Appendix A

Summary of Temperature Preference Ranges and Effects for Life Stages of Seven Species of Salmon and Trout

The information in this appendix was taken from a review of the State of Oregon standard for water temperature completed by Cara Berman, U.S. Environmental Protection Agency Region 10, on September 3, 1998.

Definitions (from McCullough 1999):

Optimum: The optimum temperature range provides for feeding activity, normal physiological response, and normal behavior. The optimum range is slightly wider than the growth range.

Preferred: The preferred temperature range is that which the organism most frequently inhabits when allowed to freely select temperatures in a thermal gradient. The final temperature preferendum is a preference made within 24 hours in a thermal gradient and is independent of acclimation temperature.

Lethal loading: Increased burden on metabolism that controls growth and activity. Lethal loading stress occurs over long periods (Brett et al. 1958).

Upper incipient lethal temperature: An exposure temperature, given a previous acclimation to a constant temperature, that 50 % of the fish can tolerate for 7 days. The **ultimate upper incipient lethal temperature** is the point where further increases in acclimation temperature results in no increase in temperature tolerated.

Upper lethal temperature: The temperature at which survival of a test group is 50 % in a 10 minute exposure, given a prior acclimation temperatures within the tolerance zone.

I. Sockeye Salmon

Adult migration:	7.2-15.6^{0}C (Bell 1986, Spence et al. 1996) 10^{0}C adult sockeye lost 7.5 % body weight and had visible fat reserves, at 16.2^{0}C they lost 12 % of their body weight and visible fat reserves were essentially depleted. Females with developing eggs lost more body weight than males; adverse gonadal development in females (Bouck et al. 1975) 21^{0}C migration inhibition (Beschta et al. 1987 from Major and Mighell 1966). Above 21^{0}C rising or stable temperatures blocked entry of fish from the Columbia River into the Okanagan River, WA; falling temperatures allowed migration to resume.
Spawning:	10.6-12.2^{0}C (Bell 1986, Spence et al. 1996)
Incubation:	4.4-13.5^{0}C (Combs 1965) 4.4-13.3^{0}C (Bell 1986, Spence et al. 1996) 10^{0}C (Dept of Fisheries Canada, International Pacific Salmon Fisheries Commission 1952) > 12.8^{0}C severe mortality (Dept of Fisheries Canada, International Pacific Salmon Fisheries Commission 1952; Combs 1965)
Rearing:	10-12.8^{0}C (Bell 1986) 10.6^{0}C (Huntsman 1942, Burgner 1991) 10.6-12.8^{0}C (Coutant 1977) 14.5^{0}C (Coutant 1977, Ferguson 1958, Huntsman 1942) 12-14^{0}C (Brett 1952) 11.2-14.6^{0}C preferred (Beschta et al. 1987) 15^{0}C optimum (Beschta et al. 1987)

Physiological optimum: 15^{0}C (Brett et al. 1958)

Smolt out-migration: 2-10^{0}C (Spence et al. 1996)

Terminates smolt out-migration: 12-14^{0}C (Brett et al. 1958)

II. Spring Chinook Salmon:

Adult migration: 3.3-13.3^{0}C (Bell 1986, Bjornn and Reiser 1991, Spence et al. 1996)
21^{0}C migration block (Temperature Subcommittee, DEQ 1995)

Spawning: 5.6-14.4^{0}C (Olson and Foster 1955)
5.6-13.9^{0}C (Bell 1986, Spence et al. 1996)
5.6-12.8^{0}C (Temperature Subcommittee, DEQ 1995)

Incubation: 5-14.4^{0}C (Bell 1986, Spence et al. 1996)
4.5-12.8^{0}C (Temperature Subcommittee, DEQ 1995)

Rearing: 11.7^{0}C (Coutant 1977, Ferguson 1958, Huntsman 1942)
10-12.8^{0}C (Bell 1986)
10-14.8^{0}C (Temperature Subcommittee, DEQ 1995)

Adult holding: 8-12.5^{0}C (Temperature Subcommittee, DEQ 1995)
13-15.5^{0}C pronounced mortality (Temperature Subcommittee, DEQ 1995)
6-14^{0}C optimal pre-spawning brood stock survival, maturation, and spawning (Marine 1992)

Smoltification and Out-migration: 3.3-12.2^{0}C (Temperature Subcommittee, DEQ 1995)
18.3^{0}C smolt lethal loading stress (Temperature Subcommittee, DEQ 1995)

