wyman 1981                  |
|                     |        |                 | 40                 | 19.6                 | 5.1                |                            |                     | Connecticut R., Conn.<br>(field occurrence)     |  | Marcy 1976a                 |
| young               |        |                 |                    | 31.1                 |                    |                            | 26.1                |   |  | Brown 1974                  |
| young               |        |                 | 36.1               |                      |                    |                            | 25                  |   |  | Brown 1974                  |
| 93-193              |        |                 | 21                 | 13                   | 7                  |                            | 3.5                 | Lab   |  | Richards and Ibara 1978     |
| 93-193              |        |                 | 26                 | 15-16                | 7                  |                            | 11.0                | Lab   |  | Richards and Ibara 1978     |
| 93-193              |        |                 | 24                 | 17-18                | 9                  |                            | 15.5                | Lab   |  | Richards and Ibara 1978     |
| 93-193              |        |                 | 26                 | 25                   | 21                 |                            | 21                  | Lab   |  | Richards and Ibara 1978     |
| 93-1 93             |        |                 | 28                 | 27                   | 22                 |                            | 28                  | Lab   |  | Richards and Ibara 1978     |
| 93-193              |        |                 | 30                 |                      |                    |                            |                     | Connecticut Yankee GS,<br>Connecticut R., Conn. |  | Richards and Ibara 1978     |

SPECIES: *Ictalurus nebulosus* (brown bullhead)

| Size or Age (mm) | Optimum °C | Range | (a) MWAT |            | No Growth Upper | Limits Lower | Location   | GROWTH TEMPERATURES:    |  |
|------------------|------------|-------|----------|------------|-----------------|--------------|--|-------------------------|--|
|                  |            |       | (a) MWAT | (b) ST Max |                 |              |  | Reference               |  |
|                  | 32         |       |          |            |                 | <18          |  | Carlander 1969          |  |
|                  | 28.2/29.9  |       |          |            |                 | 4-10         | Connecticut Yankee GS, Connecticut R. Conn. (winter migration) | Spotila et al 1979      |  |
|                  |            |       | 32       | 37         |                 |              |  | Jobling 1981            |  |
|                  |            |       |          |            |                 |              |  | Richards and Ibara 1978 |  |
|                  |            |       |          |            |                 |              |  | This study              |  |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Ictalurus nebulosus* (brown bullhead)

| Event              | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit |       |           |                         | Location  | Reference               |
|--------------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------|-------|-----------|-------------------------|---|-------------------------|
|                    |                                |              |            |          |                                |                  | Upper            | Lower | Median AT | (d) Median Lethal Final |   |                         |
| spawning           |                                | 21.1         |            |          |                                |                  |                  |       |           |                         |   | Scott and Crossman 1973 |
| hatching (6-9d)    |                                |              | 20.6-25    |          |                                |                  |                  |       |           |                         |   | Brown 1974              |
| spawning migration |                                | > 4          |            |          |                                |                  |                  |       |           |                         | Connecticut Yankee GS, Connecticut River, Conn. | Richards and Ibara 1978 |
|                    |                                |              |            | 21.1     | 25                             |                  |                  |       |           |                         |   | This study              |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Ictalurus punctatus* (channel cat)

| Size or Age<br>(mm)  | Acclimation<br>Temp | Acclimation<br>Time | Season | THERMAL TOLERANCES:               |                                   |                            |            |             |       |                  |                             |                              |          | Reference              |                              |
|----------------------|---------------------|---------------------|--------|-----------------------------------|-----------------------------------|----------------------------|------------|-------------|-------|------------------|-----------------------------|------------------------------|----------|------------------------|------------------------------|
|                      |                     |                     |        | Upper<br>Incip.<br>Lethal<br>Temp | Lower<br>Incip.<br>Lethal<br>Temp | log time =<br>a + b (temp) |            | Data Limits |       | Exposure<br>Temp | Resistance<br>Time<br>(Min) | Critical<br>Thermal<br>(Max) | Location |                        |                              |
|                      |                     |                     |        |                                   |                                   | a                          | b          | Upper       | Lower |                  |                             |                              |          |                        |                              |
|                      | 15                  |                     |        | 30.3                              | 0                                 |                            |            |             |       |                  |                             |                              |          |                        | Carlander 1969               |
|                      | 20                  |                     |        | 32.8                              | 2.5                               |                            |            |             |       |                  |                             |                              |          |                        | Carlander 1969               |
|                      | 25                  |                     |        | 33.5                              | 6.0                               |                            |            |             |       |                  |                             |                              |          |                        | Carlander 1969               |
|                      |                     |                     |        | 35                                |                                   |                            |            |             |       |                  |                             |                              |          |                        | Carlander 1969               |
| 44-57d;<br>juvenile  | 26                  |                     |        | 36.6                              |                                   | 34.7                       | 119-0.8816 | 39          | 36.6  |                  |                             |                              | 33.5     | Hatchery, Ark.         | Carlander 1969<br>Brown 1974 |
| 44-57d;<br>juvenile  | 30                  |                     |        | 37.8                              |                                   | 32.1                       | 736-0.7811 | 40.6        | 37.4  |                  |                             |                              |          |                        | Brown 1974                   |
| 44-57d;<br>juvenile  | 34                  |                     |        | 38.0                              |                                   | 26.4                       | 204-0.6149 | 42          | 38    |                  |                             |                              |          |                        | Brown 1974                   |
|                      | 12                  |                     |        |                                   |                                   |                            |            |             |       |                  |                             |                              |          |                        | Spotila et al 1979           |
|                      | 16                  |                     |        |                                   |                                   |                            |            |             |       |                  |                             |                              |          |                        | Spotila et al 1979           |
|                      | 20                  |                     |        |                                   |                                   |                            |            |             |       |                  |                             |                              |          |                        | Spotila et al 1979           |
|                      | 24                  |                     |        |                                   |                                   |                            |            |             |       |                  |                             |                              |          |                        | Spotila et al 1979           |
|                      | 28                  |                     |        |                                   |                                   |                            |            |             |       |                  |                             |                              |          |                        | Spotila et al 1979           |
|                      | 32                  |                     |        |                                   |                                   |                            |            |             |       |                  |                             |                              |          |                        | Spotila et al 1979           |
|                      | 22.7                |                     | su     |                                   |                                   |                            |            |             |       |                  |                             |                              |          |                        | Spotila et al 1979           |
|                      |                     |                     |        | 36.1                              |                                   |                            |            |             |       |                  |                             |                              |          |                        | Jobling 1981                 |
|                      |                     |                     |        | 36.4                              |                                   |                            |            |             |       |                  |                             |                              |          |                        | Jobling 1981                 |
| 11.5 mo;<br>juvenile | 25                  |                     |        | 35.5                              |                                   | 34.5                       | 554-0.8854 | 37.5        | 35.5  |                  |                             |                              |          | Hatchery, Ark.         | Brown 1974                   |
| 11.5 mo;<br>juvenile | 30                  |                     |        | 37                                |                                   | 17.7                       | 125-0.4058 | 40          | 37.5  |                  |                             |                              |          | Hatchery, Ark.         | Brown 1974                   |
| 11.5 mo;<br>juvenile | 35                  |                     |        | 38                                |                                   | 28.3                       | 031-0.6554 | 41          | 38    |                  |                             |                              |          | Hatchery, Ark.         | Brown 1974                   |
| adult                | 15                  |                     |        | 30.4                              | 0                                 | 34.7                       | 829-1.0637 | 31.5        | 30.5  |                  |                             |                              |          | Put-in-Bay, Ohio + Fla | Brown 1974                   |
| adult                | 20                  |                     |        | 32.8                              | 0                                 | 39.4                       | 967-1.1234 | 34          | 33    |                  |                             |                              |          | Put-in-Bay, Ohio + Fla | Brown 1974                   |
| adult                | 25                  |                     |        | 33.5                              | 0                                 | 46.2                       | 155-1.2899 | 35          | 44    |                  |                             |                              |          | Put-in-Bay, Ohio + Fla | Brown 1974                   |
|                      | 7.2                 |                     |        | 32.8                              |                                   |                            |            |             |       | 32.8             |                             | 60                           |          |                        | Brown 1974                   |
|                      | 11.                 |                     |        | 35                                |                                   |                            |            |             |       | 35               |                             | 60                           |          |                        | Brown 1974                   |

SPECIES: *Ictalurus punctatus* (channel cat)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES:                     |                       |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|---|-----------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                                    | Reference             |
| large            |        |              | 32              |                   | 26              |                         |                  | Wabash R., Ind.                             | Coutant 1977a         |
| large            |        |              | 34              |                   |                 |                         |                  | White R., Ind.                              | Coutant 1977a         |
| adult            | SU     |              |                 | 25.2              |                 |                         |                  | Lab   | Coutant 1977a         |
| adult            | F      |              |                 | 25.3              |                 |                         |                  | Lab   | Coutant 1977a         |
|                  |        |              | 35              | 30.5              | 23              |                         |                  | Lab   | Coutant 1977a         |
|                  |        |              |                 | 23-32.5           |                 |                         |                  | in field                                    | Spotila et al 1979    |
|                  |        |              |                 | >32               |                 |                         |                  |   | Spotila et al 1979    |
|                  |        |              |                 | 18.9              |                 | 6                       |                  |   | Spotila et al 1979    |
|                  |        |              |                 | 20.4              |                 | 9                       |                  |   | Spotila et al 1979    |
|                  |        |              |                 | 19.9              |                 | 12                      |                  |   | Spotila et al 1979    |
|                  |        |              |                 | 21.7              |                 | 15                      |                  |   | Spotila et al 1979    |
|                  |        |              |                 | 22.9              |                 | 18                      |                  |   | Spotila et al 1979    |
|                  |        |              |                 | 26.1              |                 | 21                      |                  |   | Spotila et al 1979    |
|                  |        |              |                 | 29.4              |                 | 24                      |                  |   | Spotila et al 1979    |
|                  |        |              |                 | 29.5              |                 | 27                      |                  |   | Spotila et al 1979    |
|                  |        |              |                 | 30.5              |                 | 30                      |                  |   | Spotila et al 1979    |
|                  |        |              |                 | 17                |                 | 12                      |                  |   | Spotila et al 1979    |
|                  |        |              |                 | 21                |                 | 16                      |                  |   | Spotila et al 1979    |
|                  |        |              |                 | 22                |                 | 20                      |                  |   | Spotila et al 1979    |
|                  |        |              |                 | 28                |                 | 24                      |                  |   | Spotila et al 1979    |
|                  |        |              |                 | 26                |                 | 28                      |                  |   | Spotila et al 1979    |
|                  |        |              |                 | 30                |                 | 32                      |                  |   | Spotila et al 1979    |
|                  |        |              | 28.5            | 15.2              |                 | 5.1                     |                  | Connecticut R., Conn.<br>(field occurrence) | Marcy 1976a           |
| fry              |        |              |                 | 28-29             |                 |                         |                  |   | Brown 1974            |
|                  | SU     |              |                 | 32-36             |                 |                         |                  | J.M. Stuart GS, Ohio R., Ohio               | Yoder and Gammon 1976 |
|                  | F      |              |                 | 30-32             |                 |                         |                  | J.M. Stuart GS, Ohio R., Ohio               | Yoder and Gammon 1976 |
|                  | w      |              |                 | s-14              |                 |                         |                  | J.M. Stuart GS, Ohio R., Ohio               | Yoder and Gammon 1976 |



SPECIES: *Ictalurus punctatus* (channel cat)

| Size or Age (mm) | Optimum °C | Range   | (b)         |        | No Growth Upper | Limits Lower | Location | GROWTH TEMPERATURES: |                        |
|------------------|------------|---------|-------------|--------|-----------------|--------------|----------|----------------------|------------------------|
|                  |            |         | (a) M W A T | ST Max |                 |              |          | Reference            |                        |
| larvae           | 29         |         |             |        |                 |              |          |                      | Jobling 1981           |
|                  | 30         |         |             |        |                 |              |          |                      | Jobling 1981           |
| juvenile         | 28-30      |         |             |        |                 |              |          |                      | Jobling 1981           |
|                  | 29/31      | 21-34   |             |        | 36              |              |          |                      | Brown 1974             |
|                  | 28/32      | 18.3-34 |             |        | >34             | 15.6         |          |                      | Brown 1974             |
|                  |            |         | 32          | 36     |                 |              |          |                      | EPA 1974               |
|                  | 30         |         |             |        |                 |              |          |                      | Leidy and Jenkins 1977 |
|                  | 30         |         |             |        |                 | 10           |          |                      | Cravens 1981           |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth),

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Ictalurus punctatus* (channel cat)

| Event                 | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) M W A T | (b)                        |                  | (c) Lethal Upper | (c) Lethal Lower | (d) Median Lethal ΔT | (d) Median Lethal Final | Location                   | Reference               |
|-----------------------|--------------------------------|--------------|------------|-------------|----------------------------|------------------|------------------|------------------|----------------------|-------------------------|----------------------------|-------------------------|
|                       |                                |              |            |             | ST Max for Embryo Survival | Acclimation Time |                  |                  |                      |                         |                            |                         |
| spawning              |                                | 26.7         | 23.9-29.5  |             |                            |                  |                  |                  |                      |                         |                            | Scott and Crossman 1973 |
| hatching (5-10d)      |                                |              | 15.6-27.8  |             |                            |                  |                  |                  |                      |                         |                            | Scott and Crossman 1973 |
| spawning              |                                | 23.9         |            |             |                            |                  |                  |                  |                      |                         |                            | Carlander 1969          |
| hatching              |                                | 22           | 23.9-22.8  |             |                            |                  | >28.4            |                  |                      |                         |                            | Brown 1974              |
|                       |                                |              |            | 27          | 29                         |                  |                  |                  |                      |                         |                            | EPA 1974                |
| spawning hatch        |                                | 27           | 21-29      |             |                            |                  |                  |                  |                      |                         |                            | EPA 1974                |
| wintering             |                                |              | 18-29      |             |                            |                  |                  |                  |                      |                         |                            | EPA 1974                |
| cold shock            |                                |              | 5-15       |             |                            |                  |                  |                  |                      |                         |                            | Yoder and Gammon 1976   |
| heat shock            |                                |              |            |             |                            |                  |                  |                  | -6 / -10             |                         | Lab                        | Coutant et al 1976      |
|                       |                                |              |            |             |                            |                  |                  |                  | +15                  |                         | Lab; simulated entrainment | Cada et al 1981         |
| (16-26 mm) cold shock | 34                             |              |            |             |                            |                  |                  |                  | -14                  |                         | Sandusky R. to L. Erie     | Coutant 1977b           |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Noturus flavus* (stone cat)

|                  |                   |                  |         |                          |                          |                            |  |                            |  |               | THERMAL TOLERANCES:   |                        |          |                    |
|------------------|-------------------|------------------|---------|--------------------------|--------------------------|----------------------------|--|----------------------------|--|---------------|-----------------------|------------------------|----------|--------------------|
| Size or Age (mm) | Acclimation Temp. | Acclimation Time | Sea-son | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time =<br>a + b (temp) |  | Data Limits<br>Upper Lower |  | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location | Reference          |
|                  | 1.6               |                  | W       |                          |                          |                            |  |                            |  |               |                       | 29.0                   |          | Spotila et al 1979 |

SPECIES: *Noturus flavus* (stone cat)

|                  |        |              |                 |                   |                 |                         |                  |  |  |          | PREFERRED TEMPERATURES: |  |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|--|--|----------|-------------------------|--|
| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time |  |  | Location | Reference               |  |
| adult            | W      |              |                 | 5.5               |                 |                         |                  |  |  | Lab      | Coutant 1977a           |  |
| adult            | F      |              |                 | 25.1              |                 |                         |                  |  |  | Lab      | Coutant 1977a           |  |

SPECIES: *Noturus flavus* (stone cat)

|          |                                |              |            |          |                                |                  |                        |                        |                  |                         | SPAWNING AND DEVELOPMENT TEMPERATURES: |                                       |  |  |
|----------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|------------------|-------------------------|--|---------------------------------------|--|--|
| Event    | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location                               | Reference                             |  |  |
| spawning |                                | 27.8         |            |          | 27.8                           |                  |                        |                        |                  |                         |  | Scott and Crossman 1973<br>This study |  |  |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Noturus gyrinus* (tadpole madtom)

|                  |                  |                  |         |                          |                          |                             |  |                         |  |               |                       | THERMAL TOLERANCES:    |          |           |
|------------------|------------------|------------------|---------|--------------------------|--------------------------|-----------------------------|--|-------------------------|--|---------------|-----------------------|------------------------|----------|-----------|
| Size or Age (mm) | Acclimation Temp | Acclimation Time | Sea-son | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = a + b (temp) a b |  | Data Limits Upper Lower |  | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location | Reference |

|  |  |  |  |  |  |  |  |  |  |  |  |    |                        |                  |
|--|--|--|--|--|--|--|--|--|--|--|--|----|------------------------|------------------|
|  |  |  |  |  |  |  |  |  |  |  |  | 38 | Shallow Michigan pond. | Beltz et al 1974 |
|--|--|--|--|--|--|--|--|--|--|--|--|----|------------------------|------------------|

SPECIES: *Noturus miurus* (brindled madtom)

|       |                                |              |            |          |                                |                  |                        |                        |                  |                         |          | SPAWNING AND DEVELOPMENT TEMPERATURES: |  |
|-------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|------------------|-------------------------|----------|--|--|
| Event | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location | Reference                              |  |

|          |  |      |       |      |  |  |  |  |  |  |          |                                       |
|----------|--|------|-------|------|--|--|--|--|--|--|----------|---------------------------------------|
| spawning |  | 25.6 |       |      |  |  |  |  |  |  | Michigan | Scott and Crossman 1973<br>This study |
| spawning |  |      | 25-27 | 25.6 |  |  |  |  |  |  | Ohio     | McAllister et al 1985                 |

- (a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.  
 (b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.  
 (c) Not incipient lethal temperatures as defined by Fry et al (1946).  
 (d) Simulated larval entrainment temperatures.

SPECIES: *Anguilla rostrata* (american eel)

|                  |        |              |                 |                   |                 |                         |                  | PREFERRED TEMPERATURES:  |   |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|--|---|
| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | Location   | Reference                                     |
| adult            |        |              | 33-35<br>33     | 16.7<br>20.5      | 11.9            | 6-30                    |                  | Maryland<br>Connecticut Yankee GS<br>discharge, Conn. Ft., Conn. | Carlander 1969<br>Cravens 1961<br>Marcy 1976a |

SPECIES: *Anguilla rostrata* (american eel)

|                  |            |           |                 |                 |              |          | GROWTH TEMPERATURES:     |  |
|------------------|------------|-----------|-----------------|-----------------|--------------|----------|--------------------------|--|
| Size or Age (mm) | Optimum °C | (a) Range | (b) ST Max MWAT | No Growth Upper | Limits Lower | Location | Reference                |  |
|                  | 25         |           |                 |                 | 10           | Lab      | Talmage and Coutant 1978 |  |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Anguilla rostrata* (american eel)

|          |                                |              |            |          |                            |                  |                        |                        |                      |                         | SPAWNING AND DEVELOPMENT TEMPERATURES: |                                       |
|----------|--------------------------------|--------------|------------|----------|----------------------------|------------------|------------------------|------------------------|----------------------|-------------------------|--|---------------------------------------|
| Event    | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max Embryo Survival | Acclimation Time | (c) Lethal Limit UPPER | (c) Lethal Limit Lower | (d) Median Lethal AT | (d) Median Lethal Final | Location                               | Reference                             |
| spawning |                                | 17           |            | 17       | 35                         |                  |                        |                        |                      |                         | Ocean                                  | Scott and Crossman 1973<br>This study |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures,

SPECIES: Fundulus diaphanus (banded killifish)

|                     |                          |                          |             |                          |                          |            |   |             |                       |                                  | THERMAL TOLERANCES:          |          |                        |
|---------------------|--------------------------|--------------------------|-------------|--------------------------|--------------------------|------------|---|-------------|-----------------------|----------------------------------|------------------------------|----------|------------------------|
| Size or Age<br>(mm) | Accli-<br>mation<br>Temp | Accli-<br>mation<br>Time | Sea-<br>son | Upper                    | Lower                    | log time = |   | Data Limits | Expo-<br>sure<br>Temp | Resis-<br>tance<br>Time<br>(Min) | Critical<br>Thermal<br>(Max) | Location | Reference              |
|                     |                          |                          |             | Incip.<br>Lethal<br>Temp | Incip.<br>Lethal<br>Temp | a          | b |             |                       |                                  |                              |          |                        |
| adult               | 15                       |                          |             | 27.5                     |                          |            |   |             |                       |                                  |                              | Lab      | Brown 1974             |
|                     |                          |                          |             | ≥38.3                    |                          |            |   |             |                       |                                  |                              | Field    | Leidy and Jenkins 1977 |
| adult               | 25                       |                          |             | 34.5                     |                          |            |   |             |                       |                                  |                              |          | Houston 1982           |
|                     |                          |                          |             | 26.5                     |                          |            |   |             |                       |                                  |                              |          | Beltz et al 1974       |

SPECIES: Fundulus diaphanus (banded killifish)

|                     |        |                 |                    |                      |                    |                            |                     |          |           |       | PREFERRED TEMPERATURES: |  |
|---------------------|--------|-----------------|--------------------|----------------------|--------------------|----------------------------|---------------------|----------|-----------|-------|-------------------------|--|
| Size or Age<br>(mm) | Season | Day or<br>Night | Upper<br>Avoidance | Final<br>Preferendum | Lower<br>Avoidance | Acclimation<br>Temperature | Acclimation<br>Time | Location | Reference |       |                         |  |
|                     |        |                 |                    |                      |                    |                            |                     |          |           | adult |                         |  |

SPECIES: Fundulus diaphanus (banded killifish)

|                      |  |                 |               |             |  |                          |                                 |                                 |                        |                           | SPAWNING AND DEVELOPMENT TEMPERATURES: |                         |
|----------------------|--|-----------------|---------------|-------------|--|--------------------------|---------------------------------|---------------------------------|------------------------|---------------------------|--|-------------------------|
| Event                | Season<br>and/or<br>Accli-<br>mation<br>Temp | Optimum<br>Temp | Tamp<br>Range | (a)<br>MWAT | (b)<br>ST Max<br>for<br>Embryo<br>Survival | Accli-<br>mation<br>Time | (c)<br>Lethal<br>Limit<br>Upper | (c)<br>Lethal<br>Limit<br>Lower | Median<br>Lethal<br>ΔT | Median<br>Lethal<br>Final | Location                               | Reference               |
|                      |  |                 |               |             |  |                          |                                 |                                 |                        |                           |  |                         |
| hatching<br>(11-12d) |  |                 | 22-26.7       |             |  |                          |                                 |                                 |                        |                           | -Hatchery pond, Mich.                  | Scott and Crossman 1973 |
| spawning             |  |                 | 21            |             |  |                          |                                 |                                 |                        |                           |  | Carlander 1969          |
| spawning             |  |                 | 21-23         |             |  |                          |                                 |                                 |                        |                           | L. St. Louis, L. Renaud,<br>Quebec     | Talmage 1978            |
|                      |  |                 |               | 23          | 26   |                          |                                 |                                 |                        |                           |  | This study              |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: Lota lota (burbot)

