MARINE ECOSYSTEM MONITORING

by

AN AD HOC TASK GROUP

of the

ECOLOGY COMMITTEE

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Appendix A, "Quantitative Impact Assessment," prepared by Dr. Charles Comiskey and Mr. Craig Brandt of Science Applications, Inc., Oak Ridge, Tennessee, is presented as an example of an excellent program design, data management, and data analysis system.

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PREFACE

The Executive Committee of the Science Advisory Board at its August 4-5, 1977, meeting requested the Board's Ecology Committee to assist the Agency in establishing a useful and inexpensive biological monitoring system. A study group from the Ecology Committee was asked to prepare a report and, in so doing, consider the following points:

- The feasibility and value of a biological monitoring system to the Agency.
- The overall design of such a system including criteria for selecting a limited number of test sites and guidelines for conducting the research.

A report, "Goals of and Criteria for Design of a Biological Monitoring System" (January 1980) was the outcome of that effort. During the review of the draft report and subsequent deliberations of the Ecology Committee, it became obvious that the Agency was devoting virtually no attention to monitoring of the marine environment with the exception of limited attention to estuarine areas and, to some degree, the Gulf of Mexico and the New York Bight.

During the Ecology Committee meeting February 11-12, 1980, the Committee directed that a task group be established to examine marine ecosystem monitoring and the utility of the data gathered to the mandates of EPA. It was agreed that the Task Group would address the following issues:

- Information on EPA's monitoring of the marine environment, exclusive of the estuarine environment.
- Parameters and factors that should be monitored such as abiotic parameters, observations and/or sampling of populations and communities, sampling strategy, specimen disposition, data banks, data users, fate of findings.
- Instrument devices that might be available for monitoring activities that are critical to the needs of EPA.

The Group was not limited to the above specified issues but could consider any items appropriate to its charge.

This report, "Marine Ecosystem Monitoring," is the result of the Task Group's effort.

It became obvious from the Task Group's deliberations that no group of experienced investigators would agree on a single series of methodologies which would meet all situations for resolution of all marine ecosystem problems. There was, however, a common ground where certain principles would be basic to any marine ecosystem program.

Whether or not the suggestions and guidance offered here are utilized in the immediate future or at some later time, the basic principles underlying a suitable marine ecosystem monitoring program remain essentially the same. The potential for legislative changes of current laws and regulatory activities, the state of the national economy, and the Administration's efforts to reduce government cost, as well as the Agency's reordering of priorities may modify the immediate usefulness of this report. This report may, however, serve as a basis of, or provide for, an improved understanding of the issues involved and serve as an underpinning for marine ecosystem monitoring, because the basic principles considered will remain fundamentally unchanged.

I. THE LEGAL RATIONALE FOR MARINE ECOSYSTEM MONITORING

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A. Introduction

The Nation's waters, inland and coastal, are man's waste sumps. Most of the Nation's waste works its way into the coastal waters. Sediments carrying agricultural wastes, runoff, and industrial and municipal effluents are continuously being emptied into the Nation's creeks, canals and other bodies of fresh water, which then flow into the contiguous coastline. Onshore industrial complexes discharge their waste directly into the coastal waters. Industrial and domestic ash and smoke carrying pollutants rise into the atmosphere and, mixed with rain, descend into the bodies of water of the Nation. A significant percentage of oil and waste pollutants results from the intentional or accidental spills from vessels.

In reaction to the constantly increasing water pollution, and to the national awareness of the importance of coastal marine resources, the Congress has enacted a considerable body of pollution legislation.

A variety of monitoring requirements is associated with the resultant regulations, but no national monitoring protocol exists.

Water pollution legislation dates back to August 5, 1866.[1] It was not until 1948, however, that it gained momentum.[2] In that year Congress passed the first Federal Water Pollution Control Act (FWPCA).[3] With the 1972 and 1977 amendments, the FWPCA assumed its present form. To restore and maintain the biological integrity of the Nation's waters is the dominant purpose underlying the Federal Water Pollution Control Act, as amended in 1972 and 1977.[4]

Milestones in 1970 included the signing of the National Environmental Policy Act of 1969 (PL 91-190) on January 1, 1970, and the 1972 major revisions of the FWPCA (PL 92-500), and passage of the Marine Protection, Research and Sanctuaries Act (MPRSA; PL 92-532), also known as the Ocean Dumping Act.

For nearly a century, then, the United States has had Federal pollution control legislation in force through the Rivers and Harbors Act of 1890, 1894, and 1899, and the Federal Water Pollution Control Act of 1948 and subsequent amendments (Table 1). It was not until the 1970's that the legislative base became adequate to enforce water quality control measures, which included permitting and monitoring requirements.

Table 1. FEDERAL LEGISLATION RELEVANT TO MARINE MONITORING (from Soule, unpublished)

Date	Title	Number
1890	Rivers and Harbors Act	
1894	Rivers and Harbors Act (the Refuse Acts)	
1899	Rivers and Harbors Act	
1948	Federal Water Pollution Control Act (FWPCA's Clean Water Act)	PL 80-845
1956	FWPCA Amendments	PL 84-660
1961	FWPCA Amendments	PL 87-88
1965	FWPCA Amendments	PL 89-234
1966	FWPCA Amendments	PL 89-753
1970	National Environmental Policy Act of 1969 (NEPA)	PL 91-190
1970	Water Quality Improvement Act	PL 91-224
1972	Federal Water Pollution Control Act (Major Amendments)	PL 92-500
1972	Marine Protection, Research and Sanctuaries Act (MPRSA or the "Ocean Dumping Act")	PL 92-532
1974	MPRSA Amendments	PL 92-254
1977	MPRSA Reauthorization	PL 95-153
1977	FWPCA Major Amendments	PL 95-217
1978	National Ocean Pollution Research, Development and Monitoring Planning Act of 1978	PL 95-273
1978	FWPCA Amendments	PL 95-576
1980	Clean Water Act (FWPCA Amendments)	PL 96-483

B. Enforcement

Under the Acts, the EPA has the authority, is concerned with, and is engaged in research, development, and monitoring programs relating to pollution of the oceans.[5] The EPA has divided water monitoring into three classes: (1) ambient monitoring (water quality), (2) compliance monitoring (discharge permits), and (3) intensive survey monitoring.

Enforcement falls within the EPA's compliance monitoring. There is no way that the biological integrity of the Nation's waters can be restored and maintained if the water pollution legislation of the United States is not strongly enforced. The FWPCA expressly prohibits the pollution of the marine waters. Section 301(a)[6] provides that, except as otherwise permitted by the Act, "the discharge of any pollutant by any person shall be unlawful."[7]

Section 311(b)(3)[8] provides, "the discharge of oil or hazardous substances into or upon" the navigable waters of the United States "in harmful quantities as determined by the President...is prohibited." The determinations made by the President are none other than the water quality standards designated by the states, or in their absence, the water quality criteria established by the EPA.

Section 309 of the FWPCA contains the enforcement procedure.[9] Under section 309(a)(1), when the Administrator becomes aware of any person acting in violation of the Act, the State to which the program has been delegated is to be notified of the violation. If the state in question fails to act within 30 days from the notification, the EPA is then free to commence Federal enforcement action. In those states where the EPA retains control over the program, enforcement action may be initiated immediately upon the Administrator's becoming aware of a violation. In either instance, the procedures include the issuance of an order for compliance, a violation of which may result in the imposition of a fine, initiation of civil proceedings in the Federal court, or, if the violation is willful and wanton, initiation of criminal proceedings. Under the Federal Water Pollution Control Act the citizen,[10] the EPA, and the States share the enforcement powers. Although these procedures seem to be simple, enforcement of the law, from the time a violation is detected, is cumbersome, if not impossible. In actual practice, the regulatory agency's main problem is detection of the violation. If the agency is lucky enough to detect a violation, very often it is unable to do more. Normally, after detection, the agency attempts to seek compliance extrajudicially, but if it fails, it must then give up or litigate. Litigation in this field is most uncertain; it is very slow and extremely costly.

Another enforcement problem normally encountered by the regulatory state or Federal agency is getting polluters adequately to operate and maintain in-house pollution control equipment. Sometimes it is more difficult to get polluters to operate and maintain their pollution control equipment adequately than it is to get them to install it in the first place. The operating and maintenance costs of pollution control equipment are sometimes more than the annual amortized cost of purchasing and installing the equipment. The regulatory state and Federal agencies lack effective tools for enforcing the operation and proper maintenance of pollution control equipment. The laxity with which the problem is being approached by the regulatory agencies is an invitation to violations of the Statute.

A third enforcement problem being encountered in the administration of the Federal Water Pollution Control Act arises out of the self-incriminating provision of the Statute. Under section 308 of the Act,[1] the EPA may require operators of point sources to keep records, maintain monitoring equipment, sample effluents and provide any other information necessary to the administration of the Act. EPA regulations supplementing this provision require operators of point sources to self-report violations to the EPA. One would have to be naive to believe that all operators of point sources will comply with this self-incriminating provision, especially if the violation is ongoing or repetitive in its nature. On the other hand, you find cases where the owner or operator of a point source, year after year, reports the violations, faces the Agency, settles, and pays the amount of the civil fines imposed. By paying the amount of the settlement, the owner or operator ends up paying less than he would have had to spend to upgrade his pollution control equipment.

The fourth and the most critical problem arises when an aggrieved party goes to court seeking redress for the damages inflicted by the pollution. When a polluter is caught polluting and the pollutant causes extensive damages to the environment, to government and private property, and to shore front businesses, various claims for relief automatically arise. The state may wish to collect for clean-up costs and money damages for injury to its property or to the environment, and for damages to private individuals for their shore front property or businesses.

Each of these enforcement problems could be avoided, in part, by more complete, comprehensive marine monitoring.

Assume liability is established or admitted. How then are damages to living, noncommercial natural resources, which were destroyed by the pollution, quantified? How is the total value of the destroyed resources measured? At present, no accepted methodology exists to determine the extent and value of damages. Unless the scientific community develops a method of quantifying the extent of damages to the living, noncommercial natural resources, and the economists develop a method for measuring those damages in economic terms, the polluter will continue to go free. Courts will continue to hold that those living, noncommercial natural resources are valueless, unaccounted-for creatures, and the polluters will merely be ordered to restore the areas of coastline which were affected and had not naturally recovered, but with the caveat that the restoration be done without grossly disproportionate expenditures.

C. Monitoring Programs

Monitoring is an essential component of a program structured for obtaining environmental information. There are several general categories of activity which require compliance monitoring for the granting of permits under the Acts mentioned above, and which apply to marine environments as well as to aquatic and terrestrial environments. These are

- National Pollutant Discharge Elimination System (NPDES) permits under the FWPCA;
- Ocean Dumping Permits under MPRSA;
- Monitoring for the preparation of Federal Environmental Impact Statements (EIS) is required for new construction and the associated permits. States may have legislative requirements similar to the Federal guidelines such as California's Environmental Quality Act (1970) which requires preparation of an Environmental Impact Report (EIR); and
- Monitoring which is not involved directly in permitting procedures may be classified as either episode-related monitoring or long-term baseline monitoring.

Monitoring can be viewed as a tool for eliciting information required by regulatory mandates or as a means of obtaining information needed to protect and manage marine resources.