Optimum production: 10^{0}C (Temperature Subcommittee, DEQ 1995)

Maximum growth: 14.8^{0}C (Temperature Subcommittee, DEQ 1995)

Lethal: 18-21^{0}C (Marine 1992)
17.5^{0}C - upper sub-lethal to lethal range (Berman 1990)

Sublethal: 15-17^{0}C (Marine 1992, Berman 1990)

III. Summer Chinook Salmon:

Adult Migration: 13.9-20^{0}C (Bell 1986, Spence et al 1996)

Spawning: 5.6-14.4^{0}C (Olson and Foster 1955)
6.1-18.0^{0}C (Olson and Foster 1955)
5.6-13.9^{0}C (Spence et al. 1996)

Incubation: 5.0-14.4^{0}C (Spence et al. 1996)

Rearing: 11.7^{0}C (Coutant 1977; Ferguson 1958; Huntsman 1942)
10.0-12.8^{0}C (Bell 1986)

IV. Fall Chinook Salmon:

Adult migration: 10.6-19.4^{0}C (Bell 1986, Spence et al. 1996)

Spawning: 10-12.8^{0}C (Bell 1986)
10-16.7^{0}C (Olson and Foster 1955)
5.6-13.9^{0}C (Spence et al. 1996)

Incubation: 10-12.8^{0}C (Bell 1986)
10-16.7^{0}C (Olson and Foster 1955)
10-12^{0}C (Heming 1982, Neitzel and Becker 1985, Garling and Masterson 1985)
5-14.4^{0}C (Spence et al. 1996)
> 12^{0}C alevins substantial reduction in survival (Ringler and Hall 1975)
> 15.6^{0}C mortality (Smith et al.1983)

Rearing: 12-14^{0}C (Bell 1986)

Smoltification: 4.5-15.5^{0}C typical migration (Spence et al. 1996)
ATPase Activity - 8^{0}C and 13^{0}C allow increased activity over a 6 week period, at 18^{0}C ATPase activity decreases over the same time period - inhibitory effect of water temperature on gill Na-K ATPase activity (Sauter unpublished data)

V. Chinook Salmon (general): Final Temperature Preferendum

Adult: 17.3^{0}C (Coutant 1977)

Yearling: 11.7^{0}C (Ferguson 1958, Huntsman 1942)

Spawning: 5.6-13.9^{0}C (Bjornn and Reiser, 1991)
5.6-10.6^{0}C (Bell 1986)
5.6-12.8^{0}C (Temperature Subcommittee, DEQ 1995)
15.5^{0}C causes spawning inhibition

Incubation: 5-14.4^{0}C (Bjornn and Reiser 1991)
13^{0}C (Bell 1986)
> 12.5^{0}C increases egg mortality and inhibits alevin development - produces only 50 % egg survival (California Department Water Resources 1988)

Rearing: 10-15.6^{0}C maximum productivity (Brett 1952)
12-14^{0}C preferred range (Brett 1952)
7.3^{0}C-14.6^{0}C preferred range (Beschta et al. 1987)
12.2^{0}C optimum (Beschta et al. 1987)
> 12.8^{0}C first feeding fry do not develop normally
> 15.5^{0}C disease increases mortality (Temperature Subcommittee, DEQ 1995)

Smoltification: < 12.2^{0}C for all salmonids (California Department Water Resources 1988)
18-21^{0}C sub-lethal and lethal loading stress (Brett 1952)

Independent Scientific Group (1996): Chinook salmon and other salmon species are not markedly different in their requirements.

Adult migration and spawning: optimum 10^{0}C, with range about 8 to 13^{0}C; stressful >15.6^{0}C; lethal 21^{0}C

Incubation: optimum <10^{0}C with range about 8 to 12^{0}C; stressful >13.3^{0}C; lethal >15.6^{0}C

Juvenile rearing: optimum 15^{0}C with range about 12 to 17^{0}C; stressful >18.3^{0}C; lethal 25^{0}C

National Marine Fisheries Service (1996):

Chinook habitat assessment: 10 to13.9^{0}C for properly functioning; 14 to15.5^{0}C at risk for spawning; and 14 to17.5^{0}C at risk for rearing and migration.