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Sea-son | THERMAL TOLERANCES:      |                          |                               |       |             |               |                       | Reference |                         |
|------------------|------------------|------------------|---------|--------------------------|--------------------------|-------------------------------|-------|-------------|---------------|-----------------------|-----------|-------------------------|
|                  |                  |                  |         | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time - $\frac{a+b}{temp}$ |       | Data Limits | Exposure Temp | Resistance Time (Min) |           | -Critical Thermal (Max) |
|                  |                  |                  |         |                          |                          | Upper                         | Lower |             |               |                       |           |                         |
|                  |                  |                  |         | 23.3                     |                          |                               |       |             |               |                       |           | Scott and Crossman 1973 |

SPECIES: Lota lota (burbot)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES:          |  | Reference            |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|----------------------------------|--|----------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                         |  |                      |
| small            |        |              |                 | 21.2              |                 |                         |                  |                                  |  | Spotila et al 1979   |
|                  |        |              |                 | 21.2              |                 |                         |                  | Lab                              |  | Coutant 1977a        |
|                  |        |              |                 | 11.4              |                 |                         |                  | Moosehead L., Me.                |  | Coutant 1977a        |
| 3-7.5            | Sp/Su  |              |                 | 8-17              |                 |                         |                  | Atikokan GS Preop Study, Ontario |  | Haymes 1984          |
|                  | Sp/Su  |              |                 | 6-11              |                 |                         |                  | L. Michigan                      |  | Mansfield et al 1983 |

SPECIES: Lota lota (burbot)

| Size or Age (mm) | Optimum °C | Range | (a)  |        | (b)             |              | Location | GROWTH TEMPERATURES:    |            |
|------------------|------------|-------|------|--------|-----------------|--------------|----------|-------------------------|------------|
|                  |            |       | MWAT | ST Max | No Growth Upper | Limits Lower |          | Reference               |            |
|                  | 15.6-18.3  |       | 20   | 24     |                 |              |          | Scott and Crossman 1973 | This study |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature- optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: Lota lota (burbot)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |            |          |                                |                  |                        |                        |                  |                         |                     |                                    |
|--|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|------------------|-------------------------|---------------------|------------------------------------|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location            | Reference                          |
| spawning                               |                                | 0.6-1.7      |            |          |                                |                  |                        |                        |                  |                         | Surface water temp. | Scott and Crossman 1973            |
| incubation (70d)                       |                                | 0-1.5        |            |          |                                |                  |                        |                        |                  |                         |                     | Mansfield et al 1983               |
| hatching                               |                                | <8-10        |            | 1.2      | 1.7                            |                  |                        |                        |                  |                         |                     | Mansfield et al 1983<br>This study |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

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SPECIES: Labidesthes sicculus (brook silverside)

| PREFERRED TEMPERATURES: |        |              |                 |                   |                 |                         |                  |                |                            |
|-------------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|----------------|----------------------------|
| Size or Age (mm)        | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | Location       | Reference                  |
| larval                  | SU     |              |                 | 22-27             |                 |                         |                  | Mississippi R. | Holland and Sylvester 1983 |

SPECIES: *Culaea inconstans* [brook stickleback]

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Season | THERMAL TOLERANCES:      |                          |                         |   |             |       |               |                       |                        |          | Reference      |
|------------------|------------------|------------------|--------|--------------------------|--------------------------|-------------------------|---|-------------|-------|---------------|-----------------------|------------------------|----------|----------------|
|                  |                  |                  |        | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = a + b (temp) |   | Data Limits |       | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location |                |
|                  |                  |                  |        |                          |                          | a                       | b | Upper       | Lower |               |                       |                        |          |                |
|                  | 25-26            |                  |        | 30.6                     |                          |                         |   |             |       |               |                       |                        |          | Carlander 1969 |

SPECIES: *Culaea inconstans* (brook stickleback)

| Event           | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | SPAWNING AND DEVELOPMENT TEMPERATURES: |                        |                  |                         |          |  | Reference               |
|-----------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|--|------------------------|------------------|-------------------------|----------|--|-------------------------|
|                 |                                |              |            |          |                                |                  | (c) Lethal Limit Upper                 | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location |  |                         |
|                 |                                |              |            |          |                                |                  |  |                        |                  |                         |          |  |                         |
| spawning        |                                |              | 8-19       |          |                                |                  |  |                        |                  |                         |          |  | Scott and Crossman 1973 |
| hatching (8-9d) |                                | 18.3         |            |          |                                |                  |  |                        |                  |                         |          |  | Scott and Crossman 1973 |
| spawning        |                                |              | 4.5-21     |          |                                |                  |  |                        |                  |                         |          |  | Carlander 1969          |
| hatching        |                                |              | 15-18      |          |                                |                  |  |                        |                  |                         |          |  | Carlander 1969          |
|                 |                                |              |            | 18.3     | 21                             |                  |  |                        |                  |                         |          |  | This study              |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.



SPECIES: *Gasterosteus aculeatus* (three spine stickleback)

| THERMAL TOLERANCES: |                  |                  |         |              |              |            |     |             |       |               |                       |                        |                     |   |
|---------------------|------------------|------------------|---------|--------------|--------------|------------|-----|-------------|-------|---------------|-----------------------|------------------------|---------------------|---|
| Size or Age (mm)    | Acclimation Temp | Acclimation Time | Sea-son | Upper Incip. | Lower Incip. | log time = |     | Data Limits |       | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location            | Reference   |
|                     |                  |                  |         | Lethal Temp  | Lethal Temp  | a          | b   | Upper       | Lower |               |                       |                        |                     |   |
| 37 mm               | 19               |                  |         | 28.5         |              |            |     |             |       |               |                       |                        |                     |   |
|                     | 19               |                  |         | 25.8         |              |            |     |             |       |               |                       |                        |                     |   |
|                     | 19               |                  |         | 25.8         |              | 19.34      | 9.1 | 9.59        | 4.0   | 3.2           | 2.6                   |                        | Columbia R., Oregon | Jobling 1981<br>Houston 1982<br>Brown 1974<br>Talmage 1978<br>Carlander 1969(a) |
|                     |                  |                  |         | 26           |              |            |     |             |       |               |                       |                        |                     |   |
|                     |                  |                  |         |              | -0.7         |            |     |             |       |               |                       |                        |                     |   |

(a) fatal body temperature

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SPECIES: *Gasterosteus aculeatus* (*three* spine stickleback)

| PREFERRED TEMPERATURES: |        |              |                 |                   |                 |                         |                  |          |                          |  |  |  |
|-------------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|----------|--------------------------|--|--|--|
| Size or Age (mm)        | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | Location | Reference                |  |  |  |
| adult                   |        |              |                 | 7.5-10            |                 |                         |                  |          | Jobling 1981             |  |  |  |
|                         |        |              |                 | 16-18             |                 |                         |                  |          | Jobling 1981             |  |  |  |
|                         |        |              |                 | 12-16             |                 |                         |                  |          | Wyman 1981               |  |  |  |
|                         |        |              |                 | 4-8               |                 | 11                      |                  |          | Cravens 1981             |  |  |  |
|                         |        |              |                 | 10                |                 | 20                      |                  |          | Talmage and Coutant 1980 |  |  |  |
|                         |        |              |                 |                   | 4.0             |                         |                  |          | Talmage 1978             |  |  |  |
|                         |        |              |                 | 16                |                 |                         |                  |          | Talmage and Coutant 1978 |  |  |  |

SPECIES: *Gasterosteus aculeatus* (three spine stickleback)

| Size or Age<br>(mm) | Optimum<br>°C | Range     | (b)         |           | No Growth Limits |       | Location | GROWTH TEMPERATURES: |  |
|---------------------|---------------|-----------|-------------|-----------|------------------|-------|----------|----------------------|--|
|                     |               |           | (a)<br>MWAT | ST<br>Max | Upper            | Lower |          | Reference            |  |
|                     |               | 12.8-19.3 |             |           |                  |       |          | Jobling 1981         |  |
| >19                 |               | 3-19      |             |           |                  |       |          | Jobling 1981         |  |
|                     |               |           | 22.4        | 28.5      |                  |       |          | Cravens et al 1983   |  |
|                     |               |           |             |           |                  |       |          | This study           |  |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Gasterosteus aculeatus* (three spine stickleback)

| Event | Season<br>and/or<br>Accli-<br>mation<br>Temp | Optimum<br>Temp | Temp<br>Range | (a)<br>MWAT | (b)<br>ST Max<br>for<br>Embryo<br>Survival | Accli-<br>mation<br>Time | (c)<br>Lethal<br>Limit<br>Upper | (c)<br>Lethal<br>Limit<br>Lower | Median<br>Lethal<br>$\Delta T$ | (d)<br>Median<br>Lethal<br>Final | Location | Reference  |
|-------|--|-----------------|---------------|-------------|--|--------------------------|---------------------------------|---------------------------------|--------------------------------|----------------------------------|----------|------------|
|       |  |                 |               |             |  |                          |                                 |                                 |                                |                                  |          |            |
|       |  |                 |               |             |  |                          |                                 |                                 |                                |                                  |          | This study |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Pungitius pungitius* (nine spine stickleback)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES:    |                   |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|----------------------------|-------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                   | Reference         |
|                  | SU     |              |                 | 17-24             |                 |                         |                  | Atikokan GS, Ontario       | Haymes 1974       |
|                  | F      | N            |                 | 5-6               |                 |                         |                  | L. Michigan (bottom trawl) | Brandt et al 1980 |
|                  | F      | D            |                 | 13-14             |                 |                         |                  | L. Michigan (bottom trawl) | Brandt et al 1980 |

SPECIES: *Pungitius pungitius* (nine spine stickleback)

| Event | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | SPAWNING AND DEVELOPMENT TEMPERATURES: |                        |                  |                         | Location | Reference                    |
|-------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|--|------------------------|------------------|-------------------------|----------|------------------------------|
|       |                                |              |            |          |                                |                  | (c) Lethal Limit Upper                 | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final |          |                              |
| eggs  |                                | 19-24        | 16-26      | 21       | 26                             |                  |  |                        |                  |                         |          | Carlander 1969<br>This study |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24111 maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: Percopsis omiscomaycus (trout perch)

| Size or Age (mm) | Acclimation Temp. | Acclimation Time | Sea-son | THERMAL TOLERANCES:      |                          |                         |       |             |  |               |                       | Reference |                             |
|------------------|-------------------|------------------|---------|--------------------------|--------------------------|-------------------------|-------|-------------|--|---------------|-----------------------|-----------|-----------------------------|
|                  |                   |                  |         | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = a + b (temp) |       | Data Limits |  | Exposure Temp | Resistance Time (Min) |           | Critical Thermal (Max)      |
|                  |                   |                  |         |                          |                          | Upper                   | Lower |             |  |               |                       |           |                             |
| adult            | 1.7               |                  | W       |                          |                          |                         |       |             |  |               | 22.9                  | Lab       | Reutter and Herdendorf 1976 |

SPECIES: Percopsis omiscomaycus (trout perch)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES: |  | Reference          |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------|--|--------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                |  |                    |
| adult            |        |              | 16              |                   | 10              |                         |                  | L. Michigan             |  | Coutant 1977a      |
| adult            |        |              |                 | 16-18             |                 |                         |                  | L. Michigan             |  | Brandt et al 1980  |
| adult            |        | D            |                 | 15-16             |                 |                         |                  | L. Michigan             |  | Brandt et al 1980  |
| adult            |        | N            |                 | 7-16              |                 |                         |                  | L. Michigan             |  | Brandt et al 1980  |
| adult            | F      | D            |                 | 15-16             |                 |                         |                  | L. Michigan             |  | Crowder et al 1981 |
| adult            | F      | N            |                 | 7-8               |                 |                         |                  | L. Michigan             |  | Crowder et al 1981 |

SPECIES: Percopsis omiscomaycus (trout perch)

| Size or Age (mm) | Optimum °C | Range | (a)  |        | (b)             |              | Location | GROWTH TEMPERATURES: |  | Reference      |
|------------------|------------|-------|------|--------|-----------------|--------------|----------|----------------------|--|----------------|
|                  |            |       | MWAT | ST Max | No Growth Upper | Limits Lower |          |                      |  |                |
|                  |            |       |      |        | 15.5            |              | L. Erie  |                      |  | Carlander 1969 |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: Percopsis omiscomaycus (trout perch)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |            |          |                                |                  |                        |                        |           |                         |                        |                |
|--|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|-----------|-------------------------|------------------------|----------------|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median AT | (d) Median Lethal Final | Location               | Reference      |
| spawning                               |                                | 15           |            |          |                                |                  |                        |                        |           |                         | Twelvepole Ck., W. Va. | Talmage 1978   |
| spawning                               |                                |              | 16-20      |          |                                |                  |                        |                        |           |                         | L. Winnebago, Wis.     | Carlander 1969 |
| spawning                               |                                |              | 6-11       |          |                                |                  |                        |                        |           |                         | Heming L., Man.        | Carlander 1969 |
| spawning                               |                                | 20           | 19-21.4    |          |                                |                  |                        |                        |           |                         | L. Erie                | Carlander 1969 |
|  |                                |              |            | 20       | 21.4                           |                  |                        |                        |           |                         |                        | This study     |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946)

(d) Simulated larval entrainment temperatures.

SPECIES: *Morone americana* (white perch)

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Sea-son | THERMAL TOLERANCES:      |                          |                         |       |             |               |                       | Location  | Reference |                          |
|------------------|------------------|------------------|---------|--------------------------|--------------------------|-------------------------|-------|-------------|---------------|-----------------------|-----------|-----------|--------------------------|
|                  |                  |                  |         | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = a + b (temp) |       | Data Limits | Exposure Temp | Resistance Time (Min) |           |           | Critical Thermal (Max)   |
|                  |                  |                  |         |                          |                          | Upper                   | Lower | Upper       | Lower         |                       |           |           |                          |
| larvae           |                  |                  |         | 32.4-34                  |                          |                         |       |             |               | 24-336h               | 35.6-36.4 |           | Ellis 1964               |
|                  | 8                |                  |         | 33-36                    | 8                        |                         |       |             |               | 10                    |           |           | Talmage and Coutant 1979 |
|                  | 26               |                  |         | 35                       |                          |                         |       |             |               |                       |           |           | Talmage 1978             |
| larvae           | 15               |                  |         | 35.6                     |                          |                         |       |             |               | 10                    |           | Lab       | Talmage 1978             |
|                  |                  |                  |         | 31.4                     |                          |                         |       |             |               | 30                    |           | Lab       | Jinks et al 1981         |
|                  |                  |                  |         | 30.3                     |                          |                         |       |             |               | 1440                  |           | Lab       | Jinks et al 1981         |
|                  |                  | 21-22            |         | 38.4                     |                          |                         |       |             |               | 10                    |           | Lab       | Jinks et al 1981         |
|                  |                  |                  |         | 35.2                     |                          |                         |       |             |               | 30                    |           | Lab       | Jinks et al 1981         |
|                  |                  |                  |         | 34.8                     |                          |                         |       |             |               | 60                    |           | Lab       | Jinks et al 1981         |
|                  |                  |                  |         | 31.0                     |                          |                         |       |             |               | 1440                  |           | Lab       | Jinks et al 1981         |
|                  | 24               |                  |         | 38                       |                          |                         |       |             |               | 10                    |           | Lab       | Jinks et al 1981         |
|                  |                  |                  |         | 36.1                     |                          |                         |       |             |               | 30                    |           | Lab       | Jinks et al 1981         |
|                  |                  |                  |         | 35.4                     |                          |                         |       |             |               | 60                    |           | Lab       | Jinks et al 1981         |
| 34-41            | 26-27            |                  |         | 36.8                     |                          |                         |       |             |               | 5                     |           | Lab       | Jinks et al 1981         |
|                  |                  |                  |         | 36.8                     |                          |                         |       |             |               | 10                    |           | Lab       | Jinks et al 1981         |
|                  |                  |                  |         | 37.2                     |                          |                         |       |             |               | 30                    |           | Lab       | Jinks et al 1981         |
| 31-35            | 25-26            |                  |         | 35.4                     |                          |                         |       |             |               | 60                    |           | Lab       | Jinks et al 1981         |
|                  |                  |                  |         | 34.6                     |                          |                         |       |             |               | 1440                  |           | Lab       | Jinks et al 1981         |
|                  |                  |                  |         | 34.5                     |                          |                         |       |             |               | 5760                  |           | Lab       | Jinks et al 1981         |
| larvae           | 18-24            |                  |         | 38.5                     |                          |                         |       |             |               |                       |           | Lab       | Jinks et al 1981         |
| juvenile         | 27               |                  |         | 36                       |                          |                         |       |             |               |                       |           | Lab       | Jinks et al 1981         |
| larvae           |                  |                  |         | 34.8                     |                          |                         |       |             |               |                       |           | Lab       | Kellogg and Gift 1983    |

SPECIES: *Morone americana* (white perch)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES: |              | Reference                |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------|--------------|--------------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                |              |                          |
| Small            |        |              | 35              | 32                |                 |                         |                  | Lab                     |              | Coutant 1977a            |
|                  |        |              | 40              | 27.5              | 5.7             |                         |                  | Connecticut             | Yankee plant | Marcy 1976a              |
|                  |        |              |                 | > 24              |                 |                         |                  |                         |              | Scott and Crossman 1973  |
| 51-65            |        |              |                 | 28.9-30.6         |                 | 6-33                    |                  | Lab                     |              | Talmage and Coutant 1980 |
|                  |        |              |                 | 31.6-32.5         |                 | 6-33                    |                  | Lab                     | N.C.         | Talmage and Coutant 1979 |
|                  |        |              |                 | 29.3-30.6         |                 | 6-33                    |                  | Lab                     | Maryland     | Talmage and Coutant 1979 |
|                  |        |              |                 | 29.2-29.6         |                 | 6-33                    |                  | Lab                     | N.J.         | Talmage and Coutant 1979 |
| larvae           |        |              | 32              |                   |                 |                         |                  |                         |              | Talmage and Coutant 1979 |
|                  | su     |              | 31-34           | 29-32             |                 | 26                      |                  |                         |              |                          |
|                  | W      |              | 24-25           | 13-19             | 9-10            | 3-4                     |                  | Lab                     |              | Talmage 1978             |
| 32-39 TL         |        |              |                 | 30                |                 |                         |                  | L a b                   |              | Kellogg and Gift 1983    |
| 35.1 TL          |        |              |                 | 30.6              |                 | 26                      |                  | Lab                     |              | Kellogg and Gift 1983    |
| 29.5 TL          |        |              |                 | 29.3              |                 | 26                      |                  | Lab                     |              | Kellogg and Gift 1983    |
| 3.88; larvae     | sp/su  |              |                 | 21-27             |                 |                         |                  | Connecticut             | R.           | Marcy 1976b              |

SPECIES: *Morone americana* (white perch)

| Size or Age (mm) | Optimum °C | Range     | (a)  |        | (b)             |              | Location            | GROWTH TEMPERATURES:  |            |
|------------------|------------|-----------|------|--------|-----------------|--------------|---------------------|-----------------------|------------|
|                  |            |           | MWAT | ST Max | No Growth Upper | Limits Lower |                     | Reference             |            |
| 27.5             | 28.5       | 26.3-31.7 | 30.6 | 33     | 34              |              | Lab, Hudson R. N.Y. | Kellogg and Gift 1983 | This study |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Morone americana* (white perch)

| Event          | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower |               |               | (d) Median Lethal Final | Location              | Reference                     |
|----------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|---------------|---------------|-------------------------|-----------------------|-------------------------------|
|                |                                |              |            |          |                                |                  |                        | Lethal Limit           | Median Lethal | Median Lethal |                         |                       |                               |
| spawning hatch |                                |              | 11-15      |          |                                |                  |                        |                        |               |               |                         | Bay of Quinte, L. Ont | Scott and Crossman 1973       |
| hatch          | 8-26                           | 14.1/17.6    | 15-20      |          |                                |                  |                        |                        |               |               |                         |                       | Scott and Crossman 1973       |
| eggs           | 18                             |              |            |          | 18                             |                  | 24                     |                        | 6             |               |                         |                       | Cravens et al 1983            |
| cold shock     | 20                             |              |            |          |                                |                  |                        | 2                      | -18           |               |                         |                       | Wyman 1981                    |
| spawning hatch |                                | 15.6-19.4    | 12-22.2    | 17       | 25                             |                  |                        |                        |               |               |                         | Lab                   | Talmage 1978                  |
| embryo         |                                | 14.1         | 10-24      |          |                                |                  |                        |                        |               |               |                         | Lab                   | Morgan II and Rasin, Jr. 1982 |
| spawning       |                                | 17.6         | 10-24      |          |                                |                  |                        |                        |               |               |                         | Lab                   | Morgan II and Rasin, Jr. 1982 |
| eggs           |                                | 19.0-20.9    | 8.9-27     |          |                                |                  |                        |                        |               |               |                         | Connecticut R.        | Marcy 1976b                   |
| heat shock     |                                |              |            |          |                                |                  | 28                     |                        |               |               |                         | Connecticut R.        | Marcy 1976b                   |
| heat shock     | 27                             |              |            |          |                                |                  |                        |                        | t 8.5         |               |                         | Lab                   | Marcy 1976b                   |
|                |                                |              |            |          |                                |                  |                        |                        |               |               |                         |                       | Beltz et al 1974              |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: Morone chrysops (white bass)

THERMAL TOLERANCES:

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Season | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time =<br>a + b (temp)<br>a b | Data Limits<br>Upper Lower | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location       | Reference                 |
|------------------|------------------|------------------|--------|--------------------------|--------------------------|-----------------------------------|----------------------------|---------------|-----------------------|------------------------|----------------|---------------------------|
| larvae           | 14-26            |                  |        | 30-32                    |                          |                                   |                            |               | 24h                   |                        |                | Ellis 1984                |
| YOY              |                  |                  |        | 33.5                     |                          |                                   |                            |               | 48h                   |                        |                | Ellis 1984                |
| larvae           | 21.7             |                  |        |                          |                          |                                   |                            |               |                       | 35.3                   | Lab            | Reutter & Herdendorf 1976 |
|                  | 14               |                  |        | 31.7                     | 12.8                     |                                   |                            |               |                       |                        | Lab            | McCormick 1978            |
|                  | 18               |                  |        | 30.8                     |                          |                                   |                            |               |                       |                        |                | McCormick 1978            |
|                  | 20               |                  |        | 32.0                     |                          |                                   |                            |               |                       |                        |                | McCormick 1978            |
|                  | 26               |                  |        | 30.6                     |                          |                                   |                            |               |                       |                        |                | McCormick 1978            |
| YOY              | 14-26            |                  |        | 31.3                     |                          |                                   |                            |               |                       |                        | Mississippi R. | McCormick 1978            |
|                  | 30-35            |                  |        | 36.1                     |                          |                                   |                            |               |                       |                        |                | Talmage 1978              |
|                  |                  |                  | su     | 33.5                     |                          |                                   |                            |               |                       |                        |                | Houston 1982              |
|                  |                  |                  |        | 33.5                     |                          |                                   |                            |               |                       |                        |                | Spotila et al 1979        |

SPECIES: Morone chrysops (white bass)

PREFERRED TEMPERATURES:

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | Location                            | Reference                   |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------------------|-----------------------------|
| large            |        |              | 29              |                   |                 |                         |                  | Wabash R., Ind.                     | Coutant 1977a               |
| YOY              | W      |              |                 | 10-13             |                 |                         |                  | Lab                                 | Coutant 1977a               |
| YOY              | SP     |              |                 | 16-18             |                 |                         |                  | Lab                                 | Coutant 1977a               |
| YOY              | su     |              |                 | 31.0              |                 |                         |                  | Lab                                 | Coutant 1977a               |
| YOY              | F      |              |                 | 28.0              |                 |                         |                  | Lab                                 | Coutant 1977a               |
| YOY              | su     |              |                 | 27.8              |                 |                         |                  | Lab                                 | Coutant 1977a               |
| adult            | W      |              |                 | 12-17             |                 |                         |                  | Lab                                 | Coutant 1977a               |
| adult            | SP     |              |                 | 12-17             |                 |                         |                  | Lab                                 | Coutant 1977a               |
| adult            | su     |              |                 | 28-30             |                 |                         |                  | Lab                                 | Coutant 1977a               |
| adult            | F      |              |                 | 16-17             |                 |                         |                  | Lab                                 | Coutant 1977a               |
|                  |        |              | >29.8           |                   |                 |                         |                  | Pickering GS L. Ont                 | Ellis 1984                  |
|                  |        |              | >34             |                   |                 |                         |                  | Colbert plant, Alabama              | Ellis 1984                  |
|                  |        |              |                 | 29                |                 |                         |                  | J.M. Stuart GS, Ohio R.             | Brown 1974                  |
|                  |        |              |                 | 33.9-34.4         |                 |                         |                  | Power plant discharge, Tennessee R. | Brown 1974                  |
| adult            | SU     |              |                 | 30-34             |                 |                         |                  | L. Erie                             | Brown 1984                  |
|                  |        |              | 35              |                   |                 |                         |                  |                                     | Ellis 1984                  |
|                  | su     |              |                 | 27.8              |                 |                         |                  | Lab                                 | Reutter and Herdendorf 1976 |
| young            | su     |              |                 | 30-32             |                 |                         |                  |                                     | Wyman 1981                  |
|                  | SU     |              |                 | 26-29             |                 |                         |                  | Power plant, Ohio R., Ohio          | Yoder and Gammon 1976       |
|                  | F      |              |                 | 16-28             |                 |                         |                  |                                     | Yoder and Gammon 1976       |
|                  | Wi     |              |                 | 12-16             |                 |                         |                  |                                     | Yoder and Gammon 1976       |
|                  |        |              | 29-34.4         |                   |                 |                         |                  | Ohio R., Ind.                       | Spotila et al 1979          |



SPECIES: *Morone chrysops* (white bass)

| Size or Age (mm) | Optimum °C | Range | (a)  |       | (b) |     | No Growth Limits Upper | Lower | Location        | GROWTH TEMPERATURES: |  |
|------------------|------------|-------|------|-------|-----|-----|------------------------|-------|-----------------|----------------------|--|
|                  |            |       | M    | W A T | ST  | Max |                        |       |                 | Reference            |  |
| Juvenile larvae  | 23-24      |       |      |       |     |     |                        |       | Reservoir, S.D. | EPA 1974             |  |
| juvenile         | 16         |       |      |       |     | 19  |                        | 15.6  |                 | Brown 1974           |  |
|                  |            |       | 26.7 |       | 34  |     |                        |       |                 | Brown 1974           |  |
|                  |            |       |      |       |     |     |                        |       |                 | This study           |  |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 113 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Morone chrysops* (white bass)

| Event                     | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location                      | Reference               |
|---------------------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|------------------|-------------------------|-------------------------------|-------------------------|
|                           |                                |              |            |          |                                |                  |                        |                        |                  |                         |                               |                         |
| Spawning incubation/hatch |                                |              | 12-24      | 19       | 24                             |                  |                        |                        |                  |                         |                               | EPA 1974                |
| hatch                     |                                | 16-17        |            |          |                                |                  |                        |                        |                  |                         | L. Erie                       | EPA 1974                |
| spawning cold shock       | w 27                           | 23.9         | 14.4-21.1  |          |                                |                  |                        | 9                      | - 18             |                         | L. Erie                       | Brown 1974              |
| eggs                      | 19                             |              |            |          | 26                             |                  | 30.2                   | 10                     |                  |                         | Little-Three Mile Ck. Ohio A. | Scott and Crossman 1973 |
| spawning                  |                                | 14.7-16.3    |            |          |                                |                  |                        |                        |                  |                         | Lab                           | Coutant 1977b           |
| spawning                  |                                |              | 13-26      |          |                                |                  |                        |                        |                  |                         | Lewis & Clark L. (S.D.)       | McCormick 1978          |
|                           |                                |              |            |          |                                |                  |                        |                        |                  |                         | L. Mendota. Wis.              | McCormick 1978          |
|                           |                                |              |            |          |                                |                  |                        |                        |                  |                         |                               | Talmage & Coutant 1978  |
|                           |                                |              |            |          |                                |                  |                        |                        |                  |                         |                               | Horrall 1981            |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Ambloplites rupestris* (rock bass)

|                  |                  |                  |         |                          |                          |                         |  |                         |  |               | THERMAL TOLERANCES:   |                        |          |           |
|------------------|------------------|------------------|---------|--------------------------|--------------------------|-------------------------|--|-------------------------|--|---------------|-----------------------|------------------------|----------|-----------|
| Size or Age (mm) | Acclimation Temp | Acclimation Time | Sea-son | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = a + b (temp) |  | Data Limits Upper Lower |  | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location | Reference |
| 50-l 00          |                  |                  |         |                          |                          |                         |  |                         |  |               |                       |                        |          |           |
| <1 yr            | 18-36            |                  | Su      | 36                       |                          |                         |  |                         |  |               |                       |                        |          |           |
|                  | 23.9             |                  |         | 37.5                     |                          |                         |  |                         |  |               |                       |                        |          |           |
| adult            | 23.5             |                  | su      |                          |                          |                         |  |                         |  |               |                       |                        |          |           |
|                  | 30               |                  |         | 35                       |                          |                         |  |                         |  |               |                       |                        |          |           |

SPECIES: *Ambloplites rupestris* (rock bass)

|                  |        |              |                 |                   |                 |                         |                  |  |  |                    | PREFERRED TEMPERATURES:   |  |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|--|--|--------------------|---------------------------|--|
| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time |  |  | Location           | Reference                 |  |
|                  |        |              |                 | 21.3              |                 |                         |                  |  |  | Wisconsin lakes    | Coutant 1377a             |  |
|                  |        |              |                 | 20.7              |                 |                         |                  |  |  | S. Ontario Streams | Coutant 1377a             |  |
|                  |        | D            |                 | 27-27.8           |                 |                         |                  |  |  | L. Monona, Wisc.   | Coutant 1377a             |  |
|                  |        | N            |                 | 26.8-28.3         |                 |                         |                  |  |  | L. Monona, Wisc.   | Coutant 1377a             |  |
| small            |        | D            | 29.0            | 26.2              | 25.5            |                         |                  |  |  | Lab                | Coutant 1377a             |  |
| small            |        | N            | 29.5            | 28.8              | 26.0            |                         |                  |  |  | Lab                | Coutant 1377a             |  |
| adult            | w      |              |                 | 21.6              |                 |                         |                  |  |  | Lab                | Coutant 1377a             |  |
| adult            | SP     |              |                 | 20.5              |                 |                         |                  |  |  | Lab                | Coutant 1377a             |  |
| adult            | F      |              |                 | 22.8              |                 |                         |                  |  |  | Lab                | Coutant 1977a             |  |
| 50-100 FL        |        |              |                 |                   |                 |                         |                  |  |  |                    |                           |  |
| ≤1 yr            | su     |              |                 | 30.6              |                 |                         |                  |  |  | Lab                | Cherry et al 1977         |  |
| 50-100 FL        | su     |              | 27              |                   | 15              | 18                      |                  |  |  | Lab                | Cherry et al 1977         |  |
| 50-100 FL        | su     |              | 30              |                   | 18              | 21                      |                  |  |  | Lab                | Cherry et al 1377         |  |
| 50-100 FL        | su     |              | 33              |                   | 21              | 24                      |                  |  |  | Lab                | Cherry et al 1377         |  |
| 50-100 FL        | SU     |              | 33              |                   | 24              | 27                      |                  |  |  | Lab                | Cherry et al 1377         |  |
| 50-100 FL        | su     |              | 33              |                   | 24              | 33                      |                  |  |  | Lab                | Cherry et al 1377         |  |
| 50-100 FL        | su     |              | 35              |                   | 27              | 33                      |                  |  |  | Lab                | Cherry et al 1377         |  |
| 48-59 TL         |        |              |                 |                   |                 |                         |                  |  |  |                    |                           |  |
| juvenile         |        |              |                 | 27.3              |                 |                         |                  |  |  | Lab                | Brown 1974                |  |
| 98-182 TL        |        |              |                 |                   |                 |                         |                  |  |  |                    |                           |  |
| adult            |        |              |                 | 27.5              |                 |                         |                  |  |  | L. Monona, Wisc.   | Brown 1974                |  |
|                  |        |              |                 | 27.4              |                 |                         |                  |  |  | Wabash R.          | Brown 1374                |  |
|                  |        |              |                 | 30                |                 |                         |                  |  |  |                    | Talmage and Coutant 1373  |  |
| adult            | SP     |              |                 | 19.6              |                 |                         |                  |  |  | Lab                | Reutter & Herdendorf 1976 |  |
|                  | SU     |              |                 | 20.2              |                 |                         |                  |  |  |                    | Reutter & Herdendorf 1376 |  |
|                  |        | N            | 30.5            |                   | 27              |                         |                  |  |  |                    | Carlander 1377            |  |
|                  | su     |              |                 | 18.7              |                 |                         |                  |  |  |                    | Spotila et al 1379        |  |

SPECIES: *Ambloplites rupestris* (rock bass)

| Size or Age (mm) | Optimum °C | Range | (a)  |        | No Growth Upper | Limits Lower | Location       | GROWTH TEMPERATURES:   |  |
|------------------|------------|-------|------|--------|-----------------|--------------|----------------|--|--|
|                  |            |       | MWAT | ST Max |                 |              |                | Reference  |  |
|                  | 27.7<br>29 |       | 31.8 | 35     |                 | 8.5          | Ontario stream | Carlander 1977<br>Jobling 1981<br>Jobling 1981<br>This study |  |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth)

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

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SPECIES: *Ambloplites rupestris* (rock bass)

| Event    | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a)  |    | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | (d) Median Lethal AT | (d) Median Lethal Final | Location      | Reference   |
|----------|--------------------------------|--------------|------------|------|----|--------------------------------|------------------|------------------------|------------------------|----------------------|-------------------------|---------------|---|
|          |                                |              |            | MWAT |    |                                |                  |                        |                        |                      |                         |               |   |
| spawning |                                | 20.5-21      |            |      |    |                                |                  |                        |                        |                      |                         | Lab           | Brown 1974  |
| survival |                                |              |            |      |    |                                |                  | 38                     |                        |                      |                         | Michigan pond | Brown 1974  |
| spawning |                                | 15.6-21.1    | 20.5-26    | 21   | 26 |                                |                  |                        |                        |                      |                         |               | Scott and Crossman 1973<br>Carlander 1977<br>This study |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: Lepomis cyanellus (green sunfish)

|                  |                  |                  |         |                          |                          |                         |  |                   |       |               | THERMAL TOLERANCES:   |                        |                            |  |
|------------------|------------------|------------------|---------|--------------------------|--------------------------|-------------------------|--|-------------------|-------|---------------|-----------------------|------------------------|----------------------------|--|
| Size or Age (mm) | Acclimation Temp | Acclimation Time | Sea-son | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = a + b (temp) |  | Data Limits Upper | Lower | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location                   | Reference  |
|                  |                  |                  |         |                          |                          |                         |  |                   |       |               |                       |                        | White R., Ind. Field study | Brown 1974<br>Brown 1974<br>Carlander 1977<br>Leidy and Jenkins 1977 |

SPECIES: Lepomis cyanellus (green sunfish)

|                  |        |              |                 |                   |                 |                         |                  |  |  |          | PREFERRED TEMPERATURES: |  |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|--|--|----------|-------------------------|--|
| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time |  |  | Location | Reference               |  |
|                  |        |              | >36.1           | 15.9              |                 | 6                       |                  |  |  |          | Brown 1974              |  |
|                  |        |              |                 | 22.7              |                 | 15                      |                  |  |  |          | Carlander 1977          |  |
|                  |        |              |                 | 30.6              |                 | 30                      |                  |  |  |          | Carlander 1977          |  |
|                  |        |              |                 | 26.8              |                 |                         |                  |  |  |          | Beltz et al 1974        |  |
| <74;             |        |              | 30              | 27.3              | 24              |                         |                  |  |  | Lab      | Coutant 1977a           |  |
| adult            |        |              | 33              | 30.6              | 23              |                         |                  |  |  | Lab      | Coutant 1977a           |  |
| small            |        |              | 30.3            | 28.2              | 26.5            |                         |                  |  |  | Lab      | Coutant 1977a           |  |

SPECIES: *Lepomis cyanellus* (green sunfish)

| Size or Age (mm) | Optimum °C | Range   | (b)      |        |                 |              | Location | GROWTH TEMPERATURES:                          |  |
|------------------|------------|---------|----------|--------|-----------------|--------------|----------|---|--|
|                  |            |         | (a) MWAT | ST Max | No Growth Upper | Limits Lower |          | Reference                                     |  |
|                  | 28         | 13.2-28 |          |        | >34             | 20           |          | Carlander 1977<br>Beitinger and Magnuson 1979 |  |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Lepomis cyanellus* (green sunfish)

| Event               | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower |                         |  |  | Location | Reference                    |
|---------------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|-------------------------|--|--|----------|------------------------------|
|                     |                                |              |            |          |                                |                  |                        | Median Lethal AT       | (d) Median Lethal Final |  |  |          |                              |
| spawning            |                                |              | 15.6-28    |          |                                |                  |                        |                        |                         |  |  |          |                              |
| spawning            | 16.7                           |              |            |          |                                |                  | 21.1                   |                        |                         |  |  |          | Brown 1974<br>Brown 1974     |
| heat shock spawning | F/W/SU                         |              | 20-24      |          |                                |                  |                        |                        | >11.1                   |  |  |          | Brown 1974<br>Carlander 1977 |
| hatching            |                                | 29.1         |            | 21.8     | 28                             |                  |                        |                        |                         |  |  |          | Carlander 1977<br>This study |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larvalentrainment temperatures.

SPECIES: *Lepomis gibbosus* (pumpkinseed)

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Season | THERMAL TOLERANCES:      |                          | log time =<br>a + b (temp)<br>a b | Data Limits<br>Upper Lower | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location     | Reference                   |
|------------------|------------------|------------------|--------|--------------------------|--------------------------|-----------------------------------|----------------------------|---------------|-----------------------|------------------------|--------------|-----------------------------|
|                  |                  |                  |        | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp |                                   |                            |               |                       |                        |              |                             |
| 17-18            |                  |                  | su     | <38                      |                          |                                   |                            |               |                       |                        | Pond (Mich.) | Brown 1974                  |
|                  | 18               |                  |        | 28                       |                          |                                   |                            |               |                       |                        |              | Brown 1974                  |
|                  | 24               |                  |        | 30.2                     |                          |                                   |                            |               |                       |                        |              | Brown 1974                  |
|                  | 21.1             |                  |        | 38.9                     |                          |                                   |                            |               |                       |                        |              | Brown 1974                  |
| adult            | 23.1             |                  | su     |                          |                          |                                   |                            |               |                       | 37.5                   | Lab          | Reutter and Herdendorf 1976 |
|                  |                  |                  |        |                          |                          |                                   |                            |               |                       | >35.6                  | Lab          | Carlander 1977              |
|                  | 25.26            |                  |        | 34.5                     |                          |                                   |                            |               |                       |                        | Lab          | Carlander 1977              |
|                  | 25               |                  |        | 24.5                     |                          |                                   |                            |               |                       |                        |              | Leidy and Jenkins 1977      |
|                  |                  |                  |        | 36.6                     |                          |                                   |                            |               |                       |                        |              | Jobling 1981                |
|                  |                  |                  |        | 34.8                     |                          |                                   |                            |               |                       |                        |              | Jobling 1981                |
|                  | 30               |                  |        |                          | 8.5                      |                                   |                            |               |                       |                        |              | Schneider and et al 1975    |
|                  | 25               |                  |        |                          | 5                        |                                   |                            |               |                       |                        |              | Schneider and et al 1975    |
| 90-140           | 10               |                  |        |                          |                          |                                   |                            |               |                       | 30.1                   | Lab          | Becker and Genoway 1979     |
|                  | 20               |                  |        |                          |                          |                                   |                            |               |                       | 35.1                   | Lab          | Becker and Genoway 1979     |
| adult            | 12               |                  | su     | 27.7-28.3                | 3.6                      |                                   |                            |               |                       |                        | Lab          | Evans 1977                  |
| adult            | 20               |                  | su     | 32.3-32.9                | 6.4                      |                                   |                            |               |                       |                        | Lab          | Evans 1977                  |
| adult            | 28               |                  | su     | 35.2-35.3                | 11.3                     |                                   |                            |               |                       |                        | Lab          | Evans 1977                  |
| adult            | 34               |                  | su     |                          | 16.1                     |                                   |                            |               |                       |                        | Lab          | Evans 1977                  |
| adult            | 5                |                  | Wi     |                          | 1.1                      |                                   |                            |               |                       |                        | Lab          | Evans 1977                  |
| adult            | 10               |                  | Wi     |                          | 1.2                      |                                   |                            |               |                       |                        | Lab          | Evans 1977                  |
| adult            | 12               |                  | Wi     | 28.5                     |                          |                                   |                            |               |                       |                        | Lab          | Evans 1977                  |
| adult            | 20               |                  | Wi     | 31.6                     | 6.4                      |                                   |                            |               |                       |                        | Lab          | Evans 1977                  |
| adult            | 28               |                  | Wi     | 31.9                     |                          |                                   |                            |               |                       |                        | Lab          | Evans 1977                  |
| adult            | 30               |                  | Wi     |                          | 13.4                     |                                   |                            |               |                       |                        | Lab          | Evans 1977                  |
| adult            | 32               |                  | Wi     | 33.5                     |                          |                                   |                            |               |                       |                        | Lab          | Evans 1977                  |
| adult            | 20               |                  | F      | 31.7                     | 5.9                      |                                   |                            |               |                       |                        | Lab          | Evans 1977                  |
| adult            | 34               |                  | F      | 37.0                     |                          |                                   |                            |               |                       |                        | Lab          | Evans 1977                  |
| YOY              | 20               |                  | su     |                          | 5.9                      |                                   |                            |               |                       |                        | Lab          | Evans 1977                  |
| YOY              | 12               |                  | su     |                          | 2.1                      |                                   |                            |               |                       |                        | Lab          | Evans 1977                  |
| YOY              | 20               |                  | F      | 31.7                     | 6.0                      |                                   |                            |               |                       |                        | Lab          | Evans 1977                  |
| YOY              | 8                |                  | Wi     | 26                       |                          |                                   |                            |               |                       |                        | Lab          | Evans 1977                  |
| YOY              | 16               |                  | Wi     | 30.5                     |                          |                                   |                            |               |                       |                        | Lab          | Evans 1977                  |
| YOY              | 24               |                  | Wi     | 34.2                     |                          |                                   |                            |               |                       |                        | Lab          | Evans 1977                  |

SPECIES: *Lepomis gibbosus* (pumpkinseed)

| Size or Age<br>(mm) | Season | Day or<br>Night | Upper<br>Avoidance | Final<br>Preferendum | Lower<br>Avoidance | Acclimation<br>Temperature | Acclimation<br>Time | PREFERRED TEMPERATURES:                     |                             |
|---------------------|--------|-----------------|--------------------|----------------------|--------------------|----------------------------|---------------------|---|-----------------------------|
|                     |        |                 |                    |                      |                    |                            |                     | Location                                    | Reference                   |
| large               |        | D               |                    | 28.5-32              |                    |                            |                     | L. Monona, Wis.                             | Coutant 1977a               |
| large               |        | N               |                    | 27-29                |                    |                            |                     | L. Monona, Wis.                             | Coutant 1977a               |
| small               |        |                 |                    | 31.5                 |                    |                            |                     | Lab   | Coutant 1977a               |
| adult               | SP     |                 |                    | 24.2                 |                    |                            |                     | Lab   | Coutant 1977a               |
| adult               | su     |                 |                    | 27.7                 |                    |                            |                     | Lab   | Coutant 1977a               |
| large               |        |                 | >31                | 26                   | >22                |                            |                     | Lab   | Coutant 1977a               |
| YOY                 | F/W    |                 | 31.4               |                      | 24.5               | 20                         |                     |   | Evans 1977                  |
| 100-161TL           |        | D               |                    | 28                   |                    |                            |                     | L. Monona, Wis.                             | Brown 1974                  |
| 100-161TL           |        | N               |                    | 30.5                 |                    |                            |                     | L. Monona, Wis.<br>Delaware R.              | Brown 1974<br>Brown 1974    |
|                     |        |                 | 32.2               |                      |                    |                            |                     | Lab   | Brown 1974                  |
| adult               | W      |                 |                    | 28.5                 |                    |                            |                     | Lab   | Talmage and Coutant 1979    |
|                     | SP     |                 |                    | 31.7                 |                    |                            |                     | Lab   | Talmage and Coutant 1979    |
|                     | su     |                 |                    | 31.7                 |                    |                            |                     | Lab   | Talmage and Coutant 1979    |
|                     |        |                 | 31.7               | 31.5                 | 31                 |                            |                     | Lab   | Carlander 1977              |
|                     |        |                 | 34                 |                      |                    |                            |                     | Lab   | Beitinger and Magnuson 1979 |
|                     |        |                 | 40                 | 28.4                 | 11.9               |                            |                     | Connecticut R., Conn.<br>(field occurrence) | Marcy 1976a                 |
| adult               | W      |                 | 26.1               | 22.9                 | 18.5               | 8                          |                     | Lab   | Evans 1977                  |
| adult               | W      |                 | 29.2               | 25.3                 | 20.8               | 12                         |                     | Lab   | Evans 1977                  |
| adult               | W      |                 | 30.3               | 26.9                 | 23                 | 20                         |                     | Lab   | Evans 1977                  |
| adult               | W      |                 | 31                 | 27                   | 22.4               | 24                         |                     | Lab   | Evans 1977                  |
| adult               | SP     |                 | 25                 | 23.2                 | 21.4               | 8                          |                     | Lab   | Evans 1977                  |
| adult               | SP     |                 | 28.8               | 25.5                 | 21.2               | 12                         |                     | Lab   | Evans 1977                  |
| adult               | SP     |                 | 31.4               | 28.8                 | 25.9               | 20                         |                     | Lab   | Evans 1977                  |
| adult               | SP     |                 | 32.3               | 29.5                 | 25.6               | 24                         |                     | Lab   | Evans 1977                  |
| adult               | su     |                 | 29.3               | 25.6                 | 21.8               | 12                         |                     | Lab   | Evans 1977                  |
| adult               | su     |                 | 31.3               | 28.1                 | 24.5               | 20                         |                     | Lab   | Evans 1977                  |
| adult               | su     |                 | 32.7               | 30.3                 | 26.7               | 24                         |                     | Lab   | Evans 1977                  |

SPECIES: *Lepomis gibbosus* (pumpkinseed)

| Size or Age (mm) | Optimum °C | Range | (a) MWAT |    | No Growth Upper | Limits Lower | Location  | GROWTH TEMPERATURES: |  |
|------------------|------------|-------|----------|----|-----------------|--------------|-----------|----------------------|--|
|                  |            |       | W ST Max |    |                 |              |           | Reference            |  |
| underyearling    | 25         |       |          |    |                 |              | Gt. lakes | Carlander 1977       |  |
|                  | 30         |       |          |    |                 | 13<br>5      |           | Jobling 1981         |  |
|                  |            |       | 29.3     | 36 |                 |              |           | Griffiths 1978       |  |
|                  |            |       |          |    |                 |              |           | Spotila et al 1979   |  |
|                  |            |       |          |    |                 |              |           | This study           |  |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 113 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Lepomis gibbosus* (pumpkinseed)

| Event      | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival |                  | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location              | Reference                      |
|------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|------------------|-------------------------|-----------------------|--------------------------------|
|            |                                |              |            |          | ST Max                         | Acclimation Time |                        |                        |                  |                         |                       |                                |
| spawning   |                                | 28           | 20-29      |          |                                |                  |                        |                        |                  |                         | Lake, N.Y. Lab        | Brown 1974                     |
|            |                                | 24           |            |          |                                |                  |                        |                        |                  |                         |                       | Brown 1974                     |
| hatching   |                                | 28           |            |          |                                |                  |                        |                        |                  |                         |                       | Brown 1974                     |
| spawning   |                                |              | 20-27.8    |          |                                |                  |                        |                        |                  |                         | Georgian Bay, Ontario | Scott and Crossman 1973        |
| spawning   |                                |              | 13-18      |          |                                |                  |                        |                        |                  |                         |                       | Carlander 1977                 |
| cold shock | 15                             |              |            |          |                                |                  | 0.5                    | - 10                   | 1.8              |                         | Lab                   | Scheider and Becker et al 1975 |
| cold shock | 20                             |              |            |          |                                |                  | 2                      | -10                    | 2.7              |                         | Lab                   | Scheider and Becker et al 1975 |
| cold shock | 25                             |              |            |          |                                |                  | 5                      | -18                    | 8.5              |                         | Lab                   | Scheider and Becker et al 1975 |
| cold shock | 25                             |              |            |          |                                |                  |                        | -10                    | 6.3              |                         | Lab                   | Scheider and Becker et al 1975 |
| cold shock | 30                             |              |            |          |                                |                  | 8.5                    | -18                    | 12               |                         | Lab                   | Scheider and Becker et al 1975 |
| cold shock | 30                             |              |            |          |                                |                  |                        | -10                    | 8-9              |                         | Lab                   | Scheider and Becker et al 1975 |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.