1. Compliance Monitoring (NPDES)

The most widespread marine monitoring activities currently practiced over the long term are those associated with the National Pollution Discharge Elimination System (NPDES) permit procedures under the FWPCA legislation.

The Environmental Protection Agency is charged with developing, enforcing, and revising standards for water quality, including those for the marine environment, through control of municipal sanitation discharges, industrial discharges including thermal exchanges, and ocean dumping of wastes and dredged materials.

The NPDES permitting and compliance procedures may be delegated to the states; each state may then designate one of its agencies to manage the procedures. The EPA regions are responsible for delegating the authority to the states and reviewing permits issued; the regions may also countermand state decisions or withdraw the authorizations.

The NPDES permits require monitoring of effluent quality and, in some cases, the receiving waters. The criteria monitored vary extensively as to the parameters included, as to scope in time and space, and especially in requirements for evaluating the effects on the physical and biological environment of the receiving waters.

At the present time, the NPDES permit essentially represents technology-based standards for attaining a given set of values for specific parameters at the mouth of a pipe. An initial baseline survey of the presumed area of impact may be carried out, but the parameters measured may or may not be well selected to evaluate the living environment or ecosystem. Compliance monitoring to maintain a permit may be limited in scope or may be extensive. Such studies for power plants, for example, sometimes represent the only long-term biological monitoring for an extensive coastal area.

Table 2 presents a fairly typical compliance monitoring list (City of Los Angeles Terminal Island Treatment Plant). It is easy to see that the required monitoring of water quality, without biological parameters, would not provide an ecosystems approach. Such permit holders have protested the expense of carrying out monitoring in what they regard as a useless monitoring system. Their data are routinely filed with state agencies or EPA but have not been retrieved or subjected to long-term analysis. Massive plant upsets or non-compliance is readily identifiable, in their view, without extensive monitoring.

In contrast to the monitoring requirements referred to in Table 2, a Los Angeles City power plant nearby is required only to participate in a monthly field water quality survey of temperature, dissolved oxygen, transparency, color, odor, and visible oil and floating solids. In further contrast, a Southern California Edison plant, also nearby, carried out an extensive physical, chemical, and biological survey because

Table 2. A TYPICAL COMPLIANCE MONITORNG PROGRAM FOR A POTW (from Soule, unpublished)

A. Raw Influent (Daily)

Flow (peak and mean)
Five-day BOD
Suspended Solids

B. Final Effluent (Daily)

Flow	(+ 7 day aver.)
Five-day BOD	(+ 7 day aver.)
Suspended Solids	(+ 7 day aver.)
Settleable Solids	
Oil and Grease	
Temperature	
pH	
Coliform (Most Probable Numbers)	
Residual Chlorine	
Turbidity	

Non-Compliance (No. Days, 7 Day aver., 30 Day Aver., %)
Excess BOD_5
Excess Suspended Solids

C. Visual Examination of Receiving Waters (weekly)

Materials of Sewage Origin	Materials of Non-Sewage Origin
Oil and Grease	Refuse
Suspended Solids	Oil and Grease
Rubber Goods	Tar
Odor	Plankton
Turbidity	Turbidity
Coliform (MPN)	Dead Marine Forms

Field Conditions and Receiving Waters (Weekly)

Weather	Surface & 20 ft
Wind	Temperature
Sea	Dissolved Oxygen
People Count	BOD_5
	Color
	Odor
	Transparency

D. Chemical Analysis

Weekly Aver.	Monthly	Quarterly	Annually
Ammonia-N	Nitrate	Aldrin	Arsenic
	Nitrite	BHC	Cadmium
	Org. N	Dieldrin	Chromium
		Endrin	Copper
		Heptachlor	Lead
		" Epoxide	Mercury
		Lindane	Nickel
		DDD, o,p'	Silver
		p,p'	
		DDE, o,p'	Zinc
		p,p'	
		DDT, o,p'	Cyanide
		p,p'	
		Arochlor, 1242, 1254	Selenium
			Phenolics
			Total Id. Cl HC
			PCB
			Radio activity

they were required to produce an Environmental Impact Report on reconditioning their power plant. The survey provided a limited ecosystems approach, since the survey sites designated covered only a relatively small portion of the receiving water system. Their long-term monitoring requirement is greatly reduced.

In the early years of NPDES permitting, the monitoring criteria selected were appropriate to freshwater streams but, unfortunately, were not appropriate to the marine environment. When obvious degradation of habitat occurred in spite of permit limitations, EPA turned to mandating increasing levels of in-plant technology without regard to the need for, or the benefits of, the hardware in relation to the ecosystem of the receiving waters. The assumption was that if effluent quality is sufficiently regulated, good water quality will result.

There will be a reassessment of this approach within the next few years, largely because of the escalating costs of pollution control technology, which industry and the public are increasingly unable to bear. It is therefore important that necessary revisions in the approaches be made.

2. NPDES Records as Data Sources

There are presently 232 land-based discharges whose outfalls enter the territorial seas and beyond, out of 62,400 NPDES permittees nationwide. Of these, 102 are publicly owned treatment works (POTWs), 74 are industrial discharges, 25 are steam electric plants, and 31 are Federal facilities (NACOA, 1981). There are also some 3000 offshore oil and gas exploration and production platforms which must comply with NPDES criteria.

Records compiled from NPDES permits should constitute a tremendous resource for analysis of marine data, but the past lack of consistency in monitoring and the deficiencies in systems for computer data entry and analysis have virtually precluded using past NPDES records for ecological analysis.

Revisions of monitoring requirements should be directed toward obtaining information on the biological as well as the physical water quality of receiving waters rather than the present technology- and emission-based standards now in place. Coupled with an effective data management system, the NPDES permit monitoring could provide significant records for use in an ecosystems analysis approach for a national monitoring program.

3. Ocean Dumping Permits

The Marine Protection, Research and Sanctuaries Act of 1972 (PL 95-153) mandated permit requirements for ocean dumping of wastes and dredged materials. The required monitoring to date has produced some good site-specific data, although some areas have received far less attention than

should have been required. Typically, east coast areas, such as the New York Bight and Cheasapeake Bay, have received extensive monitoring and research efforts while other coastal areas have not.

Ocean dumping permits for dredged materials are issued under the jurisdiction of the U.S. Army Corps of Engineers, with approval of EPA. The EPA designates ocean dumping sites and reviews site-specific monitoring programs in compliance with permitting. Both agencies have heavily emphasized development of bioassay/toxicity testing techniques. Recently, a baseline inventory of the various designated marine dumpsites was undertaken, funded by the Corps, through an EPA contract. NOAA, the Corps, and EPA have carried out extensive investigations related to the 106-Mile Dumpsite off New York.

Some serious differences exist between regulations applied to ocean discharge under NPDES permit criteria and the MPRSA ocean dumping permit criteria. Ocean discharges are, in some cases, also subject to more stringent controls than are discharges in estuarine and freshwater systems (NACOA, 1981). Fragmented or compartmentalized regulations have resulted in some strange constraints. For example, nontoxic, untreated fish processing wastes that could not be discharged into marine waters through a POTW effluent under NPDES permit could legally be discharged by a barge at the same marine site under an ocean dumping permit.

Monitoring requirements developed under such fragmented regulatory regimes are so diverse in scope, in parameters measured, and in time span that the programs, with few exceptions, offer little toward developing a regional or national data base.

4. The EIS Process

Baseline surveys for Environmental Impact Statements (EIS) used to obtain permits for construction in the coastal zone have produced studies of widely varied quality and scope. Some industries and public agencies have made concerted efforts to monitor intensively and to take the ecosystems approach, while others have carried out studies that were incompetently done, trivial, or too limited in scope. The Bureau of Land Management's Outer Continental Shelf Studies for oil and mineral development were widely criticized as being too expensive, but too limited in time and sampling frequency. A more serious fault lay in the lack of consistency in the scopes for different regions, which deprived them of comparability. Such studies for EIS documents could expand the data base for a given area, if measurements and data were compatible with ongoing studies and the quality of the work were verifiable. The ecosystems approach is essential to large EIS projects.

5. Episode Monitoring

Some of the most expensive and least productive monitoring has been carried out on highly visible, major oil spills, such as the ARGO MERCHANT and the IXTOC blowout. Usually no baseline data at a spill site are available, and the emergency mobilization of funds, experts, equipment, and monitoring protocol does not lead to the best use of available resources. Industry is particularly constrained by liability considerations and corporate chains-of-command in getting studies of accident sites initiated quickly enough to determine immediate impacts. Contingency plans and systems of mobilization must be refined.

D. Other Legislation

Some legislation exists which is predicated upon the existence of a data base adequate for planning and managment of resources (NOAA, 1981). For example, decisionmaking for public public policy is mandated in legislation such as the Fisheries Conservation and Management Act (FCMA) of 1976, PL 94-265. The requirement to produce Fisheries Management Plans for commercially important species necessitates developing a maximum sustainable yield (MSY) and a fish catch quota based on MSY. Yet, there is a lack of knowledge pertaining to most fisheries, knowledge which could have been obtained, at least in part, by a monitoring program. For example, information on fish eggs and larvae distributed over large regional areas is required to estimate standing stock or biomass. The California Cooperative Fisheries Investigations (CalCOFI) have been carried out jointly by the National Marine Fisheries Service, the California Department of Fish and Game, and Scripps Institute for Oceanography for thirty years, estimating egg and larvae distribution based upon net surveys and stocks by acoustic and aerial surveys. On the east coast, NOAA's Marine Resources Monitoring Assessment and Prediction Program (MARMAP) has performed extensive monitoring tasks. Such investigations are being cut back or have not been in existence in other areas; yet the FCMA presumes the existence of an adequate data base for planning but does not provide for obtaining one through an adequate research and monitoring program.

It was presumed also that the 1978 National Ocean Pollution Planning Act (PL 95-273) would provide for some coherent, long-term monitoring since it requires production of a Federal Plan for Ocean Pollution Research, Development and Monitoring. Given the constraints of recent Federal budgets, expenditures do not appear to be directed toward a long-term regional approach to monitoring.

Given these constraints, it is essential that revisions in existing regulations be made to make monitoring data that are obtained under permit systems more consistent, more relevant to the biological quality of the environment, more readily available through data management systems, and more compatible for ecosystems analysis.

The Congress of the United States enacted all pollution legislation to clean the Nation's waters and to keep them clean. To achieve this ultimate goal, that legislation must be enforced; otherwise its enactment and existence in the law books cannot in any way be justified. To enforce it, the regulator and the courts must have at hand the tools required to do so. If those tools have not been provided, then it is up to the scientific community, the economists, and the legal profession to make them available. Thus, any monitoring program must be structured in such a way that the integrity of the Nation's waters is restored and maintained and that there be a basis for enforcement of the legislation. The flaws in the existing legislation, as above demonstrated, are many. Monitoring programs with sound scientific bases will allow us to help correct these flaws and clean up our waters.