VI. Steelhead Trout:

Adult migration: 10-13^{0}C general preferred (Bjornn and Reiser 1991)
21^{0}C migration inhibition (Beschta et al. 1987)

Upper incipient lethal temperature: 21-22^{0}C (Hicks 1998)

Spawning: 3.9-9.4^{0} C (Bell 1986, Spence et al. 1996)
4.4-12.8^{0}C (Swift 1976)
Rainbow trout brood fish must be held at water temperatures below 13.3^{0}C and preferably not above 12.2^{0}C for a period of 2 to 6 months before spawning to produce eggs of good quality (Smith et al. 1983)

Incubation: 5.6-11.1^{0}C (Hicks 1998)

Preferred Temperatures Rearing:

summer run 10-12.8^{0}C (Bell 1986)

winter run 10-12.8^{0}C (Bell 1986)

fall run 10-14.4^{0}C (Bell 1986)

spring run 10-12.8^{0}C (Bell 1986)
7.3-14.6^{0}C preferred (Beschta et al. 1987)
10^{0}C optimum (Beschta et al. 1987)

Smoltification: 11-12.2^{0}C from 7.2^{0}C resulted in cessation of downstream movement (Hicks 1998)
<12^{0}C (Hicks 1998)

VII. Coho Salmon:

Adult migration: 7.2-15.6^{0}C (Reiser and Bjornn 1979, Brett 1952)

Spawning: 4.4-9.4^{0}C (Reiser and Bjornn 1979, Brett 1952)

10-12.8^{0}C (Bell 1986)
7.2-12.8^{0}C (Hicks 1998)

Incubation: 4.4-13.3^{0}C (Reiser and Bjornn 1979, Brett 1952)
10-12.8^{0}C (Bell 1986)
8-9^{0}C (Sakh 1984)
4-6.5^{0}C (Dong 1981)
Egg mortality approx. 14^{0}C (Reiser and Bjornn 1979, Brett 1952)
>12^{0}C increased mortality (Allen 1957 in Murray and McPhail 1988)

Incubation (cont.): >11^{0}C increased mortality (Murray and McPhail 1988)
1.3-10.9^{0}C produced best survival rates of eggs and alevins (Tang et al. 1987)
2-8^{0}C optimum range (Tang et al. 1987)

Lower lethal: 0.6-1.3^{0}C (Dong 1981)

Upper lethal: 12.5-14.5^{0}C (Dong 1981), University of Washington
10.9-12.5^{0}C (Dong 1981), Dungeness River, WA

Rearing: 11.8-14.6^{0}C (Reiser and Bjornn 1979, Brett 1952)
11.4^{0}C (Coutant 1977)
12-14^{0}C (Bell 1986)
Cessation of growth >20.3^{0}C (Temperature Subcommittee, DEQ 1995, Reiser and Bjornn 1979, Brett 1952)
11.8-14.6^{0}C, preferred (Beschta et al. 1987)
25.8^{0}C, upper lethal (Beschta et al. 1987)

Smoltification: 12-15.5^{0}C (Brett et al. 1958)
2.5-13.3^{0}C observed migration, most fish migrate before temperatures reach 11-12^{0}C (Spence et al. 1996)

Optimum Cruising Speed: 20^{0}C Under yearling and yearling approach velocities above dams exceeding 1.0 foot/second creates a problem in safeguarding under yearlings. Capacity to stem such a current for greater than one hour is limited to 18.5-21.5^{0}C (Brett et al. 1958)

Final Temperature Preferendum:

Adult: 11.4^{0}C (Coutant 1977) Laboratory
16.6^{0}C (Coutant 1977) L. Michigan

Upper lethal: 26^{0}C, incipient lethal temperature (Brett 1952)
Acclimation was 20^{0}C, 50 % mortality in 1,000 min.
25^{0}C (Temperature Subcommittee, DEQ 1995)

Preferred temperature: 12-14^{0}C, temperatures >15^{0}C were avoided (Brett 1952)

VIII. Chum salmon:

Adult migration: 8.3-15.6^{0}C (Bjornn and Reiser 1991)

Spawning: 7.2-12.8^{0}C (Bjornn and Reiser 1991)

Incubation: 8^{0}C (Beacham and Murray 1985)
4.4-13.3^{0}C (Bjornn and Reiser 1991)
6-10^{0}C, maximum efficiency for conversion of yolk to tissue (Beacham and Murray 1985)
12^{0}C, alevin mortality occurred 1-3 days after hatch (Beacham and Murray 1985)