SPECIES: *Lepomis macrochirus* (bluegill)

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Sea-son | THERMAL TOLERANCES:      |                          |                            |      |             |       |               |                       |                        |          |           |                             |
|------------------|------------------|------------------|---------|--------------------------|--------------------------|----------------------------|------|-------------|-------|---------------|-----------------------|------------------------|----------|-----------|-----------------------------|
|                  |                  |                  |         | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time =<br>a + b (temp) |      | Data Limits |       | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location | Reference |                             |
|                  |                  |                  |         |                          |                          | a                          | b    | Upper       | Lower |               |                       |                        |          |           |                             |
| adult            | 15               |                  |         | 31                       | 3                        |                            |      |             |       |               |                       |                        |          |           | EPA 1974                    |
| juvenile         | 12               |                  |         | 27                       | 3                        |                            |      |             |       |               |                       |                        |          |           | EPA 1974                    |
| adult            | 20               |                  |         | 32                       | 5                        |                            |      |             |       |               |                       |                        |          |           | EPA 1974                    |
| adult            | 25               |                  |         | 33                       | 7                        |                            |      |             |       |               |                       |                        |          |           | EPA 1974                    |
| juvenile         | 26               |                  |         | 36                       | 10                       |                            |      |             |       |               |                       |                        |          |           | EPA 1974                    |
| adult            | 30               |                  |         | 34                       | 11                       |                            |      |             |       |               |                       |                        |          |           | EPA 1974                    |
| juvenile         | 33               |                  |         | 37                       | 15                       |                            |      |             |       |               |                       |                        |          |           | EPA 1974                    |
| adult            | 22.8             |                  | SU      |                          |                          |                            |      |             |       |               |                       | 38.3                   | Lab      |           | Reutter and Herdendorf 1976 |
|                  |                  |                  |         | 35.5                     |                          |                            |      |             |       |               |                       | 41.5                   |          |           | Carlander 1977              |
| juvenile         | 19               |                  |         | 33                       | 6                        |                            |      |             |       |               |                       |                        |          |           | Carlander 1977              |
| eggs             | 26               |                  |         | 33.8                     | 21.9                     |                            |      |             |       |               |                       |                        |          |           | Carlander 1977              |
| fry              | 26               |                  |         | 34                       | 11                       |                            |      |             |       |               |                       |                        |          |           | Carlander 1977              |
|                  | 16               |                  |         |                          |                          |                            |      |             |       |               |                       | 31.5                   |          |           | Murphy et al 1976           |
|                  | 24               |                  |         |                          |                          |                            |      |             |       |               |                       | 35.6-37.5              |          |           | Murphy et al 1976           |
|                  | 32               |                  |         |                          |                          |                            |      |             |       |               |                       | 38.5-41.4              |          |           | Murphy et al 1976           |
| 90               | 27               |                  |         | 35.8                     |                          |                            |      |             |       |               |                       |                        | Lab      |           | Peterson and Schutsky 1976  |
|                  | 13               |                  |         | 29.3                     |                          |                            |      |             |       |               |                       |                        | Lab      |           | Peterson and Schutsky 1976  |
|                  | 1                |                  |         | 23.3                     |                          |                            |      |             |       |               |                       |                        | Lab      |           | Peterson and Schutsky 1976  |
|                  | 25               |                  |         |                          |                          |                            |      |             |       |               |                       | 35.6-37.3              |          |           | Beitinger and Magnuson 1979 |
|                  | 30               |                  |         |                          |                          |                            |      |             |       |               |                       | 37.8                   |          |           | Spotila et al 1979          |
|                  | 35               |                  |         |                          |                          |                            |      |             |       |               |                       | 40                     |          |           | Spotila et al 1979          |
|                  |                  |                  | su      | 28.5                     |                          |                            |      |             |       |               |                       | 43.4                   |          |           | Spotila et al 1979          |
|                  |                  |                  |         |                          |                          |                            |      |             | 38    | 48            |                       |                        |          |           | Brown 1974                  |
|                  | 25               |                  |         | 38.3                     |                          |                            |      |             |       |               |                       | 41.4                   |          |           | Brown 1974                  |
| 50-100           | 12-36            |                  | Su      | 36                       |                          |                            |      |             |       |               |                       |                        | Lab      |           | Cherry et al 1977           |
| adult            | 20-23            |                  |         |                          |                          | 38.6247-1.0581             | 35.5 | 34          |       |               |                       |                        |          |           | Brown 1974                  |
| 5.8-14.2g        | 30               |                  |         | 33.8                     |                          | 30.1609-0.7657             | 38   | 36          | 36.5  | 240           |                       |                        |          |           | Brown 1974                  |

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SPECIES: *Lepomis macrochirus* (bluegill1)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES: |                             |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------|-----------------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                | Reference                   |
| adult            |        |              |                 | 31                |                 | 26                      |                  |                         | Cravens 1982                |
| juvenile         |        |              |                 | 31.2              |                 | 25                      |                  |                         | Talmage and Coutant 1978    |
| juvenile         |        |              | 33.1            |                   | 29.5            | 25                      |                  |                         | Talmage and Coutant 1978    |
| 50-100; <1 yr    | Su     |              |                 | 31                |                 |                         |                  | Lab                     | Talmage and Coutant 1980    |
|                  |        |              |                 | 31.4              |                 |                         |                  |                         | Talmage and Coutant 1980    |
|                  |        |              |                 | 29.4-31.3         |                 |                         |                  | L. Monona, Wis.         | Coutant 1977a               |
| 53-99            |        | D            |                 | 28.8-31.2         |                 |                         |                  | L. Monona, Wis.         | Coutant 1977a               |
| 53-99            |        | N            |                 | 27-29             |                 |                         |                  | L. Monona, Wis.         | Coutant 1977a               |
| 100-193          |        | D            |                 | 29.6-32.6         |                 |                         |                  | L. Monona, Wis.         | Coutant 1977a               |
| 100-193          |        | N            |                 | 27.2-29           |                 |                         |                  | L. Monona, Wis.         | Coutant 1977a               |
| young            |        |              |                 | 32.3              |                 |                         |                  | Lab                     | Coutant 1977a               |
| young            |        | D            | 32.1            | 30.2              | 28.5            |                         |                  | Lab                     | Coutant 1977a               |
| young            |        | N            | 32.5            | 31.5              | 28.5            |                         |                  | Lab                     | Coutant 1977a               |
| young            |        |              | 33.1            | 31.2              | 29.3            |                         |                  | Lab                     | Coutant 1977a               |
| adult            |        | W            |                 | 27.4              |                 |                         |                  | Lab                     | Coutant 1977a               |
| adult            |        |              | 35              | 32                | 26              |                         |                  | Lab                     | Coutant 1977a               |
| 45-110           |        |              | 33              | 32.3              | 26              |                         |                  | Lab                     | Coutant 1977a               |
| 120-155          |        |              |                 | 30.5              |                 |                         |                  | Lab                     | Coutant 1977a               |
|                  |        | W            |                 |                   |                 |                         |                  | Thermal discharge       | Brown 1974                  |
|                  |        |              |                 |                   |                 |                         |                  | White R., Ind.          |                             |
|                  |        |              | 35              | 30                |                 | 30-34                   |                  | Penn.                   | Brown 1974                  |
|                  |        |              |                 | 18.7              |                 | 6                       |                  |                         | Carlander 1977              |
|                  |        |              |                 | 19.6              |                 | 9                       |                  |                         | Carlander 1977              |
|                  |        | su           | 34              |                   | 22              |                         |                  | Ohio R.                 | Yoder and Gammon 1976       |
|                  |        | F            | 24              |                   | 14              |                         |                  | Ohio R.                 | Yoder and Gammon 1976       |
|                  |        | W            | a               |                   | 5               |                         |                  | Ohio R.                 | Yoder and Gammon 1976       |
|                  |        |              | 33.5            | 30.7              | 27              |                         |                  | Lab                     | Peterson and Schutsky 1976  |
|                  |        |              | 30.3            | 24.6              | 13              |                         |                  | Lab                     | Peterson and Schutsky 1976  |
|                  |        |              | 27.6            |                   | 1               |                         |                  | Lab                     | Peterson and Schutsky 1976  |
|                  |        |              | 33.4            | 31.8              | 30.2            |                         |                  |                         | Beitinger 1976              |
|                  |        |              | 34              |                   |                 |                         |                  |                         | Beitinger and Magnuson 1979 |

SPECIES: *Lepomis macrochirus* (bluegill)

| Size or Age (mm) | Optimum °C | Range          | (a)     |        | No Growth Upper | Limits Lower | Location      | GROWTH TEMPERATURES:        |  |
|------------------|------------|----------------|---------|--------|-----------------|--------------|---------------|-----------------------------|--|
|                  |            |                | M W A T | ST Max |                 |              |               | Reference                   |  |
|                  |            |                |         |        |                 | 13           | Gt. Lakes     | Griffiths 1978              |  |
|                  |            |                |         |        |                 | 16-20        | Indiana Lakes | Evans 1984                  |  |
| juvenile         | 30         | 20-36          |         |        |                 |              |               | Talmage and Coutant 1978    |  |
| juvenile         | 30         |                |         |        |                 |              |               | Cravens 1981                |  |
| subadult         | 30-31      |                |         |        |                 |              |               | Talmage and Coutant 1980    |  |
|                  | 30.1       |                |         |        |                 |              |               | McCauley and Casselman 1980 |  |
|                  | 29-30      |                |         |        |                 |              |               | McCauley and Casselman 1980 |  |
|                  | 31         |                |         |        |                 |              |               | McCauley and Casselman 1980 |  |
| adult            | 24-27      | 24-34<br>16-30 |         | 32.2   |                 |              |               | Brown 1974                  |  |
|                  |            |                | 29      | 32     |                 |              |               | Brown 1974                  |  |
|                  |            |                |         |        | 26.7            | 10-13        | Ponds<br>Lab  | EPA 1974                    |  |
| 75-125           | 27         |                |         | 31     |                 |              |               | Carlander 1977              |  |
|                  | 31.2       |                |         |        |                 |              |               | Carlander 1977              |  |
|                  |            |                |         |        |                 |              |               | Stuntz and Magnuson 1976    |  |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Lepomis macrochirus* (bluegill)

| Event         | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b)                        |                  | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location | Reference                |
|---------------|--------------------------------|--------------|------------|----------|----------------------------|------------------|------------------------|------------------------|------------------|-------------------------|----------|--------------------------|
|               |                                |              |            |          | ST Max for Embryo Survival | Acclimation Time |                        |                        |                  |                         |          |                          |
| spawning      |                                |              | 17-26      |          |                            |                  |                        |                        |                  |                         |          | Carlander 1977           |
| hatching      | 26                             | 22.2-23.9    |            |          |                            |                  | 33.8                   |                        |                  |                         |          | Spotila et al 1979       |
| heat shock    |                                |              |            |          |                            |                  |                        |                        | + 16.7           |                         |          | Brown 1974               |
| heat shock    |                                |              |            |          |                            |                  |                        |                        | + 17.8           |                         |          | Brown 1974               |
| heat shock    |                                |              |            |          |                            |                  |                        |                        | +20              |                         |          | Brown 1974               |
| spawning      |                                | 25           |            | 25       | 34                         |                  |                        |                        |                  |                         |          | EPA 1974                 |
| hatching      |                                | 22-24        | 22-34      |          |                            |                  |                        |                        |                  |                         |          | EPA 1974                 |
| cold shock    | 25                             |              |            |          |                            |                  |                        |                        | - 10             |                         | Lab      | Wolters and Coutant 1976 |
| cold shock    | 30                             |              |            |          |                            |                  |                        |                        | - 14             |                         | Lab      | Wolters and Coutant 1976 |
| cold shock    | 32                             |              |            |          |                            |                  |                        |                        | - 16             |                         | Lab      | Wolters and Coutant 1976 |
| heat shock    |                                |              |            |          |                            |                  |                        |                        | +16.7/+20        |                         |          | Brown 1974               |
|               |                                |              |            |          |                            |                  |                        |                        | +20              |                         |          |                          |
| heat shock Su |                                |              |            |          |                            |                  |                        |                        | + 6.7            |                         |          | Brown 1974               |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Lepomis megalotis* (longear sunfish)

|                  |                  |                  |        |                          |                          |   |  |            |              |               |                       | THERMAL TOLERANCES:    |                              |                        |
|------------------|------------------|------------------|--------|--------------------------|--------------------------|---|--|------------|--------------|---------------|-----------------------|------------------------|------------------------------|------------------------|
| Size or Age (mm) | Acclimation Temp | Acclimation Time | Season | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = $\frac{a + b(\text{temp})}{a}$ |  | Data Upper | Limits Lower | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location                     | Reference              |
| >12; juvenile    | 25               |                  |        | 35.6                     |                          | 35.4953-0.9331                            |  | 36.9       | 35.4         |               |                       |                        | Middle Fork & White R., Ark. | Brown 1974             |
| >12; juvenile    | 30               |                  |        | 36.8                     |                          | 20.5981-0.4978                            |  | 39         | 36.5         |               |                       |                        | Middle Fork & White R., Ark. | Brown 1974             |
| >12; juvenile    | 35               |                  |        | 37.5                     |                          | 30.7245-9.7257                            |  | 41.5       | 37.3         |               |                       |                        | Middle Fork & White FL, Ark. | Brown 1974             |
| young            | 25               | 14h              |        | 35.5                     |                          |   |  |            |              | 36.9          | 8                     |                        | Lab                          | Brown 1974             |
| young            | 30               | 14h              |        | 36.6                     |                          |   |  |            |              | 39            | 10                    |                        | Lab                          | Brown 1974             |
| young            | 35               | 14h              |        | 38.2                     |                          |   |  |            |              | 41.5          | 8                     |                        | Lab                          | Brown 1974             |
| young            | 25               |                  |        |                          |                          |   |  |            |              | 35.6          | 160                   |                        | Lab                          | Brown 1974             |
| young            | 30               |                  |        |                          |                          |   |  |            |              | 36.7          | <250                  |                        | Lab                          | Brown 1974             |
| young            | 35               |                  |        |                          |                          |   |  |            |              | 37.3          | 9000                  |                        | Lab                          | Brown 1974             |
|                  | 15.5             |                  |        | 31.1                     |                          |   |  |            |              |               |                       |                        |                              | Houston 1982           |
|                  | >30              |                  |        | 37.9                     |                          |   |  |            |              |               |                       |                        |                              | Houston 1982           |
|                  |                  |                  |        |                          |                          | <7  |  |            |              |               |                       |                        | Field Study                  | Leidy and Jenkins 1977 |

SPECIES: *Lepomis megalotis* (longear sunfish)

|                  |        |              |                 |                   |                 |                         |                  |  |  |  |  | PREFERRED TEMPERATURES: |                |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|--|--|--|--|-------------------------|----------------|
| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time |  |  |  |  | Location                | Reference      |
|                  |        |              | >37.8           |                   |                 |                         |                  |  |  |  |  |                         | Carlander 1977 |

SPECIES: *Lepomis megalotis* (longear sunfish)

|          |                                |              |            |          |                                |                      |                        |                        |           |                         |          | SPAWNING AND DEVELOPMENT TEMPERATURES: |  |  |  |
|----------|--------------------------------|--------------|------------|----------|--------------------------------|----------------------|------------------------|------------------------|-----------|-------------------------|----------|--|--|--|--|
| Event    | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | (c) Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median AT | (d) Median Lethal Final | Location | Reference                              |  |  |  |
| spawning |                                |              | 23.4-25    |          |                                |                      |                        |                        |           |                         |          | Scott and Crossman 1973                |  |  |  |
| spawning |                                |              | 24-30      |          |                                |                      |                        |                        |           |                         | Kansas   | Carlander 1977                         |  |  |  |
|          |                                |              |            | 27       | 30                             |                      |                        |                        |           |                         |          | This study                             |  |  |  |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Micropterus dolomieu* (smallmouth bass)

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Season | Upper Incip. | Lower Incip. | log time =               |                         | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | THERMAL TOLERANCES:             |  | Reference                   |
|------------------|------------------|------------------|--------|--------------|--------------|--------------------------|-------------------------|---------------|-----------------------|------------------------|---------------------------------|--|-----------------------------|
|                  |                  |                  |        | Lethal Temp  | Lethal Temp  | $\frac{a + b}{a}$ (temp) | Data Limits Upper Lower |               |                       |                        | Location                        |  |                             |
| larvae           |                  |                  |        | 33           |              |                          |                         |               |                       |                        |                                 |  | EPA 1974                    |
| juvenile         |                  |                  |        | 35           |              |                          |                         |               |                       |                        |                                 |  | EPA 1974                    |
| juvenile         | 15               |                  |        |              | 2            |                          |                         |               |                       |                        |                                 |  | EPA 1974                    |
| larvae           |                  |                  |        |              | 4            |                          |                         |               |                       |                        |                                 |  | EPA 1974                    |
| juvenile         | 18               |                  |        |              | 4            |                          |                         |               |                       |                        |                                 |  | EPA 1974                    |
| juvenile         | 22               |                  |        |              | 7            |                          |                         |               |                       |                        |                                 |  | EPA 1974                    |
| juvenile         | 26               |                  |        |              | 10           |                          |                         |               |                       |                        |                                 |  | EPA 1974                    |
| YOY              | 35               |                  |        | 37           |              |                          |                         |               |                       |                        | Outdoor expt. channels, Alabama |  | Wrenn 1980                  |
| adult            | 35               |                  |        | 37           |              |                          |                         |               |                       |                        |                                 |  | Ellis 1984                  |
| fry              |                  |                  |        | 38           |              |                          |                         |               |                       |                        | field and lab                   |  | Wrenn 1980                  |
| larvae           |                  |                  |        | 30           | 10           |                          |                         |               |                       |                        | Lab                             |  | Shuter et al 1980           |
| juvenile         | 15               |                  |        |              | 2            |                          |                         |               |                       |                        | Lab                             |  | EPA 1974                    |
| juvenile         | 18               |                  |        |              | 4            |                          |                         |               |                       |                        | Lab                             |  | EPA 1974                    |
| juvenile         | 22               |                  |        |              | 7            |                          |                         |               |                       |                        | Lab                             |  | EPA 1974                    |
| juvenile         | 26               |                  |        |              | 10           |                          |                         |               |                       |                        | Lab                             |  | EPA 1974                    |
|                  | 23.3             |                  | SU     |              |              |                          |                         |               |                       | 36.3                   | Lab                             |  | Reutter and Herdendorf 1976 |
|                  | 12.8             |                  |        | 29.4-32.2    |              |                          |                         |               |                       |                        |                                 |  | Brown 1974                  |
| adult/ juvenile  |                  |                  |        | 35           |              |                          |                         |               |                       |                        |                                 |  | Wrenn 1980                  |
| 50-l 00; <1yr    | 18-33            |                  | su     | 35           |              |                          |                         |               |                       |                        | Lab                             |  | Cherry et al 1977           |
| larvae           |                  |                  |        | 35.8         |              |                          |                         |               |                       |                        |                                 |  | Fahmy and Crippen 1981      |
| juvenile         | 26               |                  |        |              | 10.1         |                          |                         |               |                       |                        | Lab                             |  | Leidy and Jenkins 1977      |
|                  | 35               |                  |        |              | 1.6          |                          |                         |               |                       |                        | Lab                             |  | Leidy and Jenkins 1977      |