FOOTNOTES

1. Ch. 929, Sec. 3, 24 Stat. 329.

2. Pub. L. No. 80-845, Sec. 5, 62 Stat. 1155 (1948)

3. After its enactment in 1948 the F.W.P.C.A. was amended five times. In 1956 by Pub. L. No. 84-660, Ch. 518, 70 Stat. 498; in 1961 by Pub. L. No. 87-88, 75 Stat. 204; in 1965 by Pub. L. No. 89-234, 79 Stat. 903; in 1966 by Pub. L. No. 89-753, 80 Stat. 1246 and in 1970 by Pub. L. No. 91-224, 84 Stat. 91.

4. Section 101(a)(2)

5. The Congress of the United States in both the 1972 and 1977 amendments to the F.W.P.C.A. either expressly or impliedly granted to the E.P.A. and other Federal and State agencies and private institutions the power to collect biological data needed to carry out an adequate monitoring system. See Sections 101(a)(2), 104(b)(6), 104(d)(2), 105(d)(3), 106(e)(1), 302 (a), 303(d)(1)(b), 304(g), 304(h), 305(b) 308(a)(3), 311, 314(a)(1), 316(a), 403(c)(1) and 502(15).

6. 33 U.S.C. 1311. Section 309 supplements Section 301(a)'s prohibition as it provides the penalties, civil and criminal, to which a violator of the Act may be subjected to for any violation of the Act.

7. On the other hand Section 13 of the Harbors and Rivers Act prohibits the discharge from a ship or shore installation into the navigable waters of the United States of, "any refuse, matter of any kind or description whatsoever other than flowing from streets and sewers and pass it therefrom in a liquid state".

8. 33 U.S.C. 1321(b)(3). This provision is supplemented by Sections 311(b)(5) and (6), 33 U.S.C. 1321(b)(5),(6), which provide for the criminal and civil penalties for its violation.

9. 33 U.S.C. 1319

10. Under Section 505 of the Act, 33 U.S.C. 1365, suits by private persons are allowed but authorizes only prospective relief.

11. 33 U.S.C. 1318

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II. THE LOGIC FOR MARINE ECOSYSTEM MONITORING

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A. Introduction

Marine ecosystem monitoring presupposes a sampling program to obtain information relevant to the broadest possible spectrum of interests, time spans, localities, and definable environmental compartments. In addition to the standard measurements of temperature-salinity-dissolved oxygen, and the observations done routinely to test for compliance with water quality criteria, baseline information must include data on the marine biota. EPA's mandate is often simplistically reduced to the examination of physical and chemical parameters of environmental quality. The reason for maintaining an environmental quality, however, is to make the environment suitable for the existence of organisms and to allow them to interact as viable communities.

There are no "standard methods" for marine ecosystem monitoring. Yet, when the Environmental Protection Agency brings the weight of its authority to bear against an environmental offender, the Agency must place itself in an adversary situation. It must prove environmental insult before a court of law, and it must justify the observations that lead it to believe that the environment has been adversely affected. These observations are usually in the form of data that have been obtained, presumably in keeping with wise scientific judgment.

Reference must often be made to historical data. These data are "baseline." However, the historical data may have been taken emphasizing given taxonomic groups or emphasizing description rather than function. More often than not, "baseline" assumptions are made from data that do not account for seasonal or ecological succession, and thus the "changes" within a given community may be more natural that episode- or contaminant-produced.

No standard marine ecosystem monitoring protocol can be offered. A logical rationale upon which monitoring and modeling protocols can be structured include the following:

- a rationale for handling the data obtained in such a way that it may be made comparable and compatible with data obtained from monitoring programs elsewhere;
- rationales pertinent to siting intensive monitoring programs in the light of previous monitoring, financial constraints, and reference collections; and

- suggestions as to methods of monitoring that will yield the best results with efficient and appropriate technologies, such as estimating water column biomass with acoustic devices, the use of size of organisms in understanding energy flow between trophic levels, the study of populations of marine bacteria to determine food webs in coastal waters, and some generalities about coastal monitoring.

What follows are discussions relevant to the above which could be used as guidelines or suggestions for marine ecosystem monitoring. They are presented in a format that the specialist will understand, but that also can be understood by the layman, if carefully read.

Marine monitoring may be conducted for a variety of purposes, including (1) baseline surveys, (2) impact detection, (3) compliance monitoring, (4) establishment of causality, and (5) prediction. These different objectives form a graded series from lower to higher resolution, implying different information requirements, design of sampling programs, and methods of data analysis. All monitoring, whatever its degree of refinement, is aimed at determining whether or not an environment is or will be disturbed, by either natural or anthropogenic causes, from its normal (nominal or reference) condition.

B. Baseline Monitoring

To establish nominal baseline conditions, some set of monitoring parameters is chosen for measurement. Let

$$p(s,t) = [p_1(s,t), p_2(s,t), \ldots, p_m(s,t)]$$

be a vector of m such parameters to be measured in space s (1,2 or 3 dimensional) and time t (discrete or continuous). The nominal conditions $p^{\circ}(s,t)$ are established by measurement of the parameter set accumulated over appropriate intervals of space and time. The principal issues at this level are (1) choice of parameters, (2) spatial and temporal design of sampling, and (3) data assembly, analysis, and presentation. Baseline conditions represent a starting point for all other aspects of monitoring.

C. Impact Detection

An elementary monitoring problem is the determination of environmental disturbance. Perturbations $\Delta p(s,t)$ are measured as deviations from nominal,

$$\Delta p(s,t) = p(s,t) - p^{\circ}(s,t),$$

and a suitable perturbation index P might be the integrated deviation over appropriate space and time intervals:

$$P = \left\| \int_s \int_t \Delta p(\sigma, \tau) d\tau \, d\sigma \right\| \geq 0,$$

where $\|\cdot\|$ denotes a vector norm (like absolute value for scalars).

To monitor effectively for impact detection, the monitoring program should be designed to provide both necessary and sufficient conditions to establish the existence of impact. Let

$$P = \begin{cases} P^* \text{ when } P>0, \text{ defining an impact } I^* \\ P^\circ \text{ when } P=0, \text{ defining no impact } I^\circ. \end{cases}$$

Then, by conditional logic, the following propositions, which illustrate the distinction between sufficiency and necessity, hold:

	Symbolic	Verbal
(1)	$P^* \Rightarrow I^*$	Deviation of the perturbation index from 0 is sufficient to denote an impact.
(2)	$I^\circ \Rightarrow P^\circ$	No impact is sufficient to establish that the disturbance index will be 0 (this contrapositive statement is the logical equivalent of the first).
(3)	$P^\circ \Rightarrow I^\circ$	A perturbation index of 0 is sufficient to establish no impact, or, alternatively, absence of impact is necessary for the index to be 0.
(4)	$I^\circ \Rightarrow P^*$	A nonzero perturbation index is sufficient to denote impact, that is, impact is necessary for the perturbation index to be nonzero (this statement is logically equivalent to the third).

Thus, the primary problem in monitoring to detect impact is the selection of a parameter set and sampling design that will establish a necessary and sufficient relationship between the perturbation index and the impact. If only $P^* \Rightarrow I^*$ (sufficiency) is established, then the environment may suffer an impact without its being registered by the disturbance index; the index is blind to the impact. On the other hand, if only $I^* \Rightarrow P^*$ (necessity) is established by the measurement set, then the index may be nonzero when there is no impact. Assurance of impact detection through monitoring requires that the relationship between the monitored parameters and the impact in question be both necessary and sufficient. The parameters and the design of their sampling must be tailored to the impact problem posed.

D. Compliance Monitoring

Another elementary monitoring problem is to determine if and when standards are violated. This is a more specific version of the impact detection problem, and its logic is consequently more straightforward. The "baseline" conditions in this case are the standards themselves. Let

$$\hat{p}^{\circ} = (\hat{p}_1^{\circ}, \hat{p}_2^{\circ}, \ldots, \hat{p}_k^{\circ})$$

be a vector of maximum standards (not to be exceeded, e.g., pollutant concentrations) for k parameters, and let

$$\check{p}^{\circ} = (\check{p}_1^{\circ}, \check{p}_2^{\circ}, \ldots, \check{p}_\ell^{\circ})$$

be a vector of minimum standards (not to be less than, e.g., dissolved oxygen concentration) for ℓ parameters. In most cases these standards are constants, and this is one difference between compliance monitoring and impact detection monitoring. Compliance indices are simply the differences between ambient conditions p(s,t) and the standards:

$$C = p(s,t) - \hat{p}^{\circ} \begin{cases} > 0 & \text{noncompliance (sufficient)} \\ \leq 0 & \text{compliance (necessary)} \end{cases}$$

$$C = p(s,t) - \check{p}^{\circ} \begin{cases} < 0 & \text{noncompliance (sufficient)} \\ \geq 0 & \text{compliance (necessary).} \end{cases}$$

As indicated, necessary and sufficient conditions between the indices and compliance or noncompliance are established automatically by the index values.

E. Establishment of Causality

Except in simple cases where causality is obvious, as in oil spills, nuclear reactor accidents, or accidental releases of large quantities of toxic chemicals, the attribution of causality in perturbations of the marine environment is a complicated problem. A system is observed to deviate from its historically nominal condition soon after an anthropogenic activity is initiated in an area. Is the new activity responsible for the observed changes, or are these merely part of long term variability in nominal states? Or more complexly, which ones of a set of human activities in an area are responsible for deleterious changes that are occurring, and which ones are not? How can causality be distinguished? The logic is the same as in impact detection; a necessary and sufficient relationship must be established between cause and effect. If the cause is present, the effect will be seen (sufficient), and if it is absent, the effect will not be observed (necessary).

In general, there are two approaches to the establishment of causality in environmental assessment, statistical analysis and modeling. Monitoring plays a role in both of these.

F. Modeling

The ecosystem is the unit of causality propagation in the marine environment. A disturbance introduced into the environment moves through all levels of the biotic and abiotic components of the ecosystem, which operates as a holistic unit (all parts can be influenced by all other parts through complicated networks of causal interactions). In the propagation of cause, indirect influences vastly exceed direct ones (Patten, 1981); thus, the establishment of causality in perturbations of the marine environment requires the reconstruction of the essential features of the cause propagating ecosystem network. This means modeling the marine ecosystem.

1. Specifications for Ecosystem Modeling

The following criteria should be met in the formulation of marine ecosystem models to serve in parallel with monitoring in the determination of causality.

1) Holism. The whole ecosystem reacts to both normal inputs and applied perturbations as a total unit. Its model should be constructed in such a way as to capture this attribute.

2) Causality. Direct and indirect influences in ecosystems are carried by many different kinds of markers which mediate many different kinds of interactions. Carbon and energy are the most general of these and are recommended for use in single medium models. Multimedia models are desirable if resources and information available will allow their construction.

3) Exhaustiveness. The model should span all actual or potential biotic and abiotic components of the ecosystem, at some level of resolution, so that further elaboration for a new purpose would involve expanding, contracting, or reformulating an already existing subsystem rather than having to introduce something which is entirely new. Exhaustiveness is consistent with the holistic property.

4) Versatility. A model should be general enough in its conceptual characteristics so that it can be applied to a variety of sites by requantifying its parameters. It is undesireable to have to create a new model for every different situation.