Rearing: 14.1^{0}C (Coutant 1977, Ferguson 1958, Huntsman 1942)
10-12.8^{0}C (Bell 1986)
11.2-14.6^{0}C, preferred (Beschta et al. 1987)
12-14^{0}C, preferred (Brett 1952)
13.5^{0}C, optimum (Beschta et al. 1987)
25.8^{0}C, upper lethal (Beschta et al. 1987)

Final temperature preferendum:

Under yearling: 14.1^{0}C (Coutant 1977) Laboratory

Yearling: 14.1^{0}C (Ferguson 1958) Laboratory
14.1^{0}C (Huntsman 1942) Laboratory

Smoltification: Information not available

Upper lethal: 25.4^{0}C, incipient lethal temperature (Brett 1952)
Acclimation was 20^{0}C, 50 % mortality in 1,000 min.

IX. Cutthroat trout:

Adult migration: Information not available
18-22.8^{0}C upper lethal temperature range (Kruzic 1998)

Adult Holding: Smith et al. (1983), west-slope cutthroat trout: Females held in fluctuating temperatures (2-10^{0}C) had significantly better eggs than those held at a constant 10^{0}C. Elevated temperatures experienced by mature females affected subsequent viability and survival of embryos.

Spawning: 6.1-17.2^{0}C (Beschta et al.1987, Bell 1986)

Incubation: Information not available

Rearing: 10^{0}C (Bell 1986)
9.5-12.9^{0}C, preferred (Beschta et al. 1987)
23^{0}C, upper lethal (Beschta et al. 1987)
22.8^{0}C, upper lethal (Bell 1986)

Smoltification: Information not available

X. Bull trout:

Migration: 10-12^{0}C (EPA 1997, DEQ 1995)

Spawning:	<9-10^{0}C, initiate spawning, MT (Temperature Subcommittee, DEQ 1995) <9^{0}C, initiate spawning, B.C. (Spence et al. 1996, Temperature Subcommittee, DEQ 1995, Pratt 1992) 4.5^{0}C, Metolius River, Oregon (Spence et al. 1996, Temperature Subcommittee, DEQ 1995) 4-10^{0}C (Temperature Subcommittee, DEQ 1995) 5-6.5^{0}C, peak spawning activities (EPA 1997)
Incubation:	8-10^{0}C, 0-20 % survived to hatch, B.C. (Temperature Subcommittee, DEQ 1995) 6^{0}C, 60-90 % survived to hatch, B.C. (Temperature Subcommittee, DEQ 1995) 2-4^{0}C, 80-95 % survived to hatch, B.C. (Temperature Subcommittee, DEQ 1995) 4-6^{0}C, MT (Temperature Subcommittee, DEQ 1995) 1-6^{0}C (Temperature Subcommittee, DEQ 1995) 2-6^{0}C (Spence et al. 1996)
Rearing:	4^{0}C optimal temperature for growth, B.C. (Temperature Subcommittee, DEQ 1995) 4.5^{0}C, Metolius River, Oregon (Temperature Subcommittee, DEQ 1995) 4-4.5^{0}C, optimum fry growth (Temperature Subcommittee, DEQ 1995) 4-10^{0}C, optimum juvenile growth (Temperature Subcommittee, DEQ 1995) <10^{0}C, Metolius River (EPA 1997) >14^{0}C is a thermal barrier in closely related arctic char (Pratt 1992)
Adult resident:	19^{0}C, no bull trout were observed, MT (Temperature Subcommittee, DEQ 1995) 15-18^{0}C, bull trout were present, MT (Temperature Subcommittee, DEQ 1995) <16^{0}C, bull trout present, John Day Basin, OR (Temperature Subcommittee, DEQ 1995) <12^{0}C, highest densities of bull trout, MT (Temperature Subcommittee, DEQ 1995) 9-13^{0}C, adult preference (Temperature Subcommittee, DEQ 1995) Less than or equal to 12^{0}C, highest adult density (Temperature Subcommittee, DEQ 1995) 4-18^{0}C, adults present (Temperature Subcommittee, DEQ 1995) <15^{0}C vertical distribution in lakes (Pratt 1992)
Competition:	12^{0}C, Metolius River, reach susceptible to brook trout invasion (EPA 1997)

Appendix A References

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