SPECIES: *Micropterus dolomieu* (smallmouth bass)

| Size or Age<br>(mm)          | Season | Day or<br>Night | Upper<br>Avoidance | Final<br>Preferendum | Lower<br>Avoidance | Acclimation<br>Temperature | Acclimation<br>Time | PREFERRED TEMPERATURES:                          |                          |
|------------------------------|--------|-----------------|--------------------|----------------------|--------------------|----------------------------|---------------------|--|--------------------------|
|                              |        |                 |                    |                      |                    |                            |                     | Location   | Reference                |
| small                        |        |                 |                    | 28                   |                    |                            |                     | Lab  | Coutant 1977a            |
| YOY                          | W      |                 |                    | 18                   |                    |                            |                     | Lab  | Coutant 1977a            |
| YOY                          | SP     |                 |                    | 19-24                |                    |                            |                     | Lab  | Coutant 1977a            |
|                              |        |                 |                    | 21.3                 |                    |                            |                     | Nebish L., Wis.                                  | Coutant 1977a            |
|                              |        |                 |                    | 21.4                 |                    |                            |                     | S. Ont. streams                                  | Coutant 1977a            |
| YOY                          | su     |                 |                    | 31                   |                    |                            |                     | Lab  | Coutant 1977a            |
| YOY                          | F      |                 |                    | 24-27                |                    |                            |                     | Lab  | Coutant 1977a            |
| YOY                          | F      |                 |                    | 26.6                 |                    |                            |                     | Lab  | Coutant 1977a            |
| YOY                          |        | D               | 35                 | 31.1                 | 25                 |                            |                     | Lab  | Coutant 1977a            |
| adult                        | W      |                 |                    | 12-13                |                    |                            |                     | Lab  | Coutant 1977a            |
| adult                        | SP     |                 |                    | 15-16                |                    |                            |                     | Lab  | Coutant 1977a            |
| adult                        | su     |                 |                    | 30                   |                    |                            |                     | Lab  | Coutant 1977a            |
| adult                        | F      |                 |                    | 21-23                |                    |                            |                     | Lab  | Coutant 1977a            |
|                              |        |                 | 33                 | 31.3                 | 26                 |                            |                     | Lab  | Coutant 1977a            |
| adult                        | su     |                 |                    | 30-31                |                    |                            |                     | Tennessee R., Alab.<br>(outdoor exptal channels) | Wrenn 1980               |
| 164<br>juvenile              |        |                 |                    | 28-29                |                    |                            |                     | Lab  | Shuter et al 1980        |
|                              |        | D               |                    | 30.1                 |                    |                            |                     | Lab  | Talmage and Coutant 1979 |
|                              |        | N               |                    | 26.6                 |                    |                            |                     | Lab  | Talmage and Coutant 1979 |
|                              |        |                 |                    | 30.3                 |                    |                            |                     | Lab  | Cherry et al 1977        |
| 50-100; <math>\leq</math>1yr |        |                 |                    |                      |                    |                            | Lab                 | Cherry et al 1977                                |                          |
| 50-100; &1yr                 |        |                 | 27                 | 15                   | 18                 |                            | Lab                 | Cherry et al 1977                                |                          |
| 50-100; <math>\leq</math>1yr |        |                 | 30                 | 18                   | 21                 |                            | Lab                 | Cherry et al 1977                                |                          |
| 50-100; *1yr                 |        |                 | 33                 | 21                   | 24                 |                            | Lab                 | Cherry et al 1977                                |                          |
| 50-100; *1yr                 |        |                 | 33                 | 24                   | 27                 |                            | Lab                 | Cherry et al 1977                                |                          |
| 50-100; <math>\leq</math>1yr |        |                 | 33                 | 24                   | 30                 |                            | Lab                 | Cherry et al 1977                                |                          |
| 50-100; <math>\leq</math>1yr |        |                 | 35                 | 27                   | 33                 |                            | Lab                 | Cherry et al 1977                                |                          |
| adult                        | F      |                 |                    | 26.6                 |                    |                            |                     | Lab  | Cherry et al 1977        |
|                              | W      |                 |                    | 20                   |                    | 1                          |                     |  | Ellis 1984               |
|                              |        |                 | 136.7              |                      |                    |                            |                     |  | Spotila et al 1979       |

SPECIES: *Micropterus dolomieu* (smallmouth bass)

| Size or Age (mm) | Optimum °C | Range   | (b)      |        | No Growth Upper | Limits Lower | Location                                       | GROWTH TEMPERATURES:        |  |
|------------------|------------|---------|----------|--------|-----------------|--------------|--|-----------------------------|--|
|                  |            |         | (a) MWAT | ST Max |                 |              |  | Reference                   |  |
| YOY juvenile     | 28         | 14-31.5 |          |        | 35              | 7            | Lab and field (Baie du Dore, L. Huron)         | Shuter et al 1980           |  |
| juvenile/adult   |            |         | 29       |        |                 |              | Tennessee R.. (outdoor exptal channels), Alab. | EPA 1974                    |  |
|                  |            |         | 32/33    | 35     |                 |              | Lab  | Wrenn 1990                  |  |
| 15-35SL; fry     | 25-26      |         |          |        |                 |              |  | Coutant and DeAngelis 1983  |  |
|                  | 25         |         |          |        |                 |              |  | McCauley and Casselman 1980 |  |
|                  | 29         |         |          |        |                 |              |  | McCauley and Casselman 1980 |  |
|                  | 27         |         |          |        |                 |              |  | McCauley and Casselman 1980 |  |
|                  |            |         |          |        |                 | 10           |  | Carlander 1977              |  |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth)

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Micropterus dolomieu* (smallmouth bass)

| Event             | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b)                        |                  | (c) Lethal Upper | (c) Lethal Lower | Median Lethal AT | (d) Median Lethal Final | Location  | Reference                       |
|-------------------|--------------------------------|--------------|------------|----------|----------------------------|------------------|------------------|------------------|------------------|-------------------------|---|---------------------------------|
|                   |                                |              |            |          | ST Max for Embryo Survival | Acclimation Time |                  |                  |                  |                         |   |                                 |
| spawning          |                                | 18           | 15-17      | 17       |                            | 26               |                  |                  |                  |                         | Baie du Dore, L. Huron Tennessee R., Ala. (outdoor expt. channel) | Shuter et al 1980<br>Wrenn 1984 |
| egg/larval devel. |                                | 21           | 13-26      |          |                            | 25               |                  | 30               | 10               |                         | Lab and field (Baie du Dore, L. Huron)                            | EPA 1974<br>Shuter et al 1980   |
| w                 | 19                             |              |            |          |                            |                  | 29               | 17               |                  |                         |   | Brown 1974                      |
| egg               | 16.1                           |              |            |          |                            |                  | 23.1             |                  | +7               |                         |   | Brown 1974                      |
| heat shock        | 20                             |              |            |          |                            |                  |                  |                  | +17              | 37                      |   | Moore 1979 (d)                  |
| cold shock        | 27                             |              |            |          |                            |                  |                  |                  | -20              | 2                       |   | Coutant 1977b                   |
| heat shock        | 20                             |              |            |          |                            |                  |                  |                  | +16.6            |                         | Lab (onshore discharge)   | Crippen and Fahmy 1981          |
| heat shock        | 20                             |              |            |          |                            |                  |                  |                  | +17.7            |                         | Lab (tempering discharge)   | Crippen and Fahmy 1981          |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for <sup>successful</sup> embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures,

SPECIES: *Micropterus salmoides* (largemouth bass)

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| Size or Age (mm)  | Acclimation Temp | Acclimation Time | Sea-son | THERMAL TOLERANCES:      |                          | log time =<br>a + b (temp)<br>a b | Data Limits |       | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location           | Reference                   |
|-------------------|------------------|------------------|---------|--------------------------|--------------------------|-----------------------------------|-------------|-------|---------------|-----------------------|------------------------|--------------------|-----------------------------|
|                   |                  |                  |         | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp |                                   | Upper       | Lower |               |                       |                        |                    |                             |
| juvenile          | 12               |                  |         | 36                       |                          |                                   |             |       |               |                       |                        |                    | Cherry et al 1982           |
|                   | 20               |                  |         | 33                       | 5                        |                                   |             |       |               |                       |                        |                    | EPA 1974                    |
|                   | 25               |                  |         | 35                       | 7                        |                                   |             |       |               |                       |                        |                    | EPA 1974                    |
|                   | 30               |                  |         | 36                       | 11                       |                                   |             |       |               |                       |                        |                    | EPA 1974                    |
|                   | 35               |                  |         | 36                       |                          |                                   |             |       |               |                       |                        |                    | EPA 1974                    |
| 9-11 months       | 20               |                  |         | 32                       |                          | 35.5107                           | -1.0112     |       |               |                       |                        |                    | Brown 1974                  |
| 9-11 months       | 25               |                  |         | 33                       |                          | 19.9918                           | -0.5123     |       |               |                       |                        |                    | Brown 1974                  |
| S-11 months       | 30               |                  |         | 33.7                     |                          | 17.5645                           | -0.4200     |       |               |                       |                        |                    | Brown 1974                  |
| adult             | 20               |                  |         | 32.5                     |                          | 50.8091                           | -1.4638     | 34    | 33            |                       |                        | Put-in-Bay, Ohio   | Brown 1974                  |
| adult             | 25               |                  |         | 34.5                     |                          | 26.3169                           | -0.6846     | 36.5  | 35            |                       |                        | Put-in-Bay, Ohio   | Brown 1974                  |
| adult             | 30               |                  |         | 36.4                     |                          | 29.0213                           | -0.7150     | 38.5  | 37            |                       |                        | Put-in-Bay, Ohio   | Brown 1974                  |
| under yearling    | 20               |                  |         |                          | 5.5                      |                                   |             |       |               |                       |                        | Put-in-Bay, Ohio   | Brown 1974                  |
|                   | 30               |                  |         |                          | 11.8                     |                                   |             |       |               |                       |                        | Put-in-Bay, Ohio   | Brown 1974                  |
|                   | 30               |                  |         | 36.4                     |                          | 36.0620                           | X1.9055     | 38.5  | 37            |                       |                        | Knoxville, Tenn.   | Brown 1974                  |
| 0.18g; fingerling | 35               |                  |         | 36.4                     |                          | 23.9185                           | -0.9958     | 40    | 37.5          |                       |                        | Knoxville, Tenn.   | Brown 1974                  |
|                   | 22               |                  |         | 31.5                     |                          | 34.3649                           | -0.9789     | 33.8  | 32.0          |                       |                        | Lake Mendota, Wis. | Brown 1974                  |
|                   | 30               |                  |         |                          |                          | 35.2777                           | -0.9845     | 37.5  | 35.5          |                       |                        | Lake Mendota, Wis. | Brown 1974                  |
| 0.18g; fingerling | 7.2              | 21 h             |         | 30.6                     |                          |                                   |             |       |               |                       |                        | Pennsylvania       | Brown 1974                  |
|                   | 11.1             | 43h              |         | 35                       |                          |                                   |             |       |               |                       |                        |                    | Brown 1974                  |
| 0.18g; fingerling | 15               |                  |         | 35                       |                          |                                   |             |       |               |                       |                        |                    | Venables et al 1978         |
| 0.18g; fingerling | 20               |                  |         | 35                       |                          |                                   |             |       |               |                       |                        | Lab (Texas)        | Venables et al 1978         |
| 0.18; fingerling  | 25               |                  |         | 40                       |                          |                                   |             |       |               |                       |                        | Lab (Texas)        | Venables et al 1978         |
| 0.18; fingerling  | 30               |                  |         | 40                       | 10                       |                                   |             |       |               |                       |                        | Lab (Texas)        | Venables et al 1978         |
| 0.18; fingerling  | 35               |                  |         | 40                       | 15                       |                                   |             |       | 40            | 19m                   |                        | Lab (Texas)        | Venables et al 1978         |
| 0.18; fingerling  | 35               |                  |         |                          |                          |                                   |             |       | 15            | 12-20h                |                        | Lab (Texas)        | Venables et al 1978         |
| adult             | 0.7              |                  | W       |                          |                          |                                   |             |       |               |                       | >12.0                  | Lab                | Reutter and Herdendorf 1976 |
| eggs              |                  |                  |         | 36.7/389                 |                          |                                   |             |       |               |                       |                        |                    | Carlander 1977              |
|                   | 20-21            |                  |         | 28.9                     |                          |                                   |             |       |               |                       |                        |                    | Spotila et al 1979          |
|                   |                  |                  |         | 32.5                     |                          |                                   |             |       |               |                       |                        |                    | Spotila et al 1979          |
|                   | 20               |                  |         |                          |                          |                                   |             |       |               |                       | 36.7                   |                    | Spotila et al 1979          |
| 28                |                  |                  |         |                          |                          |                                   |             |       |               | 40.1                  |                        | Spotila et al 1979 |                             |
|                   |                  |                  | SU      | 35.6                     |                          |                                   |             |       |               |                       |                        |                    | Spotila et al 1979          |



SPECIES: *Micropterus salmoides* (largemouth bass)

| Size or Age<br>(mm) | Season | Day or<br>Night | Upper<br>Avoidance | Final<br>Preferendum | Lower<br>Avoidance | Acclimation<br>Temperature | Acclimation<br>Time | PREFERRED TEMPERATURES:                     |                          |
|---------------------|--------|-----------------|--------------------|----------------------|--------------------|----------------------------|---------------------|---|--------------------------|
|                     |        |                 |                    |                      |                    |                            |                     | Location                                    | Reference                |
| large               |        |                 |                    | 26.6-27.7            |                    |                            |                     | Norris Res., Tenn.                          | Coutant 1977a            |
| large               |        |                 | 30                 | 27-30                |                    |                            |                     | Par Pond, S.C.                              | Coutant 1977a            |
| 72-99;              |        |                 |                    | 29.3-30.9            |                    |                            |                     | L. Monona, Wis.                             | Coutant 1977a            |
| 100-408;            |        | D               |                    | 29.3-32              |                    |                            |                     | L. Monona, Wis.                             | Coutant 1977a            |
| 100-408;            |        | N               |                    | 26.5-29.1            |                    |                            |                     | L. Monona, Wis.                             | Coutant 1977a            |
| adult               |        |                 | 29                 | 27                   | 25.5               |                            |                     | small lakes, Tenn.                          | Coutant 1977a            |
| small               |        |                 |                    | 30-32                |                    |                            |                     | Lab   | Coutant 1977a            |
| small               |        |                 | 30.7               | 29                   | 27.5               |                            |                     | Lab   | Coutant 1977a            |
| adult               |        |                 | 30                 |                      |                    |                            |                     | Pond C, Savannah Ft. GS,<br>S.C.            | Coutant 1977a            |
| 110-160; YOY        |        | D               |                    | 30.1                 |                    |                            |                     | Lab   | Coutant 1977a            |
| 110-150; YOY        |        | D               | 34                 | 30                   | 21                 |                            |                     | Lab   | Coutant 1977a            |
| 50-460g             |        | N               |                    | 30.2                 |                    |                            |                     | Lab   | Coutant 1977a            |
| 65-75TL;            |        |                 | 31                 | 29.1                 | 27.2               |                            |                     |   | Brown 1974               |
| 50-90TL;            |        |                 | 30.6-32.8          |                      |                    | 25                         |                     |   | Brown 1974               |
| adult               |        |                 |                    | 28                   |                    | 3-8                        |                     | Lab   | Cravens 1981             |
| adult               |        |                 |                    | 27-32                |                    |                            |                     | Lab   | Talmage and Coutant 1979 |
|                     |        | N               |                    | 29.5                 |                    |                            |                     | Lab   | Talmage and Coutant 1979 |
|                     |        | D               |                    | 27.1                 |                    |                            |                     | Lab   | Talmage and Coutant 1979 |
|                     |        |                 | 24                 | 30.4                 | 9                  | 12                         |                     | Lab   | Cherry et al 1982        |
|                     |        |                 | 33                 |                      | 21                 | 24                         |                     | Lab   | Cherry et al 1982        |
|                     |        |                 | 28.7               | 21.3                 | 14.8               |                            |                     | Connecticut R., Conn.<br>(field occurrence) | Marcy 1976a              |

SPECIES: *Micropterus salmoides* (largemouth bass)

| Size or Age<br>(mm) | Optimum<br>°C | Range     | (b)            |             | No Growth<br>Upper | Limits<br>Lower | Location         | GROWTH TEMPERATURES:        |  |
|---------------------|---------------|-----------|----------------|-------------|--------------------|-----------------|------------------|-----------------------------|--|
|                     |               |           | (a)<br>M W A T | ST<br>M a x |                    |                 |                  | Reference                   |  |
| juvenile            | 25            |           |                |             |                    |                 |                  | McCauley and Casselman 1980 |  |
| subadult            | 26-28         |           |                |             |                    |                 |                  | McCauley and Casselman 1980 |  |
|                     |               |           | 32             | 34          |                    |                 |                  | EPA 1974                    |  |
| larval              | 27            | 20-30     |                |             |                    |                 | Lab              | EPA 1974                    |  |
| juvenile            | 30            | 23-31     |                |             |                    |                 |                  | EPA 1974                    |  |
| fry                 |               | 15.9-32.5 |                |             |                    |                 | Lab              | Brown 1974                  |  |
|                     | 23.9          |           |                |             |                    |                 | Texas reservoirs | Brown 1974                  |  |
| 15.35SL; fry        | 27            |           |                |             |                    |                 | Lab              | Coutant and DeAngelis 1983  |  |
|                     |               | 17.5-27.5 |                |             | > 36               | 10              |                  | Carlander 1977              |  |
| fry                 | 25-30         |           |                |             |                    |                 | Lab              | Smagula and Adelman 1982    |  |
|                     | 18            |           |                |             |                    |                 |                  | Spotila et al 1979          |  |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Micropterus salmoides* (largemouth bass)

|                     |                                |              |            |          |                                |                  |                        |                        |                   |       | SPAWNING AND DEVELOPMENT TEMPERATURES: |                     |
|---------------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|-------------------|-------|--|---------------------|
| Event               | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | (d) Median Lethal |       | Reference                              |                     |
|                     |                                |              |            |          |                                |                  |                        |                        | AT                | Final |  | Location            |
| spawning            |                                | 15.6-21      | 12-20      | 21       | 27                             |                  |                        |                        |                   |       | field                                  | EPA 1974            |
| hatching            |                                | 20           | 13-26      |          |                                |                  |                        |                        |                   |       |  | Carlander 1977      |
| eggs                |                                |              |            |          |                                |                  | 32.5                   |                        |                   |       |  | EPA 1974            |
| spawning            |                                |              |            | 23.9     |                                |                  |                        |                        |                   |       |  | Brown 1974          |
|                     |                                |              |            |          | 29-32                          |                  |                        |                        |                   |       | Lab (Wis., Minn.)                      | Brown 1974          |
| embryo devel.20     |                                |              |            |          |                                |                  | 32.1                   |                        |                   |       | Lab                                    | EPA 1978            |
| embryo devel. 24    |                                |              |            |          |                                |                  | 32.1                   |                        |                   |       | Lab                                    | Cravens 1982        |
| embryo devel.27     |                                |              |            |          |                                |                  | 32.1                   |                        |                   |       | Lab                                    | Cravens 1982        |
| embryo devel.30     |                                |              |            |          |                                |                  | 32.1                   |                        |                   |       | Lab                                    | Cravens 1982        |
| eggs 17-21          |                                |              |            |          |                                |                  | 26.7                   |                        |                   |       | Lab (N.Y.)                             | Venables et al 1978 |
| spawning            |                                | 20           |            |          |                                |                  |                        |                        |                   |       | Lab (Minn.)                            | Carlander 1977      |
| hatching            |                                |              | 10-30      |          |                                |                  |                        |                        |                   |       |  | Carlander 1977      |
| heat shock (adult)  | Su                             |              |            |          |                                |                  |                        |                        | +10               |       |  | Brown 1974          |
| heat shock (larval) | 15-35                          |              |            |          |                                |                  |                        |                        | + 20-25           | 35-40 | Lab (Texas)                            | Venables et al 1978 |

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- (a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.
- (b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.
- (c) Not incipient lethal temperatures as defined by Fry et al (1946).
- (d) Simulated larval entrainment temperatures.

SPECIES: Pomoxis annularis (white crappie)

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Sea-son | THERMAL TOLERANCES:      |                          | log time =<br>a + b (temp)<br>a b | Data Limits |       | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location           | Reference                               |
|------------------|------------------|------------------|---------|--------------------------|--------------------------|-----------------------------------|-------------|-------|---------------|-----------------------|------------------------|--------------------|---|
|                  |                  |                  |         | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp |                                   | Upper       | Lower |               |                       |                        |                    |   |
| juvenile adult   | 24.4             |                  | su      | <33                      |                          |                                   |             |       |               |                       | >32.8                  | Lab (UUILT)<br>Lab | EPA 1974<br>Reutter and Herdendorf 1976 |

SPECIES: Pomoxis annularis (white crappie)

| Size or Age (mm) | Season | Day or Night | PREFERRED TEMPERATURES: |                   | Acclimation Temperature | Acclimation Time | Location         | Reference                   |
|------------------|--------|--------------|-------------------------|-------------------|-------------------------|------------------|------------------|-----------------------------|
|                  |        |              | Upper Avoidance         | Final Preferendum |                         |                  |                  |                             |
| large adult      | W      |              | 27                      |                   | 19.8                    |                  | Wabash R., Ind.  | Coutant 1977a               |
| adult            | SP     |              |                         |                   | 18.3                    |                  | Lab              | Coutant 1977a               |
| adult            | F      |              |                         |                   | 10.4                    |                  | Lab              | Coutant 1977a               |
| adult            | su     |              |                         |                   | 19.4                    |                  | Lab              | Reutter and Herdendorf 1976 |
|                  | SU     |              | 31                      |                   |                         | 26               | Ohio R.          | Yoder and Gammon 1976       |
|                  | F      |              | 26                      |                   |                         | 18               |                  | Yoder and Gammon 1976       |
|                  | W      |              | 8                       |                   |                         | 5                |                  | Yoder and Gammon 1976       |
|                  | su     | D            | 24-30                   |                   | 23                      |                  | Kansas Reservoir | O'Brien et al 1984          |
|                  | F      | D            |                         |                   | 23-24                   |                  |                  | O'Brien et al 1984          |

SPECIES: Pomoxis annularis (white crappie)

| Size or Age (mm) | Optimum °C | Range | (a)  |      | (b) |      | Location | GROWTH TEMPERATURES: |                       |
|------------------|------------|-------|------|------|-----|------|----------|----------------------|-----------------------|
|                  |            |       | MWAT | Max  | ST  | Max  |          | No Growth Upper      | Limits Lower          |
| juvenile         | 25         |       | 27   |      |     |      |          |                      | EPA 1974              |
|                  | 27-28.5    |       |      | 32.2 |     |      |          |                      | Brown 1974            |
|                  |            | 5-30  |      |      | 27  | 15.6 | Ohio R.  |                      | Carlander 1977        |
|                  |            |       |      |      |     |      |          |                      | Yoder and Gammon 1976 |
|                  |            |       |      |      |     |      |          |                      | O'Brien et al 1984    |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: Pomoxis annularis (white crappie)

| Event    | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b)                        |                  | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location | Reference          |
|----------|--------------------------------|--------------|------------|----------|----------------------------|------------------|------------------------|------------------------|------------------|-------------------------|----------|--------------------|
|          |                                |              |            |          | ST Max for Embryo Survival | Acclimation Time |                        |                        |                  |                         |          |                    |
| spawning | sp/su                          | 16-20        | 14-23      |          |                            |                  |                        |                        |                  |                         |          | EPA 1974           |
| spawning |                                | 18-20        |            |          |                            |                  |                        |                        |                  |                         |          | EPA 1974           |
| hatching |                                |              |            | 18       | 23                         |                  |                        |                        |                  |                         |          | EPA 1974           |
| spawning |                                | 14-16        | 18.3-20    |          |                            |                  |                        |                        |                  |                         |          | Carlander 1977     |
|          |                                |              |            |          |                            |                  |                        |                        |                  |                         |          | O'Brien et al 1984 |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: Pomoxis nigromaculatus (black crappie)

| THERMAL TOLERANCES: |                  |                  |         |              |              |            |   |       |               |                       |                        |                                     |   |
|---------------------|------------------|------------------|---------|--------------|--------------|------------|---|-------|---------------|-----------------------|------------------------|-------------------------------------|---|
| Size or Age (mm)    | Acclimation Temp | Acclimation Time | Sea-son | Upper Incip. | Lower Incip. | log time = |   |       | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location                            | Reference                                     |
|                     |                  |                  |         | Lethal Temp  | Lethal Temp  | a          | b | Upper |               |                       |                        |                                     |   |
| juvenile            | 29               |                  |         | <33          |              |            |   |       |               |                       |                        | Lab (UUILT)                         | EPA 1974                                      |
|                     | 7.2              | 1°C/h            |         | 28.9         |              |            |   |       |               |                       |                        | Lab                                 | Brown 1974                                    |
| adult               | 23.8             |                  | su      |              |              |            |   |       |               |                       | 34.9                   | Lab                                 | Reutter and Herdendorf 1976<br>Carlander 1977 |
|                     |                  |                  |         | 34           |              |            |   |       |               |                       |                        |                                     | Leidy and Jenkins 1977                        |
| >200TL              |                  |                  | su      | 32.5         |              |            |   |       |               |                       |                        | Hayes Centre L., Neb.<br>(observed) | Ellison 1984                                  |
|                     |                  |                  |         | 26-28        |              |            |   |       |               |                       |                        |                                     |   |