5) Hierarchy. An ecosystem model should be hierarchically organized to reflect the perceived hierarchical organization of marine ecosystems. Spatial and temporal characteristics

are implicit in hierarchical structures. Higher levels occupy large regions of space and operate on long time scales. Lower levels function in small space and short time. Sorting ecosystem components into levels automatically establishes the spatial and temporal scales appropriate to their representation. This feeds back into sampling design of monitoring programs whose purpose is to provide data to quantify the model. One of the most important uses of modeling in conjunction with monitoring is design of the monitoring study.

6) <u>Modularity</u>. Hierarchy facilitates the organization of an exhaustive structure into a modular structure. Modularity contributes to generality because models of varying resolution can be supplied for different needs and problems.

7) <u>Multipurpose</u>. The ecosystem model should be so constructed as to allow it to become the basis for a variety of causality assessment problems.

8) <u>Multiphasic</u>. The model should be constructed in phases, as required by program needs and purposes, and as limited by available information and resources. A scheme for multiphasic development will be outlined in Stages in Ecosystem Modeling, which follows.

9) <u>Multidisciplinary</u>. Marine ecosystems involve physical, chemical, and biological phenomena in their organization, as well as socioeconomic phenomena in their relationships to man. Ecosystem models should encompass all of these aspects as appropriate to the problem at hand.

10) <u>Multiformalism</u>. Different levels of resolution require different mathematical or computer language formalisms for expression. When causality is unknown or cannot be established, statistical models are appropriate. When causality is known but mechanisms are not, or are not to be modeled, linear models suffice. When mechanisms are understood, and their modeling is desirable, nonlinear mathematics is appropriate. An ecosystem model, in its hierarchical, modular, and multipurpose characteristics, should admit multiple formalisms within its organized structure.

2. Stages in Ecosystem Modeling

The stages in ecosystem modeling are relatively invariant, whatever the problem. Each stage has different information and data requirements and presents different opportunities for the design of monitoring studies and the use of monitoring data. In practice, the stages tend to blend somewhat together, but for description it is convenient to separate them. Also, the construction of a model through the stages is not a sequential process, but an iterative one. Developments at

any given stage may require revisions of preceding stages as new information is generated. The modeling procedure is thus adaptive.

Stage 1. Base Mode. According to Zeigler (1976), "The base model concept is introduced as an attempt to capture what is often meant by the real 'system.' It serves to formalize the modeler's thoughts on what he would like to find out about the particular ecosystem, recognizing that he is operating within a framework determined largely by the background of general scientific conceptions of the day.... The base model is what the ecologist formulates for himself independently of complexity and utilitarian considerations." The objective of Stage 1 modeling is to produce a comprehensive, qualitative model of the system under consideration. If this process is not explicit in a modeling-monitoring interaction, then it is usually implicit in that the monitoring study generally reflects conceptions of the day which figure in its design. A point we would make here is that an explicit base model is better than an implicit one in the design of monitoring programs. The reason is that in implicit models the different sections of the ecosystem do not have to relate consistently to each other, and generally do not. Consistency is one of the principal achievements of constructing a conceptual model before a monitoring effort is designed and initiated.

Stage 2. Lumped Model. Zeigler (1976) states, "given a restricted scope of inquiry, it may be possible to construct a model which is valid relative to that scope and which is at the same time much simpler than the base model." This lumped model reduces the complexity of the base model to operational terms. The model becomes mathematical at this point, and its parameters now become available for defining a monitoring program. To the extent that monitoring parameters correspond to model parameters will monitoring data be useful in the assessment of causality in the marine ecosystem. A further benefit derives from the lumped model, namely that its stated variables, inputs, outputs, and coefficients can serve to format a data bank in which data obtained from the monitoring program may be stored. Retrieval in immediately operational form is guaranteed by the consistency of the lumped model which originated in the conceptual model.

Stage 3. Model Calibration. This stage involves quantification of the lumped model by a particular data set, which may be derived from the monitoring program, supplemented by other sources. Calibration represents the most explicit tie between modeling and monitoring, and its objective is usually to produce a quantitative model of the nominal dynamics or statics of the modeled ecosystem.

Stage 4. Nominal Model. The resultant nominal model from Stage 3 represents the baseline concept (Baseline Monitoring, II. B.) in the context of the modeling approach to

establishment of causality. The nominal model may be utilized to simulate ecosystem dynamics, or analyze system structure-function relationships through various forms of systems analysis (sensitivity analysis, stability analysis, etc.). It is through such model manipulations that causality in the system begins to be revealed, sensitive or critical parameters or pathways identified, etc.

Stage 5. Perturbation Model. This stage of modeling involves the embedding of the environmental disturbance(s) of interest into the nominal model. Perturbation embedding may range from simple changes in model parameters to significant alterations in model structure in the case of highly disruptive disturbances. The consequences of perturbation are then revealed as changes in characteristics measured against the baseline of the nominal model. The data requirements for a perturbation model are usually quite stringent, involving, in many cases, knowledge of perturbation effects on the biota and biotic processes. It is a challenge to a good monitoring program to produce such data even though the perturbation model makes the information requirements known in advance. As the ecosystem model provides a cause propagating structure, the influence of the perturbations on this structure can be used to establish likely patterns of causality in the real ecosystem.

Stage 6. Model Validation. Validation is a process of progressively gaining confidence in the ability of the model to represent the real ecosystem. It involves extending the range of verifiable behavior or characteristics over additional, independently collected data sets. Thus, a nominal model constructed based on one year's monitoring data may be validated by recalibrating it with another year's data and determining that its characteristics match the observed. For each new data set so encompassed, the strength of validation is proportionately increased. Validation over perturbation data sets is a particularly strong form of assurance that the model is capable of representing much of reality, because perturbed systems are further from steady state than nominal ones, which are more difficult to model realistically.

3. Prediction

The ultimate goal of science is to predict what may or will happen in the future. A properly validated ecosystem model is the only present means to generate scenarios of responses of the marine environment to presumed or assumed future conditions. The routine, long-term monitoring of parameters revealed by a well validated ecosystem model may provide a means for early warning that an undesirable future is beginning to develop, and corrective measures can be taken to avert it.

G. Conceptual Framework

As mentioned in II.E., a complementary approach to modeling for establishment of causality is the statistical approach. Actually, the protocols of a statistically-based monitoring program are not different from those of a modeling-oriented program, and both approaches should be components of any multidisciplinary impact assessment program.

Model quantification-validation and statistical anaylsis both begin with the (qualitative) basic and lumped models discussed in II.F.2. As the basis for the development of a statistically sound monitoring program, these qualitative models provide the conceptual framework or context for the initial (Phase I) qualitative assessment, where the interactions of the particular technology and the ecosystem are defined and potential impacts and target taxa or communities identified. The identification of potential impacts leads to formulation of specific goals for impact assessment monitoring, and these goals are expressed in the design of the monitoring program. A more detailed discussion of program design protocols for marine impact assessment is given in Appendix A.

An impact assessment program, whether directed toward quantitative modeling or hypothesis testing should represent a progression of evaluations evolving through well-defined phases, each of which contributes to the directions of subsequent phases. The phases in the field program should be closely linked to the stages in the analytic scheme so that maximum utilization of the analytic capabilities is achieved, thereby optimizing the design of the monitoring program and minimizing field and laboratory effort. This coupling is provided by a responsive data management system.

In the simplest case, the quantitative impact assessment program should include the following three phases:

(I) Predesign synthesis
(II) Reconnaissance sampling
(III) Impact assessment sampling.

The goals of Phases I and II are basically the same. Both provide information to aid in the experimental design for the impact assessment phase of the monitoring program (Phase III). The data acquisition and analysis activities of Phases I and II are designed toward

- understanding the basic processes inherent in the ecological system;
- defining the major (temporal and spatial) sources of variation in the system; and
- determining the statistical nature of the data.

Phase I involves the quantitative evaluation of the historical data base and the extraction of information from these data relevant to the goals of the project. Hopefully, historical data are sufficient for design of (Phase III) impact assessment sampling. If they are not, Phase I will identify these gaps and will allow optimization of the Phase II reconnaissance efforts, which are essentially equivalent to baseline sampling or pre-impact monitoring. It is during Phase I that the conceptual model of the ecosystem is formulated and the interactions of the technology and the ecosystem are defined, leading to selection of spatial, temporal, and taxonomic target criteria for Phase II baseline sampling.

The design of the Phase II sampling scheme can be greatly aided by outputs from physical and ecological models. For example, if the goal of the program is to establish a monitoring design to assess the impacts from a major marine sewage outfall, physical modeling of the effluent plume and prediction of the dispersion and deposition of the pollutants can be very helpful in identifying the spatial scale of the baseline monitoring design and the stations for baseline characterization. These model outputs would be especially helpful if (1) the models have been parameterized with site specific current and hydrographic information and (2) the model results are coupled with field studies (e.g., dye studies) to validate the results.

In a similar manner, the results of dynamic ecosystem modeling can be useful in an impact assessment program. If adequate historical data exist to quantify the basic or lumped model and run impact scenarios, the modeling effort could be very instructive in defining those ecosystem components to study in greater detail. Just the process of quantifying and verifying the model will identify flaws or misconceptions regarding the structure of the basic and lumped qualitative models, which will guide the approach for hypothesis testing. Once the model is quantified and verified, sensitivity analysis can be used to identify those components and transfers which would be expected to respond to the perturbation and which deserve a relatively more intensive sampling effort for adequate statistical characterization. This information would then be used, along with site specific information for other environmental covariates (e.g., depth and sediment type), to identify baseline stations for Phase II characterization. The Phase II baseline sampling program can provide the data necessary for model quantification/verification as well as the data required for the development and refinement of hypotheses to be tested in Phase III of the program.

While dynamic ecosystem modeling attempts to look at the ecosystem holistically, models necessarily represent simplifications of the real world. As such they cannot hope to adequately portray the heterogeneity of the ecosystem. Adequate baseline sampling is required to identify that

heterogeneity and assess its effect in the impact assessment scenario. This assessment can only be adequately conducted using statistical and pattern analysis tools. Given the fact that impact assessment must involve collection of samples from the real world, the statistical variability (spatial, temporal, and within cell) of target entities and the importance of major environmental covariates (especially heterogeneity) must be assessed before formalized hypothesis testing can be conducted to establish causal relationships.

The third phase of the program (Phase III) generally involves replicated sampling at stations or strata chosen on the basis of the results of the Phase I and II analyses. The major purpose of replicate sampling is to allow hypothesis testing, mainly through analysis of variance (or other applications of the general linear model, such as regression analysis), to ascertain if there are any significant differences in treatment (station) means for the parameters of concern. The identification of the occurrence of statistically (and ecologically) significant differences in the means for the target entities is one means of approaching causality in impact assessment. The predictive capabilities provided by hypothesis testing techniques (e.g., multiple regression) also allow the researcher to qualitatively assess degrees of impact and the causal mechanisms underlying this impact.

Since hypotheses testing represents the culmination of the impact assessment program, the design of the monitoring program should reflect a thorough understanding of the site-specific characteristics of the ecosystem under consideration. Once established, the design for Phase III sampling should not be rigid, but instead should be subject to modification during the course of Phase III activities. The successful utilization of these generic experimental design criteria are obviously dependent on responsive data management and analysis systems.