SPECIES: Pomoxis nigromaculatus (black crappie)

| PREFERRED TEMPERATURES: |        |              |                 |                   |                 |                         |                  |   |                             |       |  |   |
|-------------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|---|-----------------------------|-------|--|---|
| Size or Age (mm)        | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | Location                                    | Reference                   |       |  |   |
|                         |        |              |                 |                   |                 |                         |                  |   |                             | large |  | D |
| large                   |        | N            |                 | 27-28.2           |                 |                         |                  | L. Monona, Wis.                             | Coutant 1977a               |       |  |   |
| small                   |        |              | 30              |                   | 26.5            |                         |                  | Lab   | Coutant 1977a               |       |  |   |
| small                   |        |              | 29.5            |                   | 25.5            |                         |                  | Lab   | Coutant 1977a               |       |  |   |
| adult                   | w      |              |                 | 20.5              |                 |                         |                  | Lab   | Coutant 1977a               |       |  |   |
| adult                   | Sp     |              |                 | 21                |                 |                         |                  | Lab   | Coutant 1977a               |       |  |   |
| adult                   | SU     |              |                 | 21.7              |                 |                         |                  | Lab   | Coutant 1977a               |       |  |   |
| adult                   | F      |              |                 | 22.2              |                 |                         |                  | Lab   | Coutant 1977a               |       |  |   |
| medium                  |        |              | 26              | 24                | 20              |                         |                  | Lab   | Coutant 1977a               |       |  |   |
| larvae                  | Su     |              |                 | 18-20             |                 |                         |                  | Northern Wis. Lakes                         | EPA 1974                    |       |  |   |
| adult                   | s u    |              | 34              |                   | 24              |                         |                  | Lab   | EPA 1974                    |       |  |   |
| 75-88TL;                |        |              |                 | 28.3              |                 |                         |                  | L. Monona, Wis.                             | Brown 1974                  |       |  |   |
| adult                   | w      |              |                 | 20.7              |                 |                         |                  | Lab   | Reutter and Herdendorf 1976 |       |  |   |
| adult                   | F      |              |                 | 24.6              |                 |                         |                  | Lab   | Reutter and Herdendorf 1976 |       |  |   |
|                         |        |              | 30.5            |                   | 24              |                         |                  | L. Monona, Wis.                             | Carlander 1977              |       |  |   |
|                         |        |              | 27.3            | 21.3              | 16.5            |                         |                  | Connecticut R., Conn.<br>(field occurrence) | Marcy 1976a                 |       |  |   |

**SPECIES: Pomoxis nigromaculatus (black crappie)**

| Size or Age (mm) | Optimum °C | Range | (a) MWAT | (b) ST Max | No Growth Limits |       | Location                      | GROWTH TEM     |           |
|------------------|------------|-------|----------|------------|------------------|-------|-------------------------------|----------------|-----------|
|                  |            |       |          |            | Upper            | Lower |                               | Reference      | Reference |
| juvenile         | 22-25      |       | 27       | 32.2       | 30               | 11    |                               | EPA 1974       |           |
| <76TL;           |            | 27-29 |          |            |                  | 6.5   | L. Monona, Wis.               | Brown 1974     |           |
| >200TL;          | 9-17       | 9-25  |          |            | 26               |       | Ontario                       | Brown 1974     |           |
|                  |            |       |          |            | 27               |       | Hayes Center State Lake, Neb. | Carlander 1977 |           |
|                  |            |       |          |            |                  |       | Clear L., Iowa                | Ellison 1984   |           |

- (a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).  
 (b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

**S. Pomoxis nigromaculatus (black crappie)**

**SPAWNING AND DEVELOPMENT TEMPERATURES:**

| Event            | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal ΔT | (d) Median Lethal Final | Location          | Reference               |
|------------------|--------------------------------|--------------|------------|----------|--------------------------------|-------------|------------------------|------------------------|------------------|-------------------------|-------------------|-------------------------|
| spawning         |                                |              | 14-18      |          |                                |             |                        |                        |                  |                         |                   | EPA 1974                |
| spawning         |                                |              | 14-20      |          |                                |             |                        |                        |                  |                         |                   | EPA 1974                |
| spawning         |                                | 19-20        |            |          |                                |             |                        |                        |                  |                         | Buckeye L., Ohio  | Scott and Crossman 1973 |
| spawning         |                                |              | 4.4-15.6   |          |                                |             |                        |                        |                  |                         | Wis.              | Carlander 1977          |
| spawning         |                                | 17.8-20      |            |          |                                |             |                        |                        |                  |                         | L. Opinicon, Ont. | Carlander 1977          |
| larval devel.    |                                |              | 13-23      |          |                                |             |                        |                        |                  |                         |                   | Carlander 1977          |
| hatching         |                                | 18.3         |            |          |                                |             |                        |                        |                  |                         | Lab (Minn.)       | Carlson and Herman 1978 |
| spawning         |                                |              | 14-21      |          |                                |             |                        |                        |                  |                         |                   | Carlson and Herman 1978 |
| hatching/ devel. |                                | 16-20        |            | 8        | 2                              |             |                        |                        |                  |                         |                   | This study              |

- (a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum; or middle of range of spawning temperatures.  
 (b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.  
 (c) Not incipient lethal temperatures as defined by Fry et al (1946).  
 (d) Simulated larval entrainment temperatures.

SPECIES: *Perca flavescens* (yellow perch)

| Size or Age (mm) | Acclimation Temp. | Acclimation Time | Season | Thermal Tolerances:      |                          | log time =<br>a + b (temp)<br>a b | Data Limits<br>Upper Lower | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location                  | Reference                   |
|------------------|-------------------|------------------|--------|--------------------------|--------------------------|-----------------------------------|----------------------------|---------------|-----------------------|------------------------|---------------------------|-----------------------------|
|                  |                   |                  |        | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp |                                   |                            |               |                       |                        |                           |                             |
| adult            | 5                 |                  |        | 21                       |                          |                                   |                            |               |                       |                        | Toronto, Ontario          | EPA 1974                    |
| larvae           | 10                |                  |        | 10                       |                          |                                   |                            |               |                       |                        |                           | EPA 1974                    |
| adult            | 11                |                  |        | 25                       |                          |                                   |                            |               |                       |                        |                           | EPA 1974                    |
| adult            | 15                |                  |        | 28                       |                          |                                   |                            |               |                       |                        |                           | EPA 1974                    |
| larvae           | 19                |                  |        | 19                       |                          |                                   |                            |               |                       |                        |                           | EPA 1974                    |
|                  | 18                |                  |        | 26.5                     |                          |                                   |                            |               |                       |                        |                           | Spotila et al 1979          |
| adult            | 25                |                  | su     | 32.3                     |                          |                                   |                            |               |                       |                        |                           | EPA 1974                    |
| juvenile         | 25                |                  |        |                          | 4                        |                                   |                            |               |                       |                        |                           | EPA 1974                    |
| 49; juvenile     | 19                | 4 day            |        |                          |                          | 15.3601-0.4126                    | 38 32                      |               |                       |                        | Columbia R., Oregon       | Brown 1974                  |
| 4 yr; adult      | 5                 |                  |        | 21.3                     |                          | 7.0095-0.2214                     | 26.5 22                    |               |                       |                        | Black Ck., L.Simcoe, Ont. | Brown 1974                  |
|                  | 11                |                  |        | 25.0                     | 1.1                      | 17.6536-0.6021                    | 26.5 26                    |               |                       |                        | Black Ck., L.Simcoe, Ont. | Brown 1974                  |
|                  | 15                |                  |        | 27.7                     |                          | 12.4149-0.3641                    | 30.5 28.5                  |               |                       |                        | Black Ck., L.Simcoe, Ont. | Brown 1974                  |
|                  | 25                |                  |        | 28.7                     | 3.7                      | 21.2718-0.5909                    | 33.0 30.0                  |               |                       |                        | Black Ck., L.Simcoe, Ont. | Brown 1974                  |
| larvae           |                   |                  |        | 23.9                     |                          |                                   |                            |               |                       |                        |                           | Brown 1974                  |
| young            | 22-23             |                  |        | 29.6                     |                          |                                   |                            | 31.5          | 240                   |                        |                           | Brown 1974                  |
| young            | 22-23             |                  |        | 29.6                     |                          |                                   |                            | 32            | 60                    |                        |                           | Brown 1974                  |
| y o u n g        | 22-23             |                  |        | 29.6                     |                          |                                   |                            | 34            | 15                    |                        |                           | Brown 1974                  |
| 125 TL adult     | 23-25             |                  | SU     | 30.9                     |                          |                                   |                            |               |                       |                        |                           | Hokanson 1977               |
| 30-50 TL         |                   |                  |        | 26                       |                          |                                   |                            |               |                       |                        |                           | Cherry et al 1977           |
| adult            | 22                |                  | Su     |                          |                          |                                   |                            |               |                       | 35                     | Lab                       | Reutter and Herdendorf 1976 |
| larval           | 15                |                  |        | 33.7                     |                          |                                   |                            |               | 10                    |                        |                           | Jinks et al 1981            |
|                  |                   |                  |        | 31.3                     |                          |                                   |                            |               | 30                    |                        |                           | Jinks et al 1981            |
| larval           |                   |                  |        |                          | 9.8                      |                                   |                            |               |                       |                        |                           | Dunford 1978                |
| embryo           |                   |                  |        | 19.9                     | 6.8                      |                                   |                            |               |                       |                        |                           | Hokanson 1977               |
| 6-24 g juvenile  | 25                |                  | W      | 29.7                     |                          |                                   |                            |               |                       | 33.4                   |                           | Hokanson 1977               |
| 0.5 g juvenile   | 28                |                  | SU     | 33-34                    |                          |                                   |                            |               |                       |                        |                           | Hokanson 1977               |
| larval           | 7.6               |                  |        | >24                      |                          |                                   |                            |               |                       | 34.8                   | Lab                       | Dunstall 1979               |
| larval           | 15.8              |                  |        | >26.6                    |                          |                                   |                            |               |                       | 37.6                   |                           | Dunstall 1979               |
|                  | 22-24             |                  |        | 29.2                     |                          |                                   |                            |               |                       |                        |                           | Spotila et al 1979          |
| hatch            |                   |                  |        | 19.9                     | 6.8                      |                                   |                            |               |                       |                        |                           | Spotila et al 1979          |
| swim-up larvae   |                   |                  |        | 18.8                     | 9.8                      |                                   |                            |               |                       |                        |                           | Spotila et al 1979          |

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| Size or Age<br>(mm) | Season | Day or<br>Night | Upper<br>Avoidance | Final<br>Preferendum | Lower<br>Avoidance | Acclimation<br>Temperature | Acclimation<br>Time | PREFERRED TEMPERATURES: |               |
|---------------------|--------|-----------------|--------------------|----------------------|--------------------|----------------------------|---------------------|-------------------------|---------------|
|                     |        |                 |                    |                      |                    |                            |                     | Location                | Reference     |
| small               |        |                 |                    | 12.2                 |                    |                            |                     | Muskellunge L., Wis.    | Coutant 1977a |
| large               |        |                 |                    | 20.2                 |                    |                            |                     | Muskellunge L., Wis.    | Coutant 1977a |
|                     |        |                 |                    | 20.2                 |                    |                            |                     | Silver L., Wis.         | Coutant 1977a |
|                     |        |                 |                    | 21.0                 |                    |                            |                     | Nebish L., Wis.         | Coutant 1977a |
|                     |        |                 |                    | 20.8                 |                    |                            |                     | Trout L., Wis.          | Coutant 1977a |
|                     |        |                 |                    | 19.7                 |                    |                            |                     | L. Nipissing, Ont.      | Coutant 1977a |
|                     |        |                 |                    | 21.1                 |                    |                            |                     | L. Opeongo, Ont.        | Coutant 1977a |
| adult               | W      |                 |                    | 21.0                 |                    |                            |                     | Costello L., Ont.       | Coutant 1977a |
|                     |        |                 |                    |                      | 11                 |                            |                     | L. Michigan             | Coutant 1977a |
| small               |        |                 |                    | 21.0                 |                    |                            |                     | Lab                     | Coutant 1977a |
| small               |        |                 |                    | 24.2                 |                    |                            |                     | Lab                     | Coutant 1977a |
| small               |        | D               | 26.5               | 23.3                 | 20.2               |                            |                     | Lab                     | Coutant 1977a |
| small               |        | N               | 25                 | 22.5                 | 19.5               |                            |                     | Lab                     | Coutant 1977a |
| small               |        |                 |                    | 23.3                 |                    |                            |                     | Lab                     | Coutant 1977a |
| adults              |        |                 |                    | 20.1                 |                    |                            |                     | Lab                     | Coutant 1977a |
| YOY                 | W      |                 |                    | 10-13                |                    |                            |                     | Lab                     | Coutant 1977a |
| YOY                 | SP     |                 |                    | 18.0                 |                    |                            |                     | Lab                     | Coutant 1977a |
| YOY                 | su     |                 |                    | 25-27                |                    |                            |                     | Lab                     | Coutant 1977a |
| YOY                 | F      |                 |                    | 28.0                 |                    |                            |                     | Lab                     | Coutant 1977a |
| adult               | W      |                 |                    | 7-12                 |                    |                            |                     | Lab                     | Coutant 1977a |
| adult               | SP     |                 |                    | 13-16                |                    |                            |                     | Lab                     | Coutant 1977a |
| adult               | su     |                 |                    | 27.0                 |                    |                            |                     | Lab                     | Coutant 1977a |
| adult               | F      |                 |                    | 22-25                |                    |                            |                     | Lab                     | Coutant 1977a |
| adult               | W      |                 |                    | 14.1                 |                    |                            |                     | Lab                     | Coutant 1977a |
| adult               | su     |                 |                    | 20.9                 |                    |                            |                     | Lab                     | Coutant 1977a |
| adult               | F      |                 |                    | 19.9                 |                    |                            |                     | Lab                     | Coutant 1977a |
| juvenile            | w      |                 |                    | 22                   |                    |                            |                     | Lab                     | EPA 1974      |
| juvenile            | su     |                 |                    | 24                   |                    |                            |                     | Ont. Lakes              | EPA 1974      |
| juvenile            |        |                 |                    | 20-23                |                    | 24                         |                     | Lab                     | EPA 1974      |
| adult               |        |                 |                    | 18-20                |                    | 24                         |                     | Lab                     | EPA 1974      |
| larva               |        |                 |                    | 13-18                |                    |                            |                     |                         | Brown 1974    |



| Size or Age<br>(mm)          | Season   | Day or<br>Night | Upper<br>Avoidance | Final<br>Preferendum | Lower<br>Avoidance | Acclimation<br>Temperature | Acclimation<br>Time | PREFERRED TEMPERATURES:                             |  |
|------------------------------|----------|-----------------|--------------------|----------------------|--------------------|----------------------------|---------------------|---|--|
|                              |          |                 |                    |                      |                    |                            |                     | Location  | Reference  |
| small<br>underyear-<br>lings | W        |                 | 30.5               | 13                   |                    | 1                          |                     | L. Monona, Wis.                                     | Brown 1974<br>Brown 1974                             |
| 82-118TL                     |          |                 | 26                 | 23                   | 20                 | 20-22                      |                     |   | Brown 1974   |
| 121-169TL                    |          |                 | 33.3-34.4          |                      |                    | 25                         |                     |   | Brown 1974   |
| 30-50FL                      |          |                 | 21                 | 19.2                 | 12                 | 15                         |                     | Lab   | Cherry et al 1977                                    |
| 30-50FL                      |          |                 | 27                 | 20.4                 | 15                 | 18                         |                     | Lab   | Cherry et al 1977                                    |
| 30-50FL                      |          |                 | 27                 | 21.1                 | 18                 | 21                         |                     | Lab   | Cherry et al 1977                                    |
| 30-50FL                      |          |                 | 29                 | 22.4                 | 18                 | 24                         |                     | Lab   | Cherry et al 1977                                    |
| 30-50FL                      |          |                 |                    | 21.4                 |                    |                            |                     | Lab   | Cherry et al 1977                                    |
| juvenile                     | F        | D               |                    | > 15                 |                    |                            |                     | L. Michigan   | Brandt et al 1980                                    |
| juvenile                     | F        | N               |                    | > 17                 |                    |                            |                     | L. Michigan   | Brandt et al 1980                                    |
| larvae                       | su       |                 |                    | 12-25                |                    |                            |                     | Atikokan GS, Ont.                                   | Haymes 1984  |
| adult                        | F        |                 |                    | 12.3-13.8            |                    | 5                          |                     | Lab   | EPA 1976   |
| adult                        | F        |                 |                    | 13.5-18.8            |                    | 10                         |                     | Lab   | EPA 1976   |
| adult                        | F        |                 |                    | 17.6-20.2            |                    | 15                         |                     | Lab   | EPA 1976   |
| adult                        | F        |                 |                    | 16.1-24.2            |                    | 20                         |                     | Lab   | EPA 1976   |
| adult                        | Wi       |                 |                    | 25                   |                    |                            |                     | Lab   | EPA 1976   |
| adult                        | su       |                 |                    | 17                   |                    |                            |                     | Lab   | EPA 1976   |
| adult                        | Wi       |                 |                    | 6.3                  |                    | 5.4                        |                     | power plant thermal effluent                        | Cravens et al 1983                                   |
| adult                        |          |                 |                    | 8.0                  |                    | 0                          |                     |   | Cravens et al 1983                                   |
| adult                        |          |                 |                    | 22                   |                    | 18                         |                     |   | Cravens et al 1983                                   |
|                              | Wi       |                 |                    | 5.4                  |                    |                            |                     | Pokegama Res., Minn.<br>near thermal outfall, Minn. | Cravens 1981   |
|                              | Wi       |                 |                    | 6.3                  |                    |                            |                     |   | Cravens 1981   |
| adult                        | F        |                 |                    | 7-8, 11-17<br>14-19  |                    |                            |                     | L. Michigan<br>Wickett L., Manitoulin Isl., Ont.    | Talmage and Coutant 1980<br>Talmage and Coutant 1980 |
| 60 g                         |          |                 |                    | 20.2                 |                    | 20                         |                     | Lab   | Talmage and Coutant 1980                             |
| newly hat-<br>ched larvae    |          |                 |                    | 24.3                 |                    | 20                         |                     |   | Talmage and Coutant 1980                             |
|                              |          |                 |                    | 24.2                 |                    | 23                         |                     |   | Talmage and Coutant 1979                             |
|                              |          |                 |                    | 21.7                 |                    | 25                         |                     |   | Talmage and Coutant 1979                             |
| 8-11<br>adult                | SP<br>su |                 | >29                | 12-16<br>18-21       |                    |                            |                     | Keowee Res., S.C.                                   | Clugston et al 1978<br>Clugston et al 1978           |
| juvenile                     | su       |                 |                    | 20-24                |                    |                            |                     |   | Clugston et al 1978                                  |

SPECIES: *Perca flavescens* (yellow perch)

| Size or Age (mm) | Optimum °C | Range     | (a)  |        | (b)             |              | Location | GROWTH TEMPERATURES:        |  |
|------------------|------------|-----------|------|--------|-----------------|--------------|----------|-----------------------------|--|
|                  |            |           | MWAT | ST Max | No Growth Upper | Limits Lower |          | Reference                   |  |
| adult            |            | 13-20     | 22   | 29     |                 |              |          | EPA 1974                    |  |
| juvenile         | 22.5       |           |      |        |                 |              |          | EPA 1974                    |  |
| juvenile         | 23         | 20-23.3   |      |        |                 |              |          | McCauley and Casselman 1980 |  |
| adult            |            | 17.6-20.1 |      |        |                 |              |          | Smagula and Adelman 1982    |  |
|                  | 24.2       |           |      |        |                 |              |          | Leidy and Jenkins 1977      |  |
| 5.2-23.7 g       | 23         |           |      |        |                 |              |          | Leidy and Jenkins 1977      |  |
| 0.5 g            | 28         |           |      |        |                 |              |          | Leidy and Jenkins 1977      |  |
| YOY              | 23-24      |           |      |        |                 |              |          | Jobling 1981                |  |
| juvenile/adult   | 29         |           |      |        |                 | 32           |          | Jobling 1981                |  |
|                  | 23         |           |      |        |                 | 28           |          | Jobling 1981                |  |
|                  | 26-30      |           |      |        |                 |              |          | Kitchell et al 1977         |  |
|                  | 24.7       |           |      |        |                 |              |          | Kitchell et al 1977         |  |
|                  |            |           |      |        |                 |              |          | Ney 1978                    |  |
|                  |            |           |      |        |                 |              |          | Casselman 1978              |  |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 113 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Perca flavescens* (yellow perch)

| Event            | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b)                        |                  | (c) Lethal Upper | (c) Lethal Lower | (d)              |                     | Location | Reference                         |
|------------------|--------------------------------|--------------|------------|----------|----------------------------|------------------|------------------|------------------|------------------|---------------------|----------|-----------------------------------|
|                  |                                |              |            |          | ST Max for Embryo Survival | Acclimation Time |                  |                  | Median Lethal ΔT | Median Lethal Final |          |                                   |
| spawning         |                                | 12           | 7-15       | 12       | 20                         |                  |                  |                  |                  |                     |          | EPA 1974                          |
| incubation/hatch |                                | 10-20        | 7-20       |          |                            |                  |                  |                  |                  |                     |          | EPA 1974                          |
| wintering        |                                | <6           | 4-11       |          |                            |                  |                  |                  |                  |                     |          | Brown 1974                        |
| spawning         |                                | 7.8-12.2     | 7-16       |          |                            |                  |                  |                  |                  |                     |          | Brown 1974                        |
| incubation       |                                |              | 7-15       |          |                            |                  |                  |                  |                  |                     |          | Brown 1974                        |
| heat shock       |                                |              |            |          |                            |                  | 32               |                  |                  |                     |          | Ellis 1984                        |
|                  |                                |              |            |          |                            |                  | <37              |                  |                  |                     |          | Teleki 1976                       |
| spawning         |                                | 5-6          | 3          |          |                            |                  |                  |                  |                  |                     |          | Dunford 1978                      |
|                  |                                |              |            |          |                            |                  |                  |                  |                  |                     |          | Big Point, Bay of Quinte, L. Ont. |

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |                |      |                                |                  |                        |                        |           |                         |                                     |                                      |
|--|--------------------------------|--------------|----------------|------|--------------------------------|------------------|------------------------|------------------------|-----------|-------------------------|-------------------------------------|--------------------------------------|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp (a) Range | MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median AT | (d) Median Lethal Final | Location                            | Reference                            |
|  |                                |              |                |      |                                |                  |                        |                        |           |                         |                                     |                                      |
| larval devel                           |                                | 13.1-18.2    |                |      |                                |                  |                        |                        |           |                         | Lab                                 | Griffiths 1978                       |
| hatching                               |                                | <12          | 8-19           |      |                                |                  |                        |                        |           |                         | Lab                                 | Griffiths 1978                       |
| hatching                               |                                | 8.4          | 7-10           |      |                                |                  |                        |                        |           |                         | Lab                                 | Griffiths 1978                       |
| heat shock/ 7                          |                                |              |                |      |                                |                  |                        | +17                    | 24        |                         |                                     | Moore 1979(d)                        |
| spawning                               |                                | 8-10         |                |      |                                |                  |                        |                        |           |                         | Long Point Bay, L. Erie             | Talmage and Coutant 1978             |
| spawning                               |                                | 10           |                |      |                                |                  |                        |                        |           |                         | Lab                                 | Talmage and Coutant 1980             |
| spawning                               |                                | 10           |                |      |                                |                  |                        |                        |           |                         | Keowee Res., S.C.                   | Talmage and Coutant 1980             |
| incubation                             |                                | 9.9          |                |      |                                |                  |                        |                        |           |                         | Lab                                 | Talmage and Coutant 1980             |
| Incubation                             |                                | <16          |                |      |                                |                  | 22                     |                        |           |                         | Lab                                 | Wyman 1981                           |
| heat shock/ 7 larvae                   |                                |              |                |      |                                |                  |                        | +17                    |           |                         | Lab; simulated onshore discharge    | Crippen and Fahmy 1981               |
| heat shock/ 7 larvae                   |                                |              |                |      |                                |                  |                        | +21.6                  |           |                         | Lab; simulated tempering discharge  | Crippen and Fahmy 1981               |
| heat shock/ 7 larvae                   |                                |              |                |      |                                |                  |                        | +15.5                  |           |                         | Lab; simulated offshore discharge   | Crippen and Fahmy 1981               |
| spawning                               |                                |              | 4-18.5         | 11.9 |                                |                  |                        |                        |           |                         |                                     | Hokanson 1977                        |
| spawning                               |                                | 6-12         |                |      |                                |                  |                        |                        |           |                         |                                     | Houston 1982                         |
| spawning                               |                                | <9-10        |                |      |                                |                  |                        |                        |           |                         | L. Opinicon, L. Ont. Wisc.          | Thorpe 1977                          |
| heat shock (larval)                    | 7.6-15.8                       |              | 7.2-11         |      |                                |                  |                        | > +15                  |           |                         | Lab; simulated once-through cooling | Clugston et al 1978<br>Dunstall 1979 |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: Stizostedion canadense (sauger)

| THERMAL TOLERANCES:  |                  |                  |         |                          |                          |                             |  |                         |  |               |                       |                        |          |                       |
|----------------------|------------------|------------------|---------|--------------------------|--------------------------|-----------------------------|--|-------------------------|--|---------------|-----------------------|------------------------|----------|-----------------------|
| Size or Age (mm)     | Acclimation Temp | Acclimation Time | Sea son | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = a + b (temp) a b |  | Data Limits Upper Lower |  | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location | Reference             |
| 119; juvenile larval | 25.8             |                  | F       | 30.4                     | 6.0                      |                             |  |                         |  |               |                       |                        |          | Hokanson 1977         |
| 119; juvenile        | 10.1             |                  |         | 20.9                     |                          |                             |  |                         |  | 27            | 114                   |                        | Lab      | Hokanson 1977         |
| 119; juvenile        | 12.0             |                  |         | 26.6                     |                          |                             |  |                         |  | 28            | 68                    |                        | Lab      | Smith and Koenst 1975 |
| 119; juvenile        | 13.9             |                  |         | 26.7                     |                          |                             |  |                         |  | 30            | 16                    |                        | Lab      | Smith and Koenst 1975 |
| 119; juvenile        | 16.0             |                  |         | 28.4                     |                          |                             |  |                         |  | 30            | 18                    |                        | Lab      | Smith and Koenst 1975 |
| 119; juvenile        | 18.3             |                  |         | 28.6                     |                          |                             |  |                         |  | 30            | 19                    |                        | Lab      | Smith and Koenst 1975 |
| 119; juvenile        | 19.9             |                  |         | 28.7                     |                          |                             |  |                         |  | 31            | 122                   |                        | Lab      | Smith and Koenst 1975 |
| 119; juvenile        | 22.0             |                  |         | 29.5                     |                          |                             |  |                         |  | 31            | 545                   |                        | Lab      | Smith and Koenst 1975 |
| 119; juvenile        | 23.9             |                  |         | 29.9                     |                          |                             |  |                         |  | 32            | 348                   |                        | Lab      | Smith and Koenst 1975 |
| 119; juvenile        | 25.8             |                  |         | 30.4                     |                          |                             |  |                         |  | 32            | 246                   |                        | Lab      | Smith and Koenst 1975 |
| juvenile             | 26               |                  |         | 30.4                     |                          |                             |  |                         |  |               |                       |                        |          | EPA 1974              |
|                      |                  |                  |         | 26                       |                          |                             |  |                         |  |               |                       |                        |          |                       |

SPECIES: Stizostedion canadense (sauger)

| PREFERRED TEMPERATURES: |        |              |                 |                   |                 |                         |                  |                            |                       |  |
|-------------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|----------------------------|-----------------------|--|
| Size or Age (mm)        | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | Location                   | Reference             |  |
| large                   |        |              |                 | 19.2              |                 |                         |                  | Norris Res., Tenn.         | Coutant 1977a         |  |
| large                   |        |              | 28              |                   | 22              |                         |                  | Wabash R., Ind.            | Coutant 1977a         |  |
|                         |        |              |                 | 22.6              |                 |                         |                  |                            | Jobling 1981          |  |
|                         |        |              |                 | 21.3              |                 |                         |                  |                            | Jobling 1981          |  |
|                         |        |              |                 | 18.6-19.2         |                 |                         |                  | lake                       | Hokanson 1977         |  |
|                         |        |              |                 | 22-28             |                 |                         |                  | stream                     | Hokanson 1977         |  |
|                         |        |              |                 | 19                |                 |                         |                  | field                      | EPA 1974              |  |
| adult                   | su     |              |                 | 27-29             |                 |                         |                  | Wabash Ft., Ind.           | EPA 1974              |  |
|                         | F      |              |                 | 14-21             |                 |                         |                  | power plant, Ohio R.       | Yoder and Gammon 1976 |  |
|                         | W      |              |                 | 8-11              |                 |                         |                  | power plant, Ohio R.       | Yoder and Gammon 1976 |  |
|                         |        |              |                 | 26-28             |                 |                         |                  | power plant, Ohio R.       | Yoder and Gammon 1976 |  |
|                         | SP     |              |                 | 7.2               |                 |                         |                  | Norris Res., Tenn.         | Brown 1974            |  |
|                         | su     |              |                 | 21.1              |                 |                         |                  | Norris Res., Tenn.         | Brown 1974            |  |
|                         |        |              |                 | <20               |                 |                         |                  | Lewis and Clark Res., S.D. | Brown 1974            |  |

SPECIES: *Stizostedion canadense* (sauger)

| Size or Age (mm) | Optimum °C | Range   | (a)  |        | No Growth Upper | Limits Lower | Location | GROWTH TEMPERATURES:   |  |
|------------------|------------|---------|------|--------|-----------------|--------------|----------|--|--|
|                  |            |         | MWAT | ST Max |                 |              |          | Reference  |  |
| juvenile         | 22         | 16.1-26 | 25   | 30     | 26              |              | Lab      | Smith and Koenst 1975<br>EPA 1974<br>Talmage and Coutant 1980<br>Fitz and Holbrook II 1978 |  |
|                  | 315.4      |         |      |        |                 | 5            |          |  |  |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: *Stizostedion canadense* (sauger)

| Event            | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location          | SPAWNING AND DEVELOPMENT TEMPERATURES: |
|------------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|------------------|-------------------------|-------------------|--|
|                  |                                |              |            |          |                                |                  |                        |                        |                  |                         |                   | Reference                              |
| spawning         |                                |              | 4-14.4     |          |                                |                  |                        |                        |                  |                         | N. Dak., Tenn.    | Hokanson 1977                          |
| spawning         |                                | 9-15         |            |          |                                |                  |                        |                        |                  |                         |                   | Hokanson 1977                          |
| incubation       |                                | 12-15        |            |          |                                |                  |                        |                        |                  |                         |                   | Hokanson 1977                          |
| spawning         |                                | 9            | S-12       | 10       | 21                             |                  |                        |                        |                  |                         |                   | Smith and Koenst 1975<br>EPA 1974      |
| spawning         |                                | 10           | 6-14       |          |                                |                  |                        |                        |                  |                         | Norris Res., Tenn | EPA 1974                               |
| incubation/hatch |                                | 12-15        | 10-16      |          |                                |                  |                        |                        |                  |                         |                   | EPA 1974                               |
| spawning         |                                |              | 3.0-11     |          |                                |                  |                        |                        |                  |                         |                   | Brown 1974                             |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: Stizostedion vitreum (walleye)

| Size or Age<br>(mm)     | Accli-<br>mation<br>Temp | Accli-<br>mation<br>Time | Sea-<br>son | THERMAL TOLERANCES:               |                                   |                            |                       |                                  |                              |                     | Reference                      |
|-------------------------|--------------------------|--------------------------|-------------|-----------------------------------|-----------------------------------|----------------------------|-----------------------|----------------------------------|------------------------------|---------------------|--------------------------------|
|                         |                          |                          |             | Upper<br>Incip.<br>Lethal<br>Temp | Lower<br>Incip.<br>Lethal<br>Temp | log time =<br>a + b (temp) | Expo-<br>sure<br>Temp | Resis-<br>tance<br>Time<br>(Min) | Critical<br>Thermal<br>(Max) | Location            |                                |
|                         |                          |                          |             | Data Limits<br>Upper Lower        |                                   |                            |                       |                                  |                              |                     |                                |
| 115; juvenile<br>larval | 25.8                     |                          | F           | 31.6<br>19.2                      | 6.0                               |                            |                       |                                  |                              |                     | Hokanson 1977<br>Hokanson 1977 |
| 115; juvenile           | 8.0                      |                          |             | 27                                |                                   |                            |                       |                                  |                              | Lab                 | Smith and Koenst 1975          |
| 115; juvenile           | 10.1                     |                          |             | 28.6                              |                                   |                            |                       |                                  |                              | Lab                 | Smith and Koenst 1975          |
| 115; juvenile           | 12.1                     |                          |             | 29                                |                                   |                            |                       |                                  |                              | Lab                 | Smith and Koenst 1975          |
| 115; juvenile           | 13.9                     |                          |             | 29.5                              |                                   |                            |                       |                                  |                              | Lab                 | Smith and Koenst 1975          |
| 115; juvenile           | 16.0                     |                          |             | 30.6                              |                                   |                            |                       |                                  |                              | Lab                 | Smith and Koenst 1975          |
| 115; juvenile           | 18.2                     |                          |             | 30.5                              |                                   |                            |                       |                                  |                              | Lab                 | Smith and Koenst 1975          |
| 115; juvenile           | 20.2                     |                          |             | 30.5                              |                                   |                            |                       |                                  |                              | Lab                 | Smith and Koenst 1975          |
| 115; juvenile           | 22.1                     |                          |             | 30.5                              |                                   |                            |                       |                                  |                              | Lab                 | Smith and Koenst 1975          |
| 115; juvenile           | 24.0                     |                          |             | 31.5                              |                                   |                            |                       |                                  |                              | Lab                 | Smith and Koenst 1975          |
| adult                   | 23.3                     |                          | su          |                                   |                                   |                            |                       |                                  | 234.4                        | Lab                 | Reutter and Herdendorf 1976    |
| adult                   | 7.2                      |                          |             | 28.9                              |                                   |                            |                       |                                  |                              |                     | Ellis 1984                     |
| adult                   |                          |                          |             | 31                                |                                   |                            |                       |                                  |                              |                     | Ellis 1984                     |
| 42;                     | 26                       |                          |             | 34                                |                                   |                            |                       |                                  |                              | Wheeler Res.. Tenn. | Wrenn and Forsythe 1978        |

SPECIES: Stizostedion vitreum (walleye)

| Size or Age<br>(mm) | Season | Day or<br>Night | Upper<br>Avoidance | Final<br>Preferendum | Lower<br>Avoidance | Acclimation<br>Temperature | Acclimation<br>Time | PREFERRED TEMPERATURES:           |          | Reference                |
|---------------------|--------|-----------------|--------------------|----------------------|--------------------|----------------------------|---------------------|-----------------------------------|----------|--------------------------|
|                     |        |                 |                    |                      |                    |                            |                     | Location                          | Location |                          |
| large               |        |                 |                    | 20.6                 |                    |                            |                     | Trout Lake, Wis.                  |          | Coutant 1977a            |
| large               |        |                 |                    | 23.2                 |                    |                            |                     | Norris Res., Tenn.                |          | Coutant 1977a            |
|                     |        |                 |                    | 23                   |                    |                            |                     |                                   |          | Jobling 1981             |
|                     |        |                 |                    | 20.6-23.2            |                    |                            |                     | field                             |          | Houston 1982             |
|                     |        |                 |                    | 21                   |                    |                            |                     | field                             |          | Houston 1982             |
| larvae              | SP     |                 |                    | 16                   |                    |                            |                     | Atikokan GS, Ont.                 |          | Haymes 1984              |
|                     |        |                 |                    | 10.6-11.2            |                    |                            |                     | (epilimnion) West Blue Lake, Man. |          | Talmage and Coutant 1980 |
|                     |        |                 | 24                 |                      |                    |                            |                     | Norris Res., Tenn.                |          | Fitz and Holbook II 1978 |
| adult               |        |                 | 21                 |                      |                    |                            |                     | L. Winnibigoshish, Minn.          |          | Inskip and Magnuson 1983 |
| adult               |        |                 |                    | 22                   |                    |                            |                     |                                   |          | Spotila et al 1979       |
|                     |        |                 |                    | 20                   |                    |                            |                     |                                   |          | Spotila et al 1979       |

SPECIES: Stizostedion vitreum (walleye)

| Size or Age<br>(mm) | Optimum<br>°C | Range | (b)            |             | No Growth<br>Upper | Limits<br>Lower | Location                               | GROWTH TEMPERATURES:     |  |
|---------------------|---------------|-------|----------------|-------------|--------------------|-----------------|--|--------------------------|--|
|                     |               |       | (a)<br>M W A T | ST<br>M a x |                    |                 |  | Reference                |  |
|                     |               |       | 25             | 31          |                    |                 |  | This study               |  |
| age 0               |               | 12-28 |                |             | 27                 |                 | West Blue Lake. Man.                   | Cheshire and Steel 1972  |  |
| 85                  | 22.1          |       |                |             | 29                 | 12              |  | Kelso and Ward 1972      |  |
| 65                  | 25.2          |       |                |             |                    |                 |  | Hokanson 1977            |  |
| 1.81-2.00 g         | 22            | 19-25 |                |             |                    |                 |  | Hokanson 1977            |  |
|                     |               |       |                | 32-33       |                    |                 | outdoor experimental channels, Alabama | Smith and Koenst 1975    |  |
|                     | 22.6          |       |                |             |                    |                 |  | Talmage and Coutant 1980 |  |
| <35; fry            | 15            |       |                |             | 20                 | 10              | Lab                                    | Casselmann 1978          |  |
| 425;<br>fingerling  | 22            |       |                |             | 27                 |                 | Lab                                    | Nickum 1978              |  |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 113 (upper incipient lethal temperature - optimum temp for growth).

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: Stizostedion vitreum (walleye)

SPAWNING AND DEVELOPMENT TEMPERATURES:

| Event                     | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | (d) Median Lethal |       | Location                   | Reference                        |
|---------------------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|-------------------|-------|----------------------------|----------------------------------|
|                           |                                |              |            |          |                                |                  |                        |                        | AT                | Final |                            |                                  |
| spawning                  |                                |              | 2.2-15.6   |          |                                |                  |                        |                        |                   |       | Wis.                       | Hokanson 1977                    |
| hatching                  |                                | 6            | 6-12       |          |                                |                  |                        |                        |                   |       |                            | Hokanson 1977                    |
| spawning                  |                                | 8            | 4.4-14.4   |          |                                |                  |                        |                        |                   |       |                            | Marshall 1977                    |
| hatching                  |                                | 9-15         |            |          |                                |                  |                        |                        |                   |       | Lab                        | Smith and Koenst 1975            |
| spawning                  |                                | 6-12         |            |          |                                |                  |                        |                        |                   |       | Lab                        | Smith and Koenst 1975            |
| incubation                |                                | 19-15        |            |          |                                |                  |                        | 20.9                   |                   |       | Lab                        | Smith and Koenst 1975            |
| larval devel              |                                | 9-21         |            |          |                                |                  |                        |                        |                   |       | Lab                        | Smith and Koenst 1975            |
| heat shock<br>(fry-5 day) | 6                              |              |            |          |                                |                  | 21                     |                        | +15               |       | Lab                        | Smith and Koenst 1975            |
| cold shock<br>(fry-2 day) | 11                             |              |            |          |                                |                  |                        | 6                      | - 5               |       | Lab                        | Smith and Koenst 1975            |
| cold shock<br>(fry-7 day) | 21                             |              |            |          |                                |                  |                        | 6                      | - 15              |       | Lab                        | Smith and Koenst 1975            |
| cold shock<br>(80-100 mm) | 25                             |              |            |          |                                |                  |                        | 8.1                    | -16.9             |       | Lab                        | Smith and Koenst 1975            |
| hatching                  |                                | 17.8-19.4    |            |          |                                |                  |                        |                        |                   |       |                            | Smith and Koenst 1975            |
| spawning                  |                                | 6.1-8.3      | 4.4-10.0   |          |                                |                  |                        |                        |                   |       | Kawartha Lakes, Ont.       | Smith and Koenst 1975            |
| incubation                |                                | 7.8-8.9      |            |          |                                |                  |                        |                        |                   |       | Northern Minn.             | Smith and Koenst 1975            |
| spawning                  |                                |              | 6.7-13.0   |          |                                |                  |                        |                        |                   |       | Manitoba                   | Smith and Koenst 1975            |
| spawning                  |                                | 7.2-10       |            |          |                                |                  |                        |                        |                   |       | Lake Gogebic, Mich.        | Smith and Koenst 1975            |
| spawning                  |                                | 4.4-6.7      |            |          |                                |                  |                        |                        |                   |       | Muskegon R., Mich.         | Smith and Koenst 1975            |
| spawning                  |                                | 3.4-10       |            |          |                                |                  |                        |                        |                   |       | Bay of Quinte, L. Ont.     | Smith and Koenst 1975            |
| spawning                  |                                | 5-10         |            |          |                                |                  |                        |                        |                   |       | Northern Wis.              | Smith and Koenst 1975            |
| hatching                  |                                | 16.7-19.4    |            |          |                                |                  |                        |                        |                   |       | Lab                        | Smith and Koenst 1975            |
| spawning                  |                                |              | 8-12       |          |                                |                  |                        |                        |                   |       | Clinch and Powell R, Tenn. | Talmage and Coutant 1980         |
| heat shock<br>(42 mm)     | 26                             |              |            |          |                                |                  |                        |                        | + 6               |       | Wheeler Res., Tenn. Ft.,   | Wrenn and Forsythe 1978          |
| juvenile                  |                                | 21           |            |          |                                |                  |                        |                        |                   |       | Lab                        | Smith and Koenst 1975            |
| spawning                  |                                | 7.1-9.9      |            | 8.9      | 15.6                           |                  |                        |                        |                   |       |                            | This study<br>Spotila et al 1979 |
| incubation                |                                | 10.5-15.5    | 5-19       |          |                                |                  |                        | 20                     |                   |       | Lab                        | Griffiths 1981                   |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.



SPECIES: *Ammocrypta pellucida* (eastern sand darter)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES:     |                         |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-----------------------------|-------------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                    | Reference               |
|                  |        |              |                 | 25                |                 |                         |                  | Chateauguay R., Que         | Scott and Crossman 1973 |
|                  |        |              |                 | 24                |                 |                         |                  | Lake of Two Mountains, Que. | Scott and Crossman 1973 |

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SPECIES: *Etheostoma blennoides* (greenside darter)

| Size or Age (mm) | Acclimation Temp | Acclimation Time | Sea-son | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = $\frac{a + b(\text{temp})}{a \cdot b}$ | Data Limits |       | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | THERMAL TOLERANCES: |                     |
|------------------|------------------|------------------|---------|--------------------------|--------------------------|---|-------------|-------|---------------|-----------------------|------------------------|---------------------|---------------------|
|                  |                  |                  |         |                          |                          |   | Upper       | Lower |               |                       |                        | Location            | Reference           |
|                  | 15               |                  |         |                          |                          |   |             |       |               |                       | 32.2                   | Lab (N.Y.)          | Kowalski et al 1978 |

SPECIES: Etheostoma caeruleum (rainbow darter)

|                  |                  |                  |         |                          |                          |                                     |            |              |               |                       | THERMAL TOLERANCES:    |            |                     |
|------------------|------------------|------------------|---------|--------------------------|--------------------------|-------------------------------------|------------|--------------|---------------|-----------------------|------------------------|------------|---------------------|
| Size or Age (mm) | Acclimation Temp | Acclimation Time | Sea-son | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = $\frac{a-t}{a-b}$ (temp) | Data Upper | Limits Lower | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location   | Reference           |
|                  | 15               |                  |         |                          |                          |                                     |            |              |               |                       | 32.1                   | Lab (N.Y.) | Kowalski et al 1978 |

SPECIES: Etheostoma caeruleum (rainbow darter)

|                  |        |              |                 |                   |                 |                         |                  | PREFERRED TEMPERATURES: |                  |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------|------------------|
| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | Location                | Reference        |
| prolarva         | SP     |              |                 | 20                |                 |                         |                  | Drake's Ck., Ky.        | Floyd et al 1984 |

SPECIES: Etheostoma caeruleum (rainbow darter)

|                |                                |              |            |          |                                |                  |                        |                        |           |                         | SPAWNING AND DEVELOPMENT TEMPERATURES: |                         |
|----------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|-----------|-------------------------|--|-------------------------|
| Event          | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median AT | (d) Median Lethal Final | Location                               | Reference               |
| hatching (Ild) |                                | 17-18.5      |            |          |                                |                  |                        |                        |           |                         |  | Scott and Crossman 1973 |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for Spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: Etheostoma exile (Iowa darter)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES:       |             |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------------|-------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                      | Reference   |
| larval           | Sp/Su  |              |                 | 12-25             |                 |                         |                  | Field, Atikokan GS site, Ont. | Haymes 1984 |

SPECIES: Etheostoma exile (Iowa darter)

| Event    | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location | Reference               |
|----------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|------------------|-------------------------|----------|-------------------------|
|          |                                |              |            |          |                                |                  |                        |                        |                  |                         |          |                         |
| hatching |                                | 13-16        |            |          |                                |                  |                        |                        |                  |                         |          | Scott and Crossman 1973 |

- (a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.
- (b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.
- (c) Not incipient lethal temperatures as defined by Fry et al (1946).
- (d) Simulated larval entrainment temperatures.