H. Data Analysis

Large scale monitoring programs produce a wealth of environmental and biological data. Under these conditions, the observer's ability to comprehend the important ecological relationships and processes is often confounded by the sheer mass of information. There are a variety of numerical and statistical tools available, which, when collectively used in a structured framework, can aid in reducing the multidimensionality of complex data sets to fewer, more interpretable dimensions, thereby facilitating the elucidation of patterns and the development and testing of hypotheses regarding impacts. These methodologies should be organized into a hierarchical analytical approach for the identification and testing of patterns within and between abiotic and biotic data sets. Within this framework, hypothesis testing activities can be optimized.

Such an analysis system is presented in Appendix A. The five stages in the analysis scheme (Exploratory Analysis, Basic Descriptive Statistics, Bivariate Measures of Association, Multivariate Pattern and Classification Analysis, and Hypothesis Testing) are meant to represent logical steps in the extraction of information from biotic and abiotic data sets. Although there is some overlap of the stages, it is felt that the sequence of their application results in a progression of evaluations, with the results of each stage guiding the activities in subsequent stages.

The stages in the analysis system are meant to correspond closely to the phases of the program design. Thus, in Phases I and II of the program (analysis of historical data and reconnaissance or baseline sampling, respectively), emphasis is placed on the first four stages of the analysis system, while in the third phase of the program (involving quantitative impact assessment) hypothesis testing is stressed.

In the exploratory phase of the analysis system, we are attempting to summarize field data temporally, spatially, and taxonomically and utilize this information to describe the overall taxonomic composition of the samples. This summary information serves as a guide toward reducing the number of variables (taxa) which will be utilized in subsequent analyses. Since the data set will be taxonomically subsetted after exploratory analysis, parameters requiring all variables in the sample for calculation, such as diversity, total number of species, and total number of individuals or various trophic indices are generated at this stage for use in subsequent analyses.

In the next two stages of the analysis system, basic descriptive statistics and bivariate measures of association are calculated for those taxonomic or geochemical variables selected in exploratory analysis. The basic descriptive statistics help define the statistical variability of the data (the benchmark), define the need for data transformation (to satisfy the criteria of normality, equality of variance, and additivity), and serve to guide the design for Phase III hypothesis testing (e.g., determination of adequacy of replication). Basic descriptive statistics play their greatest role in an impact assessment program in the reconnaissance (baseline) phase. By calculating basic descriptive statistics in the early phases of the program, the necessary statistical groundwork will be set to establish an efficient design for impact assessment sampling (in Phase III).

Bivariate measures of association are calculated in the third stage of the analysis scheme, and these fall into four categories:

1) Interspecific relationships.
2) Relationships between taxa and environmental variables.
3) Relationships between environmental variables.
4) Relationships between samples based on taxonomic composition or environmental parameters.

The first three relationships are usually expressed using the Pearson product moment correlation coefficient, while the fourth is expressed by such indices as Czekanowski's coefficient or various metric measures.

While these bivariate relationships are instructive in identifying the strongest intervariable trends, the myriad of relationships is difficult to comprehend when a large number of taxa are involved. Classification and pattern analyses techniques, which represent the fourth stage in the analysis scheme, are statistical tools for reducing complex data to a set of dominant trends which can then be further studied using hypothesis testing techniques. Multivariate techniques are also very useful in identifying outlier samples which should then be examined more closely. Without the "Occham's Razor" of classification and pattern analyses, the most important trends in the data could be ignored, leading to erroneous hypotheses and conclusions. Five techniques are generally employed (hierarchical clustering, correspondence analysis, factor analysis, canonical correlation analysis, and discriminant function analysis). Because of their great utility in deriving major assemblage-level trends from large data sets, multivariate pattern and classification analysis techniques are most applicable to the reconnaissance or baseline phases of a monitoring program (Phase II). Because each type of analysis technique reveals somewhat different aspects of the data, several of these techniques should be applied to each data set of interest and the results compared for consistency.

The establishment of a Phase III sampling design represents the culmination of the activities of the predesign synthesis and reconnaissance phases of the program, wherein the systematic application of the first four stages of the analysis system reveals information required to define impact-related hypotheses and establish the optimum experimental approach for testing these hypotheses.

The following are objectives and components of hypothesis testing:

<u>Objectives</u>

- Test hypotheses regarding the standing stock (biomass and abundance) for various habitat types and communities.
- Statistically control extraneous error variance and influence of covariates on group means.
- Develop predictive tools to allow statistical classification of post-impact observations.

- Determine number of samples required for given α, β levels and differences in means for different design configurations.

- Draw inferences concerning real-world patterns.

- Provide recommendations for Phase III design changes to optimize information/cost ratios.

Hypotheses can be tested using a number of techniques (analysis of variance [ANOVA], analysis of covariance [ANCOVA], regression), which are based on the general linear model. The initial conceptualization of the ecosystem and the identification of the relationships of the technology with the environment will have already generated initial and general hypotheses. These initial hypotheses will be modified, depending upon the results from the application of earlier stages of the data analysis scheme (in Phases I and II), with appropriate changes being made in the experimental design prior to and during Phase III of the program.

Analysis of variance and t-tests can be used to test differences in means for class variables while analysis of covariance can be used to remove extraneous variance from the main effects. Intelligent use of analysis of covariance can often have the same effect as increasing replication (by reducing Type II errors). Hypothesis testing includes, as additional features, the calculation of the number of samples required for significance testing, the optimization of the sampling design based on comparison of variance ratios, and predictive capabilities, expressed through multiple regression analysis and discriminant function analysis. Through these predictive capabilities, samples can be classified or dependent variables of interest can be predicted from sets of independent variables.

The implementation of this analysis system is dependent on the ability for rapid acquisition and computerization of relevant historical and project generated data, and creation of a project data base (PDB) where all relevant data are brought into a common format. Without a responsive data management system for rapid incorporation, accessing, and subsetting of the data, the timely application of the analysis protocols would be impossible.

I. Data Management

Multidisciplinary environmental monitoring programs often generate large and diverse sets of data. These data in turn are often used by different parties for different purposes. For example, an enforcement agency may use the data to determine if the system under study is in compliance with a set of environmental standards. A modeler may be interested in using the data to parameterize or validate an ecological model of the system. A statistician may wish to subject the data to a series of statistical and numerical analyses. All of these uses require a sound and integrated data management system for retrieving and manipulating the information generated by a monitoring study.

The large volume of data generated in a monitoring program is best handled by a computerized data management system. A properly designed computerized system offers several advantages including the following:

- the ability to store and manipulate large amounts of data efficiently;
- extensive quality controls during incorporation of data (e.g., range checking) to ensure data accuracy and integrity;
- reduction in clerical handling of the data thereby minimizing the probability of error;
- concurrent utilization of the data by more than one user;
- rapid and easy generation of data subsets for analysis;
- automated data product generation (e.g., tabular and graphical displays);
- access to powerful "canned" packages such as the Statistical Package for the Social Sciences (SPSS), Statistical Analysis System (SAS), and the International Mathematical and Statistical Library (IMSL).

A sound and integrated data management system is the cornerstone to building a project data base (PDB) for a monitoring program. In addition to the data collected during the monitoring study, the PDB should include pertinent historical data. These historical data may come from a variety of sources including the scientific literature and national archives, such as the National Oceanographic Data Center (NODC). If available, the historical data can provide a baseline against which the data from the monitoring program can be compared.

Once the data management system and the data base have been identified, several additional considerations must be addressed. For example, there must be a way of uniquely identifying each sample in the data base. Without this unique identification, retrieval of data is severely hindered. Another consideration involves the formats in which the data are to be stored. Water column temperature data will require a different format from that of phytoplankton data. The types of data retrieval must also be considered. In addition to retrieval of data based on location and time, biotic data may require taxonomic retrieval. For example, an investigator may wish to retrieve all samples containing a certain taxon. Closely linked with biotic data retrieval is the capability to taxonomically or trophically aggregate biotic data to generate new data sets. This capability is especially useful

for parameterizing models. For example, a model may require, as an initial condition, the standing stocks of various trophic groups in each model compartment. The capability of aggregating the biotic data based on trophic characteristics is essential to generating this information for the model. Trophic and taxonomic data aggregation can also be important in statistical analyses for community characterization.

Appendix A contains a detailed description of a data management system which has been successfully employed in a number of marine monitoring programs. All of the points briefly discussed in this section are more fully elaborated upon in Appendix A.

J. Conclusion

The legal requirements of monitoring programs were outlined earlier in this report. In this section the logic of monitoring for environmental protection has been explored. A graded series of monitoring activities was identified, each with different purposes and each with different information and data requirements. The most important points are

- monitoring programs should be designed to establish both a sufficient and a necessary relationship between the measured parameters and the environmental problem at hand, and

- to establish causality and make predictions, monitoring must be joined in a mutualistic relationship to ecosystem modeling, and both should be developed hand in hand as part of the same program.

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III. SUGGESTIONS AS TO METHODS AND SITES OF MONITORING

III. SUGGESTIONS AS TO METHODS AND SITES OF MONITORING

A. Assumptions

Monitoring is the repetitive, quantitative, and qualitative observation of various sets of physical, chemical, and/or biological parameters which are thought to represent or approach representation of existing conditions in the environment. As such, it encompasses a suite of tools from which the most appropriate can be selected to fit particular problems and objectives.

The inherent assumptions on which regulatory requirements for monitoring are based include, but are not limited to, the following: 1) that it is possible to determine what is "normal" in a given micro- or macro-ecosystem by establishing a baseline monitoring system; 2) that it is possible to detect changes which reflect the "natural" range of variability by repetitive monitoring; and 3) that it is then possible to analyze monitoring data sufficiently to distinguish between "natural" and "non-natural" changes during or after their occurrence, over either long or short term, and over large or small scale space. These assumptions imply that it is possible to obtain both qualitative and quantitative data which will distinguish between the aforementioned kinds of changes; and that, given information on "change," those events which society deems to be in violation of its value system can be eliminated, altered, or otherwise brought under control.

If these assumptions cannot, to some extent, be approached or sustained, then monitoring becomes only a ritual through which some type of compliance is measured.

To a large extent, the perceived failure of earlier water quality control criteria in the United States to be translated into water quality improvements led to virtual abandonment by enforcement agencies of biological criteria and standards for receiving waters. Although environmental protection implies protection of biological quality, not just drinking water safety or physical water quality, the criteria and measurements presently enforced under technology-based standards largely do not reflect the living environment. The assumption was made that if levels of all sorts of pollutant inputs could be reduced by technology to some numerical values at points of discharge, impacts on ecosystems would automatically be satisfactory.

Canada, on the other hand, has persevered with the biological basis of protection. By improved selection of criteria which are more appropriate to the living environment, they have succeeded in protecting the environment at least as well as, if not better than, the United States has without relying solely on technology-based standards.

B. Orientation

Monitoring may be categorized under various systems which represent differing objectives, scopes, and methodologies. Common to all monitoring programs should be the objectives to obtain time-series observations (measurements) of baseline conditions and of range of variation, whether natural or man-induced, and of trends if discernible. Beyond this very general approach, the objectives will vary according to the sites and needs; and the array of tools, techniques, and methodologies may vary accordingly.