SPECIES: Etheostoma flabellare (fantail darter)

| THERMAL TOLERANCES: |                  |                  |         |                          |                          |                             |  |                         |               |                       |                        |           |                     |
|---------------------|------------------|------------------|---------|--------------------------|--------------------------|-----------------------------|--|-------------------------|---------------|-----------------------|------------------------|-----------|---------------------|
| Size or Age (mm)    | Acclimation Temp | Acclimation Time | Sea-son | Upper incip. Lethal Temp | Lower incip. Lethal Temp | log time = a + b (temp a b) |  | Data Limits Upper Lower | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location  | Reference           |
|                     | 15               |                  |         |                          |                          |                             |  |                         |               |                       | 32.1                   | Lab, N.Y. | Kowalski et al 1978 |

SPECIES: Etheostoma flabellare /fantail darter)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |                |      |                                |                  |                        |                        |           |                         |          |                         |
|--|--------------------------------|--------------|----------------|------|--------------------------------|------------------|------------------------|------------------------|-----------|-------------------------|----------|-------------------------|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp Range (a) | MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median AT | (d) Median Lethal Final | Location | Reference               |
| hatching                               |                                | 21.1         |                |      |                                |                  |                        |                        |           |                         |          | Scott and Crossman 1973 |
| spawning                               |                                |              | 18.9-24.4      |      |                                |                  |                        |                        |           |                         | N.Y.     | Brown 1974              |
| spawning                               |                                |              | 7-15           |      |                                |                  |                        |                        |           |                         | N.Y.     | Cooper 1979             |
| migration                              |                                |              |                |      |                                |                  |                        |                        |           |                         |          |                         |
| hatching (30-354)                      |                                |              | 17-20          |      |                                |                  |                        |                        |           |                         |          | Cooper 1979             |
| hatching (21d)                         |                                | 21-22        |                |      |                                |                  |                        |                        |           |                         |          | Cooper 1979             |
| hatching (14-16d)                      |                                | 23.5         |                |      |                                |                  |                        |                        |           |                         |          | Cooper 1979             |

SPECIES: Etheostoma microperca (least darter)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |                |      |                                |                  |                        |                        |           |                     |          |                         |
|--|--------------------------------|--------------|----------------|------|--------------------------------|------------------|------------------------|------------------------|-----------|---------------------|----------|-------------------------|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp Range (a) | MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median AT | Median Lethal Final | Location | Reference               |
| hatching                               |                                | 18-20        |                |      |                                |                  |                        |                        |           |                     |          | Scott and Crossman 1973 |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.  
 (b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.  
 (c) Not incipient lethal temperatures as defined by Fry et al (1946).  
 (d) Simulated larval entrainment temperatures.



SPECIES: *Percina caprodes* (logperch)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES: |                            |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------|----------------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                | Reference                  |
| larval           | SP     |              |                 | 16                |                 |                         |                  | Field, Atikokan GS site | Haymes 1984                |
| larval           | SP     |              |                 | 9-16              |                 |                         |                  | Mississippi R.          | Holland and Sylvester 1983 |
| prolarva         | SP     |              |                 | 11.8              |                 |                         |                  | Drake's Ck., Ky.        | Floyd et al 1984           |
| mesolarva        | SP     |              |                 | 20-23             |                 |                         |                  | Drake's Ck., Ky.        | Floyd et al 1984           |
| metalarva        | Sp/Su  |              |                 | 21-25             |                 |                         |                  | Drake's Ck., Ky.        | Floyd et al 1984           |

SPECIES: *Percina caprodes* (logperch)

| Event      | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal $\Delta T$ | (d) Median Lethal Final | Location | Reference  |
|------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|--------------------------|-------------------------|----------|------------|
|            |                                |              |            |          |                                |                  |                        |                        |                          |                         |          |            |
| egg/larval |                                |              | 22-25      |          |                                |                  |                        |                        |                          |                         | Texas    | Brown 1974 |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures,

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: Percina copelandi (channel darter)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |            |          |                                |                  |                        |                        |                  |                         |                      |                         |
|--|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|------------------|-------------------------|----------------------|-------------------------|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location             | Reference               |
| spawning                               |                                |              | 20.5-21.2  |          |                                |                  |                        |                        |                  |                         | Cheboygan Ft., Mich. | Scott and Crossman 1973 |

- (a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.
- (b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.
- (c) Not incipient lethal temperatures as defined by Fry et al (1946).
- (d) Simulated larval entrainment temperatures.

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SPECIES: Percina maculata (blackside darter)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |            |          |                                |                  |                        |                        |                  |                         |             |                         |
|--|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|------------------|-------------------------|-------------|-------------------------|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location    | Reference               |
| spawning                               |                                | 16.5         |            |          |                                |                  |                        |                        |                  |                         | S. Michigan | Scott and Crossman 1973 |

- (a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.
- (b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.
- (c) Not incipient lethal temperatures as defined by Fry et al (1946).
- (d) Simulated larval entrainment temperatures.

SPECIES: Aplodinotus grunniens (freshwater drum)

| Sire or Age<br>(mm) | Accli-<br>mation<br>Temp | Accli-<br>mation<br>Time | Sea-<br>son | THERMAL TOLERANCES:               |                                   |                            |   |             |       |                       |                                  |                              |          |   |
|---------------------|--------------------------|--------------------------|-------------|-----------------------------------|-----------------------------------|----------------------------|---|-------------|-------|-----------------------|----------------------------------|------------------------------|----------|---|
|                     |                          |                          |             | Upper<br>Incip.<br>Lethal<br>Temp | Lower<br>Incip.<br>Lethal<br>Temp | log time =<br>a + b (temp) |   | Data Limits |       | Expo-<br>sure<br>Temp | Resis-<br>tance<br>Time<br>(Min) | Critical<br>Thermal<br>(Max) | Location | Reference                                   |
|                     |                          |                          |             |                                   |                                   | a                          | b | Upper       | Lower |                       |                                  |                              |          |   |
| adult               | 21.2<br>29-35            |                          |             | 32.8                              |                                   |                            |   |             |       |                       |                                  | 34.0                         | Lab      | Reutter and Herdendorf 1976<br>Houston 1982 |
| YOY                 |                          |                          | su          | 32.8                              |                                   |                            |   |             | 32.8  | 2880                  |                                  |                              |          | Jinks et al 1981                            |

SPECIES: Aplodinotus grunniens [freshwater drum)

| Size or Age<br>(mm) | Season | Day or<br>Night | Upper<br>Avoidance | Final<br>Preferendum | Lower<br>Avoidance | Acclimation<br>Temperature | Acclimation<br>Time | PREFERRED TEMPERATURES:            |                           |
|---------------------|--------|-----------------|--------------------|----------------------|--------------------|----------------------------|---------------------|------------------------------------|---------------------------|
|                     |        |                 |                    |                      |                    |                            |                     | Location                           | Reference                 |
| large               |        |                 |                    | 22.2                 |                    |                            |                     | Norris Res., Tenn                  | Coutant 1977a             |
| large               |        |                 | 30                 |                      | 22                 |                            |                     | Wabash R., Ind.                    | Coutant 1977a             |
| small               |        | D               |                    | 29.5-30.3            |                    |                            |                     | L. Monona, Wis.                    | Coutant 1977a             |
| small               |        | N               |                    | 27.529               |                    |                            |                     | L. Monona, Wis.                    | Coutant 1977a             |
| YOY                 | su     |                 |                    | 31.3                 |                    |                            |                     | Lab                                | Coutant 1977a             |
| adult               | su     |                 |                    | 26.5                 |                    |                            |                     | Lab                                | Coutant 1977a             |
| adult               | F      |                 |                    | 19.6                 |                    |                            |                     | Lab                                | Coutant 1977a             |
|                     |        |                 |                    | 21.1-26.1            |                    |                            |                     | Lewis and Clark L., S.D. (CUE)     | Brown 1974                |
|                     |        |                 |                    | 22                   |                    |                            |                     | thermal discharge, Ohio R.         | Brown 1974                |
|                     |        |                 |                    | 29-31                |                    |                            |                     | thermal discharge, Wabash R., Ind. | Brown 1974                |
|                     | F      |                 |                    | 22-30                |                    |                            |                     | J.M. Stuart GS, Ohio R., Ohio      | Yoder and Gammon 1976     |
|                     | Wi     |                 |                    | 6-11                 |                    |                            |                     | J.M. Stuart GS, Ohio R., Ohio      | Yoder and Gammon 1976     |
| 5-10; larvae        | Su     |                 |                    | 20-28                |                    |                            |                     | Missouri R., Nebr. (CUE)           | Cada and Hergenrader 1980 |



SPECIES: Aplodinotus grunniens (freshwater drum)

| Size or Age (mm) | Optimum °C | Range | (b) ST Max |     | No Growth Limits |       | Location | GROWTH TEMPERATURES: |            |
|------------------|------------|-------|------------|-----|------------------|-------|----------|----------------------|------------|
|                  |            |       | (a) MWAT   | Max | Upper            | Lower |          | Reference            |            |
|                  | 22         |       |            |     |                  | 14.4  | L. Erie  |                      | Brown 1974 |
|                  |            |       | 25.6       | 33  |                  | 18.3  | L. Erie  |                      | Brown 1974 |
|                  |            |       |            |     |                  |       |          |                      | This study |

(a) MWAT (maximum weekly average temperature for growth) = optimum + 1/3 (upper incipient lethal temperature - optimum temp for growth)

(b) Maximum temperature for short-term exposure during growth season to protect against lethal effects.

SPECIES: Aplodinotus grunniens (freshwater drum)

| Event             | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival |  | (c) Lethal Limit Upper | (c) Lethal Limit Lower |     | (d) Median AT | Median Lethal Final | Location                              | Reference     |
|-------------------|--------------------------------|--------------|------------|----------|--------------------------------|--|------------------------|------------------------|-----|---------------|---------------------|---------------------------------------|---------------|
|                   |                                |              |            |          | Acclimation Time               |  |                        |                        |     |               |                     |                                       |               |
| spawning          |                                | 21           | 18-22.2    |          |                                |  |                        |                        |     |               |                     | Wis.                                  | Brown 1974    |
| spawning          |                                |              | 18.0-24.5  |          |                                |  |                        |                        |     |               |                     | Lewis and Clark L., S.D.              | Brown 1974    |
| hatching (36-22h) |                                |              | 21-25      |          |                                |  |                        |                        |     |               |                     |                                       | Brown 1974    |
| hatching          |                                | 23.9         |            |          |                                |  |                        |                        |     |               |                     | L. Erie                               | Brown 1974    |
| heat shock        | W                              |              |            |          |                                |  | 35.6                   |                        |     |               |                     | winter thermal discharge, Sandusky R. | Brown 1974    |
| spawning          |                                |              |            | 21       | 26                             |  |                        |                        |     |               |                     |                                       | EPA 1974      |
| incubation        |                                | 21           | 19-24      |          |                                |  |                        |                        |     |               |                     |                                       | EPA 1974      |
| and hatch         |                                |              | 22-26      |          |                                |  |                        |                        |     |               |                     |                                       | EPA 1974      |
| cold shock        | 27                             |              |            |          |                                |  |                        | 9                      | -18 |               |                     |                                       | Coutant 1977b |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Cottus bairdii* (mottled sculpin)

| THERMAL TOLERANCES: |                  |                  |         |                          |                          |                         |  |                         |               |                       |                        |          |                    |
|---------------------|------------------|------------------|---------|--------------------------|--------------------------|-------------------------|--|-------------------------|---------------|-----------------------|------------------------|----------|--------------------|
| Size or Age (mm)    | Acclimation Temp | Acclimation Time | Sea-son | Upper Incip. Lethal Temp | Lower Incip. Lethal Temp | log time = a + b (temp) |  | Data Limits Upper Lower | Exposure Temp | Resistance Time (Min) | Critical Thermal (Max) | Location | Reference          |
|                     | 15               |                  |         |                          |                          |                         |  |                         |               |                       | 30.9                   |          | Spotila et al 1979 |

SPECIES: *Cottus bairdii* (mottled sculpin)

| PREFERRED TEMPERATURES: |        |              |                 |                   |                 |                         |                  |                    |                             |
|-------------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|--------------------|-----------------------------|
| Size or Age (mm)        | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | Location           | Reference                   |
|                         |        |              |                 | 16.5<br>16.7      |                 |                         |                  | S. Ontario streams | Coutant 1977a<br>Wyman 1981 |

SPECIES: *Cottus bairdii* (mottled sculpin)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |                        |          |                                |                  |                        |                        |                  |                         |                                   |  |
|--|--------------------------------|--------------|------------------------|----------|--------------------------------|------------------|------------------------|------------------------|------------------|-------------------------|-----------------------------------|--|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp Range             | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location                          | Reference  |
| spawning hatching (21-28d)             |                                | 12.8         | 5.0 - 16.1<br>7.8-17.3 |          |                                |                  |                        |                        |                  |                         | Lab                               | Brown 1974<br>Brown 1974   |
| spawning cold shock                    | 18.7                           | 10           |                        |          |                                |                  |                        |                        | 7                | -11.7                   | Field, N.Y.<br>L. Huron, (Seiche) | Scott and Crossman 1973<br>Scott and Crossman 1973<br>This study |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for Spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Cottus cognatus* (slimy sculpin)

| Size or Age<br>(mm) | Accli-<br>mation<br>Temp | Accli-<br>mation<br>Time | Sea-<br>son | THERMAL TOLERANCES:               |                                   |                            |   |             |       |                       |                                  |                              |               |                    |                    |
|---------------------|--------------------------|--------------------------|-------------|-----------------------------------|-----------------------------------|----------------------------|---|-------------|-------|-----------------------|----------------------------------|------------------------------|---------------|--------------------|--------------------|
|                     |                          |                          |             | Upper<br>Incip.<br>Lethal<br>Temp | Lower<br>Incip.<br>Lethal<br>Temp | log time =<br>a + b (temp) |   | Data Limits |       | Expo-<br>sure<br>Temp | Resis-<br>tance<br>Time<br>(Min) | Critical<br>Thermal<br>(Max) | Location      | Reference          |                    |
|                     |                          |                          |             |                                   |                                   | a                          | b | Upper       | Lower |                       |                                  |                              |               |                    |                    |
| 40-1 00             |                          |                          |             | 26.5                              |                                   |                            |   |             |       |                       |                                  |                              | Lab, L. Mich. | Otto and Rice 1977 |                    |
| 70-80               | 5                        |                          | SP          | 18.5                              | <1                                |                            |   |             |       |                       |                                  |                              | 22.7          | Lab, L. Mich.      | Otto and Rice 1977 |
| 70-80               | 10                       |                          | SP          | 22.5                              | <1                                |                            |   |             |       |                       |                                  |                              | 24.8          | Lab, L. Mich.      | Otto and Rice 1977 |
| 70-80               | 15                       |                          | SP          | 23.5                              | 3.5                               |                            |   |             |       |                       |                                  |                              | 26.3          | Lab, L. Mich.      | Otto and Rice 1977 |
| 70-80               | 20                       |                          | SP          |                                   |                                   |                            |   |             |       |                       |                                  |                              | 29.4          | Lab, L. Mich.      | Otto and Rice 1977 |
| 80-100              | 5                        |                          | w           |                                   |                                   |                            |   |             |       |                       |                                  |                              | 24            | Lab, L. Mich.      | Otto and Rice 1977 |
| 80-1 00             | 10                       |                          | w           |                                   |                                   |                            |   |             |       |                       |                                  |                              | 25.1          | Lab, L. Mich.      | Otto and Rice 1977 |
| 80-1 00             | 15                       |                          | w           |                                   |                                   |                            |   |             |       |                       |                                  |                              | 27.3          | Lab, L. Mich.      | Otto and Rice 1977 |
| 80-100              | 20                       |                          | w           |                                   |                                   |                            |   |             |       |                       |                                  |                              | 29.4          | Lab, L. Mich.      | Otto and Rice 1977 |
| 40-100              | 5                        |                          |             |                                   |                                   |                            |   |             | 19    | 305                   |                                  |                              |               | Lab, L. Mich.      | Otto and Rice 1977 |
| 40-100              | 5                        |                          |             |                                   |                                   |                            |   |             | 22    | 25                    |                                  |                              |               | Lab, L. Mich.      | Otto and Rice 1977 |
| 40-100              | 10                       |                          |             |                                   |                                   |                            |   |             | 23    | 8800                  |                                  |                              |               | Lab, L. Mich.      | Otto and Rice 1977 |
| 40-100              | 10                       |                          |             |                                   |                                   |                            |   |             | 26    | 8                     |                                  |                              |               | Lab, L. Mich.      | Otto and Rice 1977 |
| 40-100              | 15                       |                          |             |                                   |                                   |                            |   |             | 24    | 3000                  |                                  |                              |               | Lab, L. Mich.      | Otto and Rice 1977 |
| 40-100              | 15                       |                          |             |                                   |                                   |                            |   |             | 27    | 35                    |                                  |                              |               | Lab, L. Mich.      | Otto and Rice 1977 |
| 40-100              | 20                       |                          |             | 25                                |                                   |                            |   |             |       |                       |                                  |                              |               |                    | Talmage 1978       |

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SPECIES: *Cottus cognatus* (slimy sculpin)

| Size or Age<br>(mm) | Season | Day or<br>Night | Upper<br>Avoidance | Final<br>Preferendum | Lower<br>Avoidance | Acclimation<br>Temperature | Acclimation<br>Time | PREFERRED TEMPERATURES: |                    |
|---------------------|--------|-----------------|--------------------|----------------------|--------------------|----------------------------|---------------------|-------------------------|--------------------|
|                     |        |                 |                    |                      |                    |                            |                     | Location                | Reference          |
| large               |        |                 | 6                  |                      | 4                  |                            |                     | L. Michigan             | Coutant 1977a      |
|                     |        |                 |                    | 6-8                  |                    |                            |                     | L. Michigan             | Brandt et al 1980  |
|                     | F      | N               |                    | 4-6                  |                    |                            |                     | L. Michigan             | Brandt et al 1980  |
|                     |        |                 | 15.2               | 9                    |                    | 5                          |                     | Lab                     | Otto and Rice 1977 |
|                     |        |                 | 21.5               | 12                   |                    | 15                         |                     | Lab                     | Otto and Rice 1977 |
|                     |        |                 |                    | 10                   |                    |                            |                     | L a b                   | Otto and Rice 1977 |
|                     |        |                 | 16                 |                      |                    | 10                         |                     | Lab                     | Otto and Rice 1977 |
|                     |        |                 |                    | 13                   |                    | 20                         |                     |                         | Talmage 1978       |

SPECIES: *Cottus cognatus* (slimy sculpin)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |            |          |                                |                  |                        |                        |                  |                         |                      |                         |
|--|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|------------------|-------------------------|----------------------|-------------------------|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location             | Reference               |
| spawning                               |                                | 5            |            |          |                                |                  |                        |                        |                  |                         | Cayuga L., N.Y.      | Scott and Crossman 1973 |
| spawning                               |                                | 10           |            |          |                                |                  |                        |                        |                  |                         | Trib. Fall Ck., N.Y. | Scott and Crossman 1973 |
| spawning                               |                                | 8            |            |          |                                |                  |                        |                        |                  |                         | Montreal, R., Sask.  | Scott and Crossman 1973 |
| 40-100 mm; 5 heat                      |                                |              |            |          |                                |                  | 22                     |                        | +17              |                         | Lab                  | Otto and Rice 1977      |
| shock                                  | 10                             |              |            |          |                                |                  | 26                     |                        | +16              |                         | Lab                  | Otto and Rice 1977      |
| shock                                  | 15                             |              |            |          |                                |                  | 27                     |                        | +12              |                         | Lab                  | Otto and Rice 1977      |
| cold shock                             | 15                             |              |            |          |                                |                  |                        | 2.5                    | -12.5            |                         | Lab                  | Otto and Rice 1977      |
|  |                                |              |            | 8.       | 1                              | 0                |                        |                        |                  |                         |                      | This study              |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

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SPECIES: *Cottus ricei* (Spoonhead sculpin)

| SPAWNING AND DEVELOPMENT TEMPERATURES: |                                |              |            |          |                                |                  |                        |                        |                  |                         |                        |                                       |
|--|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|------------------|-------------------------|------------------------|---------------------------------------|
| Event                                  | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median Lethal AT | (d) Median Lethal Final | Location               | Reference                             |
| spawning                               |                                | 4.5          |            | 4.5      |                                |                  |                        |                        |                  |                         | Pemichangan L., Quebec | Scott and Crossman 1973<br>This study |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

SPECIES: *Myoxocephalus quadricornis* (deepwater sculpin)

| Size or Age (mm) | Season | Day or Night | Upper Avoidance | Final Preferendum | Lower Avoidance | Acclimation Temperature | Acclimation Time | PREFERRED TEMPERATURES:       |                                    |
|------------------|--------|--------------|-----------------|-------------------|-----------------|-------------------------|------------------|-------------------------------|------------------------------------|
|                  |        |              |                 |                   |                 |                         |                  | Location                      | Reference                          |
| large            |        |              | 4.5<br>10       |                   | 4               |                         |                  | L. Michigan<br>Field          | Coutant 1977a                      |
|                  | F      | N            |                 | <5                |                 |                         |                  | L. Michigan<br>(bottom trawl) | Coutant 1977a<br>Brandt et al 1980 |
| 9-18TL           |        | N            |                 | 2-10              |                 |                         |                  | L. Michigan                   | Mansfield et al 1983               |
| 9-18TL           | SP     | N            |                 | 2-6               |                 |                         |                  | L. Michigan                   | Mansfield et al 1983               |

SPECIES: *Myoxocephalus quadricornis* (deepwater sculpin)

| Event            | Season and/or Acclimation Temp | Optimum Temp | Temp Range | (a) MWAT | (b) ST Max for Embryo Survival | Acclimation Time | (c) Lethal Limit Upper | (c) Lethal Limit Lower | Median AT | (d) Median Lethal Final | Location | Reference            |
|------------------|--------------------------------|--------------|------------|----------|--------------------------------|------------------|------------------------|------------------------|-----------|-------------------------|----------|----------------------|
|                  |                                |              |            |          |                                |                  |                        |                        |           |                         |          |                      |
| incubation (97d) |                                | 1.5          |            |          |                                |                  |                        |                        |           |                         |          | Mansfield et al 1983 |

(a) MWAT = maximum weekly average temperature during month of peak spawning, less than or equal to optimum, or middle of range of spawning temperatures.

(b) Short-term (24h) maximum temperature for successful embryo survival (incubation temp) or maximum temperature for spawning.

(c) Not incipient lethal temperatures as defined by Fry et al (1946).

(d) Simulated larval entrainment temperatures.

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