Two general sorts of programs should be included in a national monitoring design; that is, one program element should be long-term, with a relatively few basic parameters measured, and large in scale, with stations widely separated and representative of various coastal shelf environments in various geographic areas. The other program element should be site-specific, designed to follow the environmental quality of differing, potentially productive areas such as bays, estuaries, reefs, shorelines, fishing grounds, and the like. Pollution monitoring is an integral part of the site-specific program, smaller in scale as to area, and in some cases more intensive in frequency and number and parameters measured. The National Pollutant Discharge Elimination System, administered by the Environmental Protection Agency, should be a basic, integral part of such a monitoring system, provided that some uniformity in parameters measured is established, some expansion of stations is made, and some more relevant biological criteria are added to permit conditions where they are not presently being applied.

Specialty programs such as Mussel Watch and MARMAP are appropriate to the smaller-scale category, but such programs must never be considered as substitutes for the basic large-scale, long-term network indicated. Although Mussel Watch is a national program designed to assess the uptake of pollutants, mussels are not represented in many coastal environments, and other parameters commonly included in monitoring are not measured. The water temperature data assembled for many years from lighthouse and harbor records on the Pacific Coast by SIO has provided almost the only long-term, large-scale record of seasonal and annual variation in Pacific coastal waters, assisting in the development of concepts concerning the effects of long-term variation in water mass movements and seasonal changes in current regimes.

1. Habitat-Oriented Monitoring

Monitoring may be classified in several ways for purposes of addressing philosophy, scope, and methodologies. One system is based upon physical habitat types such as the traditional estuary, rocky intertidal, sandy beach, and the

like (Hedgpeth, 1962) or littoral, supralittoral and sublittoral, and divisions of pelagic, oceanic, and neritic (Hedgpeth, 1957). Physical classifications differ among various authorities, but they are similar enough to be useful in categorizing the habitats, as well as suggesting the methodology by which habitats can be inventoried and subsequently monitored.

2. Food Web Monitoring

Another type of classification involves the so-called food chain or food web (or energy flow) categories. The classic food pyramid diagram has generally been relegated to representing only limited portions of systems which identify the essential elements of commercially or socially valued top consumers, such as fishes, whales, and humans.

It is essential, however, to identify other key sequences which support intermediate food links, such as phytoplankton and zooplankton blooms that must occur at the appropriate time and places when larval fish must feed or die, the presence of the quantity and species of krill on which whales feed, or the timely appearance of northern anchovy on which brown pelicans feed during the nesting period. An essential question must also be addressed as to whether monitoring can eventually result in better understanding of the crucial systems, which also are in need of concomitant extensive, skilled field and laboratory research. It is possible that important factors could be masked by collection of enormous amounts of virtually irrelevant data if parameters are not properly selected and the appropriate basic research also carried out.

C. The Ecosystem Approach

The ecosystem approach of monitoring is essential if there is to be any possibility of understanding and managing the environment. Without the integration of physical and chemical data with biological data, there can be no coherence to a monitoring program, and utilization of data will be minimized. It is recognized that an ecosystems monitoring program is viewed as expensive; but at least a portion of the costs could be ameliorated by incorporating NPDES and other permit requirement programs. Where an ecosystem is relatively well understood, monitoring of particular parameters might be reduced or eliminated, but it is perilous to limit the scope of a program initially when the ecosystem is not well known.

Monitoring is too often categorized by the technology used to obtain data rather than by the habitat or energy systems under investigation. The use of such techniques as remote-sensing, infra-red photography, or automated analysis of nutrients sometimes appear to dictate the purpose of the monitoring program rather than the reverse.

Numerous conferences have been held and volumes written on selecting the scope of monitoring and debating methodologies and technologies for implementing monitoring programs. As many authorities have pointed out, there is no accepted "Standard Methods" (APHA, 1981) for biological monitoring, and no consensus among professional environmental scientists on what or how to monitor. The problems of monitoring marine environments are much more complex than problems addressed by public health authorities in examining drinking water and waste water, because of the added dimensions of concern for habitats and food webs. Whereas there has been no consensus on marine monitoring methods, the continued updating of "Standard Methods" has produced 15 editions since the turn of the century.

The rapid evolution of technologies in remote sensing and automated sampling of some parameters for biological monitoring must be contrasted with the essentially turn-of-the-century gear commonly associated with benthic grab samplers, trawls, and nets. This does not eliminate the still-unavoidable need, after collecting, for time-consuming taxonomic identification by the shrinking numbers of experts in the various systematic disciplines.

The ecosystems approach will be followed in subsequent sections of this report. While it is not the intent of the Task Group to provide a "Standard Methods" manual, some of the techniques for obtaining ecosystems information will also be discussed.

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D. Determination of Microheterotrophic (Microbial) Activity

1. Introduction

While the roles of bacteria in breaking down complex organic matter and in returning minerals to the environment have been recognized for many years, it has only been recently that the importance of marine bacterioplankton has been recognized in the trophic structure of ecosystems. The microheterotrophs are of particular importance in coastal waters, where large amounts of organic material of both natural and anthropogenic origin are received.

Not only do the bacteria perform bioclastic activities, they also consume organic debris and waste, multiply rapidly, and provide a base for the detrital food web. Microheterotrophic activity may well be of equal importance with autotrophic phytoplankton in food webs of coastal waters.

Measurement of this important component of coastal and estuarine ecosystems has been largely neglected in biological surveys; it is only in recent years that standard techniques for assessing microbial activity have been developed. Further research is needed to develop more rapid, more accurate, and less costly methodologies.

2. Measurements

At the present time, three measurements are considered to be important in evaluating the microheterotrophs: microbial numbers (standing stock), microbial biomass, and metabolic activity. All three currently require shipboard field sampling followed by laboratory procedures, carried out either on board or ashore.

Seawater samples may be collected with sterile Niskin bag samplers or equivalent apparatus. Samples are then filtered through a 203 μm mesh to remove zooplankton grazers and are stored in sterile flasks maintained at or below ambient water temperatures; they are not to be frozen.

3. Standing Stock

Determination of bacterial numbers provides information about the degree of organic enrichment in the environment, but high standing stock counts may be influenced by a paucity of bacterial consumers or skewed by the influx of terrigenous bacteria, which are metabolically inactive although they may be carried into marine waters. Low bacterial counts may be due to unfavorable conditions or to a high rate of consumption by microzooplankton. Although public health considerations require counts of coliform bacteria as an indicator of the

presence of potential pathogens, coliform counts are not good indicators of the presence of natural heterotrophic populations.

Where low levels of oil are present chronically, as they usually are in ports and marinas and at natural oil seeps, oil-consuming bacteria occur in higher numbers than elsewhere. When spills occur in areas of chronic, low level discharge, bacteria reproduce rapidly, increase greatly in numbers and biodegrade the oil. In open ocean waters, low numbers of oil-consuming bacteria slow the biodegradation process. In arctic waters, metabolic processes are so slowed that biodegradation is almost nonexistent.

To determine bacterial numbers, an aliquot (2 ml for open ocean samples and less for enriched waters) of the sample is preserved with borate-buffered formalin for a 2% final concentration (volume to volume). The sample is placed in a vacuum filtration apparatus over a 25 mm diameter Nuclepore membrane of appropriate porosity, stained with Irgalan black. Nuclepore membranes of 1.0 µm and 0.2 µm porosity are recommended since Azam and Hodson (1977) found that 80-95% of bacterioplankton are less than 1.0 um and greater than 0.2 µm in diameter and thus may be separated from the rest of the plankton.

The sample is exposed, prior to filtration, to either a 0.01% solution of acridine orange (AO) for two minutes (Hobbie, et al., 1977) or to a 0.01 $ug \cdot ml^1$ solution of 4'6-diamidino-2-phenylindole (DAPI) for five minutes as described by Porter and Feig (1980).

After staining and filtration, the membrane is mounted on a slide with low fluorescence immersion oil and a cover slip. Such samples may be stored at 4°C for two weeks. Slides are analyzed with an epifluorescent microscope equipped with 455-490 nm excitation filter for AO or a 365 nm filter for DAPI. Counts are made of ten fields of known diameter or ten Whipple disc grid fields.

Bacterial concentrations may be calculated using sample volume, area of exposed membrane, area of visual field, and mean bacterial count, as described by Hobbie et al. (1977) or Porter and Feig (1980).

4. Biomass (Biocarbon)

Microbial biomass may be determined by assaying the ATP content of a filter retentate and multiplying ug $ATP \cdot L^1 x$ 250 which yields ug $C \cdot L^{-1}$. This technique allows the quantification of biomass in selected size fractions. The bacterioplankton are found almost exclusively in the 0.2-1.0 um range, and the phytoplankton and microzooplankton are found in the 1.0-203 µm range. The ratio of ATP to carbon will vary with the metabolic state of the population assayed, but the factor of 250 seems to be a good average value and is used widely.

This technique is described in detail by Holm-Hansen and Booth (1966). Aliquots of fresh sample are immediately filtered onto membranes of the desired porosity (0.2 µm and 1.0 µm) under low vacuum pressure (<10 cm Hg). The membranes are then placed in 4 ml of boiling Tris buffer (0.2M, pH 7.75) for 5 minutes to extract the ATP. The extract is then placed in a test tube and a subsequent extraction on the membrane is performed with an additional 2 ml of boiling Tris for another 2 minutes. The total extract can then be frozen until ready for ATP analysis.

The ATP assay is performed by photometric analysis of the ATP-mediated, luciferin-luciferase reaction and standard curves obtained. Commercially manufactured ATP photometers are available and are recommended.

After ATP concentrations within the samples have been determined, these data may be converted to the carbon biomass contained in the size fractions sampled.

Bacterial biomass may also be determined microscopically by measuring the cell dimensions of an Acridine Orange-stained preparation. Cell volumes are calculated based on ideal geometric forms, and from these volumes biomass is calculated assuming the relationship of 0.08 - 0.16 g of C per cm^3 of bacterial cell volume (Newell and Christian, 1981).

5. Heterotrophic Metabolic Activity

In an effort to find a technique comparable to ^{14}C-primary productivity measurements in phytoplankton, Wright and Hobbie (1965) and other investigators developed techniques to assess heterotrophic metabolic activity by means of radiolabeled organic substrates. Radiolabeled amino acids, carbohydrates, nucleotides and organic acids have all been used, but glucose seems to be one of the most readily utilizable and naturally available substrates (Vaccaro and Jannasch, 1966). Many investigators routinely use ^{14}C-glucose incorporation and respiration techniques to assess microbial heterotrophic activity. Radiolabeled glucose of high specific activity is available and is advantageous because it minimizes perturbation of the system that would be caused by a large addition of a nutrient. In addition to incorporation of ^{14}C-glucose, the determination of ^{14}C-respiration of this compound is useful to establish rates of uptake (incorporation + respiration) and thereby calculate turnover times of the substrate.

Detailed descriptions of the techniques of ^{14}C-glucose incorporation and ^{14}C-respiration determinations are presented respectively in Wright and Hobbie (1965) and Hobbie and Crawford (1969). High specific activity ^{14}C-glucose is added to a sample in nM quantities and allowed to incubate under simulated in situ conditions. Aliquots are placed in sealed serum bottles with gas traps suspended from the stoppers. At selected time intervals, aliquots of the samples and controls,

preserved with 2% (final concentration, volume to volume) formalin, are vacuum filtered through membranes of selected porosity (0.2 and 1.0 µm), and rinsed with chilled, filtered sea water. The membranes are filtered to dryness, placed in scintillation vials and radioassayed.

To determine respiration rates at selected intervals, the experimental and control serum bottles are acidified to pH 2.8 with HCl by syringe, and a CO_2 absorbent (phenethylamine) is added to the filter paper in the gas trap by means of a syringe. The bottles are then agitated until all $^{14}CO_2$ has been evolved from the sample and absorbed on filter paper (approximately 40 minutes @ 200 rpm on reciprocating shaker table). The filter papers are then removed and placed in scintillation vials for radioassay analysis. The efficiency of CO_2 recovery may range from 90 to 98%.

Short-term incubations are preferred for both incorporation and respiration techniques (3-6h and certainly less than 24). Incubations longer than 24h are not believed to be valid, due to the possibility of species selection and community succession in conditions not representative of natural circumstances.

The uptake and substrate turnover rates may be calculated from the incorporation and respiration rates. This information yields the best estimate of microbial heterotrophic activity available to date. These data can then be synthesized with the standing stock and biomass data to obtain cell and biomass specific metabolic activity.

Recently it has been proposed to use shipboard sampling, with direct counting of dividing cells in a visual field as an index of metabolic activity. This method has apparently been used successfully in the Black Sea, but has not been sufficiently tested and calibrated for U.S. marine waters. In some instances, optimum reproduction levels are below maximum levels; indeed, the latter may well represent the approach to lethality. Research to verify the assumption that cell division represents optimum metabolic activity rather than stress is needed, as are studies comparing the data derived from direct counts of dividing cells with those from radiolabeled investigations.

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E. Phytoplankton as a Monitoring Parameter

The marine phytoplankton are ubiquitous, planktonic, unicellular, autotrophic microorganisms which are traditionally viewed as the base of the food chain pyramid web. As photosynthetic autotrophs, they contain chlorophyll to effect the production of living organic matter from the carbonates of sea water. Natural variations in population size, composition, and metabolic activities occur on seasonal and daily cycles. The phytoplankton also react to many non-cyclic events of natural or man-made origins such as the influx of a broad variety of contaminants that may enhance or inhibit their activities. If the stimulus or stress-inducing factor is persistent and affects a large body of receiving waters, the reaction can result in alterations in the size and makeup of the population exposed to it. Short-term exposure may cause death or alterations in metabolic activities which return to asymptotic levels as the stress-inducing factor is diminished by time, distance, or dilution. Although many publications are available describing the various methods for assessing phytoplankton activity, the most commonly used methods are reviewed and described in some detail in APHA (1975) and Strickland and Parsons (1972).

Alterations to the phytoplankton can be determined by collection and assessment of population size and, possibly, the species composition in the affected receiving waters. These data should then be compared with seasonal data taken from control areas or with data from periods when the receiving waters were not affected by the particular stress. The populations can be enumerated most conveniently by using preserved samples that usually have been concentrated. Methods of concentration include sedimentary centrifugation and filtrations and are described in greater detail in APHA (1975). Slide mounts are then made from these concentrations and are directly examined by microscope. The major advantage of this method is that it can give the most precise evaluation of the population present. The major disadvantages are that the method is slow and requires a level of training not readily available.

In relatively clean waters, a more crude assessment of population can be carried out by using particle counters such as the Coulter counter. These devices can rapidly give information on the size spectrum of particles present but cannot differentiate between living and non-living particles. In the presence of higher, variable quantities of particulates, these data would not be acceptable for evaluation.

Several chemical tests are also available and are used to assess the size of the phytoplankton population. These methods do not give information on cell numbers or species present. They are intended to give a measure of biomass or standing crop of the phytoplankton present.

The determination of the quantity of chlorophyll present in a volume of water provides a good estimate of phytoplankton biomass, since these organisms are the predominant planktonic autotrophs. However, there is no adequate means of accurately translating such data into other units of standing crop, such as dry weight.

1. Spectrophotometric Determinations

The spectrophotometric determination of chlorophylls in samples from the marine environment is subject to relatively few possible interferences. The discussion of the method in Strickland and Parsons (1972) is quite complete and presents, in detail, some possible problems that can be avoided. The method, once samples are collected, is fairly rapid, requiring about one day. The pigments are extracted, and the absorbance of the extract at wavelenghts corresponding to the characteristic peaks for chlorophylls a, b, and c and for plant caroteroids is determined. From these data, the quantities of the various pigments are estimated by empirically derived formulae.

2. Fluorometric Measurements

A fluorometric method for the determination of chlorophyll a is also widely used. Although not as accurate, it offers the advantages of greater speed, requires smaller samples, and the possibility of in situ measurement. In this method, rather than measuring the extinction of light at specific wave lengths, the fluorescence of chlorophyll a caused by excitation from a light source of specific color is being measured.

As indicated above, the method can be applied either to extracts of samples collected and treated as for spectrophotometric determination of chlorophylls or directly to the water sample. In the latter case, frequent calibration of the fluorometer is necessary and, since no means of concentrating the sample is used, sensitivity of the method is restricted.

3. Adenylate Measurements

Another method of estimating phytoplankton biomass is based on the determination of adenylates found within a size range that would exclude most microheterotrophs and large organisms but would include most phytoplankters. Adenylates are found in all living organisms and are not characteristic of the phytoplankton alone. Therefore, the size fraction selected for consideration as typical of phytoplankton must be a major consideration, since overlap at size ranges between microheterotrophs and autotrophs, which include the phytoplankton and larger heterotrophs, can be expected. Microheterotrophic measurement is discussed in III. D.

The basic method involves the detection of light emitted when luciferin is oxidized by luciferase. The light emitted is proportional to the amount of adenylate contained in the sample. The adenylate in this case provides the energy source to initiate the enzymatic reaction.

4. Biological Activity Measurement

Methods of assessing short-term effects of environmental stress on phytoplankton utilize living organisms and are, therefore, bioasssay tests. These tests usually are aimed at determination of the rate of uptake or of production of some particular substance rather than determination of mortality. With the phytoplankton, these methods are related to some aspect of the photosynthetic process, as it is carried out by these organisms.

The populations of phytoplankton used for bioassay tests may be ambient in the area to be monitored and in nearby control sites, although monocultures can be used. Temperature during tests may be controlled by use of environmental chambers or by immersing test vessels in water at ambient sea surface temperature. Light is either controlled by artificial, timed illumination or obtained by exposure to ambient or filtered sunlight. Both clear and opaque bottles of the sample water are usually processed to permit correction for non-photosynthetic activity.

The biological methods differ significantly from the other methods described above, in that these are measurements of rates rather than measurements of standing crop at a point in time. Rate measurements are generally useful when turnover time is relatively short. The parameters being measured are fairly simple, and the methods are adaptable to use in the field.

5. Rate Measurements

The earliest of these methods involved the measurement of oxygen evolved over a period of time. The samples were collected and aliquotted into clear and opaque bottles which were then exposed to experimental conditions of temperature and light for a known incubation period. Replicate bottles of sample water were immediately processed to determine the concentration of dissolved oxygen. At the end of the experimental period, the dissolved oxygen was determined on the incubated samples. Increased dissolved oxygens in the clear bottles are considered to be due to photosynthetic oxygen production, and reduced values in the opaque bottles are considered as respiratory loss.

This method is limited by the sensitivity and precision of the method used to determine dissolved oxygen (DO). In general, for most waters, the low sensitivity of the analytical method for dissolved oxygen makes a prolonged incubation period necessary to get a detectable change in DO. This means that processes other than photosynthesis may begin to

dominate in the regulation of DO within the bottle, thus giving rise to less than valid results.

The use of isotopically labeled carbon as a photosynthetic tracer increased the sensitivity of photosynthetic measurements dramatically and resulted in the widespread use of such measurements. In this method, a small quantity of radioisotopic carbon, as a carbonate or bicarbonate, is added to each bottle of sample water, usually including both clear and opaque bottles. These are incubated under controlled temperature and light conditions for the incubation period. During this time, the labeled carbon is utilized, along with inert carbon, in photosynthesis and is incorporated into the cells. Following filtration to recover the cells, the proportion of radiocarbon retained by the cells is determined. This is considered proportional to the assimilation of carbon from all available sources, and the production can thus be calculated.

Because of the short incubation period involved in the isotopic carbon method, one problem arises in its general application. There is a diurnal periodicity in the capability of natural phytoplankton to function photosynthetically. Although incubated at the same light intensity, there is a cyclic difference in the quantity of carbon fixed, depending on the time of day in which incubation takes place. Usually the peak diurnal activity is in the 0800 to 1200 period and the lowest is 2200 to 0300. This requires early collection of samples and a synchronous start of incubation for all collected in a series.

6. Remote sensing

Linkage of phytoplankton populations to the "physical forcing functions," as used by ecosystem modelers, requires synoptic collections of phytoplankton data concurrent with data on processes such as wind currents and light attenuation (Esaias, 1981). Sample collection from shipboard, even with multiple vessels, is too slow to separate time-dependent functions from spatial differences due to natural patchiness of phytoplankton and natural or man-induced events.

Since chlorophyll a is the primary photosynthetic pigment in plants and it is highly fluorescent, and since photosynthetic pigments are the most important contributor to ocean color, accurate measurement of color and fluorescence by remote sensing makes possible the measurement of phytoplankton abundance.

Phytoplankton, along with degraded plant remains and suspended sediment, control the depth of light penetration and hence of the euphotic zone. The coefficient of light attenuation can be determined by remote measurement of ocean color and by laser light-scattering techniques. The rate of photosynthesis

of particulate matter in the sea can then be estimated, based on the information on the depth of the euphotic zone, incident light intensity, and phytoplankton concentrations (Esaias, 1981). The phytoplankton measurements are essential to investigations on marine ecology, food web dynamics, pollution control, and fisheries management. However, it must be reiterated that remote sensing data are of value only to the extent that "ground truth" data are gathered and that careful calibrations with imaging data are carried out.

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F. Assessment of Marine Benthic Macrofauna

Benthic associations, like all communities, change with both space and time. Knowledge of the extent of natural temporal variations is a prerequisite to monitoring activities designed to assess the effects of any potential man-caused impacts. Only by knowing how associations of organisms vary naturally can one separate normally occurring changes from anthropogenic variations. The distinction between natural variation and anthropogenic changes is basic to determining that an impact has occurred, evaluating its magnitude, and assigning probable cause of the impact.

1. Sampling Design

a. Sampling Program

The specific nature of the sampling program, including such matters as the distribution of sampling locations, whether replicate samples will be collected, and if sampling will be conducted over time to assess temporal variation, will be dictated by the objectives of each particular investigation. Obviously, no matter what sampling regimen is used, this design must minimize sampling bias. Further, studies should be designed so that the habitat complexity and faunal diversity of the study area are adequately assessed.

b. Replicate Sampling

When replicate samples are to be collected at sampling locations, a method should be employed that insures that the effort involved in positioning the research vessel should deliberately be moved off the station and repositioned prior to the collection of the second sample; hereafter, repositioning should precede each repetitive sampling effort. The result will be a cluster of samples collected about a predetermined point. "...[C]lose clustering minimizes the probability of crossing large-scale gradients and intercommunity boundaries...." (Jumars, 1975, p. 246).

c. Periodic Sampling

The duration and frequency of periodic sampling that will be needed to determine temporal variation of the macrobenthos in each particular area will be a function of the extent of the natural changes that are encountered. Financial limitations, the length of the study, and the objectives of the project also will influence program design.

d. Navigational Accuracy

The precision of the navigational system selected will depend on the general nature of the benthic study. For a broad-scale survey where sampling locations are fairly widely separated (a nautical mile or more), standard navigational systems will be satisfactory. If the scale of the sampling grid is small (less than a nautical mile) or if replicate and/or temporal sampling is planned, more refined systems should be employed; in such studies a navigational system that guarantees an accuracy of plus or minus 30.5 meters is recommended.

2. Sampling Methods

Standardization of methodology for benthic studies is needed to insure that the results of different studies may be directly compared.

a. Benthic Sampling Devices

A large number of benthic "grab" samplers have been developed (Hopkins, 1964). Whichever device is selected, it should meet all of the following criteria:

1) applicability--functions well in a wide variety of benthic habitats;

2) durability--resists damage and requires little maintenance;

3) efficiency--a large number of samples can be collected per unit time; and

4) consistency--provides undisturbed samples of similar size (areal extent).

The USNEL spade or box corer (Hessler and Jumars, 1974; Jumars, 1975a) meets all of these requirements and is highly recommended as a standard marine bottom sampler. For most studies, a 1/16 m^2 USNEL or modified Reinecke box corer (20 x 30 cm areal coverage) is adequate; corers may be equipped with stainless steel boxes of various lengths, but 60 cm is standard. The box corer also has the advantage that sediments are not mixed and subsample cores can be taken for chemical and grain size analysis.

It is desirable to attach an underwater shutter bottom camera and stroboscopic lighting unit to the box corer frame designed to photograph the area of the bottom sampled by the box corer prior to penetration. The camera is triggered by the release of tension on a weighted line hung below the box corer frame. Under ideal conditions, a single photograph is made of an area of about a square meter within which the core is

collected. The benthic photographs are used to assess the benthic epifauna and to document the general nature of the habitat at each sampling location.

b. Trawling and Dredging

Benthic samples collected by the box corer (or other "grab" sampler) should be augmented by trawl and dredge samples. Samples can be collected with a small, 6-foot (1.8 m) beam trawl in areas of unconsolidated sediments and with a biological rock dredge in rocky areas. The beam trawl is a light piece of gear that is effective and yet easy to use in rough weather. The rock dredge is a very sturdy piece of equipment that, although heavy, can be used under adverse climatic conditions.

The importance of trawl samples is that they include large epifaunal species distributed on a scale larger than that sampled by the box corer, and the adults of infaunal species are often represented in box core samples only as juvenile specimens. The rock dredge can be used in areas of consolidated sediments where "grab" samplers function inadequately. Areas of rock can also be studied by use of SCUBA-equipped divers, underwater TV, and submersible vehicles. While subtidal rocky areas comprise a very small proportion of the world's sea floor (less than 10%), they contain unique faunal assemblages and present unique sampling problems.

3. Shipboard Sample Processing

A narrative description of each core sample should be made prior to its removal from the corer. This step is usually not possible when grab devices, which mix the samples, are used. The log description should cover sample size (core length), nature of the sediment and biotic features, particularly surface features. Additional observations may be added to the sample decription following processing.

Samples should be screened through both 1.0 mm and 0.5 mm stainless steel or brass screens using the overflow-barrel method; this sample washing technique minimizes the damage to delicate organisms that is caused by traditional screening methods. Analysis of the 0.5 mm fraction may be optional in some studies, particulary "broad-scale" surveys.

Careful processing of benthic macrofaunal samples for preservation and storage is essential to ensure that the specimens remain in the excellent conditions required by systematists for proper identification. Great care must be given to labeling the containers used to store and transport preserved benthic samples.

4. Sample Analysis

a. Sample Sorting and Preliminary Analysis

Since there may be considerable variation in sediment types in a sample-set, several different processing techniques may be required to reduce the volume of the sample prior to sorting. The particular sieving and/or flotation routine used will be dictated by the nature of the substrate of each particular sample. Regardless of the method used, however, care must be taken to keep the sample in water during "pre-sorting" processing to avoid damage to delicate specimens.

Fine sands, silts, and clays that easily pass through a screen with 1 mm mesh or less can be quickly reduced to a minimum volume. Samples with large amounts of coarser sediments (medium to coarse sands, pebbles, or rocks) can be divided into several size fractions by sieving, and each size fraction treated separately. In the case of these samples with coarse substrates, a small portion of animal-containing sediment is placed in water in a plastic pan, and with a gentle "gold panning" motion the animals are extracted from the sediment and decanted onto a 1.0 mm mesh and 0.5 mm mesh screen. Each portion is thus treated several times until no more animals are removed. The remaining sediment should be examined carefully to ensure that maximum retrieval of the benthic organisms has been accomplished.

Samples that contain rocks and pebbles with encrusting organisms present a difficult problem. Representative encrusting forms can sometimes be "picked off" the rocks by hand, and the rocks rinsed well and returned to their sample jars. Quantification of encrusting organisms which may be damaged by removal is difficult. Dahl (1973) has recommended quantification by conversion of algae and colonial organisms to ideal geometric shapes and multiplying by average individual size.

Sorting is best accomplished with a specially designed sorting tray viewed with a dissecting stereoscope microscope. The trays are made of black plastic and have two circular depressions connected by a narrow trough, the whole forming a "dog bone" or "dumb-bell" shape. A small portion of reduced substrate containing animals is placed in one of the circular depressions and passed beneath the microscope, through the trough, to the other depression. Animals are removed with fine stainless steel forceps and placed in appropriate vials.

The faunal components may be sorted into five major groups: polychaetous annelids, crustaceans, mollusks, echinoderms, and all other taxa. After each sample is sorted, the quality and accuracy of the work should be verified by a senior scientist. Following "verification," the number of animals in each major group and the alcohol wet weight standing crop can be determined. The results of the preliminary analysis of the benthic samples include:

1) total number of specimens in each sample;
2) number of specimens in each of the major groups;
3) total standing crop; and
4) standing crop of each of the major groups.

In addition, the percent of the total number of specimens and the percent of the total wet weight can be calculated for each of the five major groups.

b. Rapid Identification Procedure (RIP)

The rapid identification procedure (RIP), a technique relatively new to benthic biology, can be used to further analyze the samples which have undergone preliminary analysis. One at a time, the jars containing the vials of animals previously sorted to the five major taxonomic groups are placed in Petri dishes in water with labels bearing the station number. Using dissecting stereoscopic microscopes, systematists examine the animals in their groups for approximately 10 minutes. Making the best possible identification and enumerations of the animals, they record the results of their analysis on previously compiled data sheets which list the taxa most likely, in their opinions, to be encountered in the sample-set. After 10 minutes, the samples will be exchanged for the next samples.

Some taxa (for example, gammarid amphipods and mollusks) will be, for the most part, identified to species level, while others (such as polychaetes) can be identified only to the familial or generic level under the limitations of this procedure. Abundances are obtained by counting, or estimating if time is limited. <u>The RIP presumes a staff of highly competent taxonomists</u>. The method is applicable to baseline studies or monitoring efforts and is not sufficiently precise for critical ecological investigations.

c. Detailed Sample Analysis

Taxonomic analysis, the process of specimen identification, is the most difficult and time-consuming aspect of any benthic study. For most phylogenetic groups, the systematists must be capable of identifying all of the frequently recurring species, relying on consultants for assistance only with the more difficult forms. The efficiency and accuracy of the efforts of the identification team are enhanced, as each person specializes in a particular phylogenetic group or groups. A list of identifed taxa and the number of specimens in each taxon will be made for each core.

d. Epibenthic Photograph Description

The epibenthic photographs are described by the systematists. These descriptions include the appearance of the substrate, estimation of bioturbation, and identification and enumeration of macrofaunal invertebrates pictured in the photographs.

The prevalent epifaunal taxa visible in the benthic photographs typically include the pennatulaceans (sea pens), holothuroids, echinoids, asteroids, large ophiuroids, decapod crustaceans, and some species of mollusks. Of these taxa, the echinoderms usually account for the largest number of animals pictured in the photographs.

5. Sample Characterization

Sample analysis will yield the following primary data:

1) Wet weight standing crop per sample for each major phylogenetic group--polychaetous annelids, mollusks, crustaceans, echinoderms, and minor phyla (combined as a unit);
2) Total wet weight standing crop per sample;
3) The number of individuals per sample of each major phylogenetic group--polychaetous annelids, mollusks, crustaceans, echinoderms, and minor phyla (combined as a unit);
4) The total number of individuals per sample;
5) A list of taxa, identified to the lowest systematic category practicable, and a count of the number of individuals of each identified taxon;
6) Total number of identified taxa.

Conversion and analysis of the primary data will yield the following secondary data:

1) The percent of total wet weight standing crop by major phylogenetic group--polychaetous annelids, mollusks, crustaceans, echinoderms, and minor phyla (combined as a unit);
2) The percent of the total number of individuals by major phylogenetic group--polychaetous annelids, mollusks, crustaceans, echinoderms, and minor phyla (combined as a unit);
3) Species richness, based on an edited species list from which identified taxa that may represent more than one species population (e.g., *Photis* sp.) have been eliminated. This edited species list will be used in all statistical analyses based on faunal composition;
4) The percent distribution of each species in each sample, expressed as the percent of the whole--the total number of individuals in the sample--that each species comprises;
5) The dominant species encountered based on an occurrence of 5% or more of the total number of individuals in the sample;
6) Measures of species diversity, including indices based on dominance as well as species richness.

6. Habitat Description

Responsibility for habitat description will rest mainly on the correlative investigations of other disciplines. Useful information can be provided by oceanographic, geologic, and geochemical studies; bottom water characteristics, sedimentary analysis, and determination of trace metal and hydrocarbon sediment levels will define the environment of the benthic associations under study. Variability of the sedimentary parameters will provide an indication of the extent of environmental heterogeneity. Epibenthic photographs taken on repetitive box corer casts will also aid in documenting the degree of habitat variability.

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G. Monitoring of Pelagic Fauna

The environmental monitoring system for open water must deal with large-scale spatial variation and temporal dynamics of marine systems as well as high resolution of quantitative marine ecology and biological oceanography. It is essential to use the recent advances in remote sensing from atmosphere and space as well as acoustical sensing from ships (III. K.). Such measurements place samples into a spatial context, prevent errors of extrapolation from point samples, and gather data over large areas in an efficient manner. Acoustic samples can also provide high spatial resolution. Direct sampling of fauna will record the number, body size, biomass, and taxonomic identifications of organisms caught in conventional quantitative samples, such as plankton pumps and nets and mid-water and bottom trawls. Such measurements must be made in a statistically sufficient pattern of sampling and replication and must reflect current expertise in methods of collection, processing, and identification. Useful references for sampling of neuston are Smith and Richardson (1977); for zooplankton, Beers and Stuart (1967), Wiebe et al. (1976), Smith and Richardson (1977), Colton et al. (1980), Sameoto et al. (1980); and for nekton, Food and Agriculture Organization (1971), Saville (1977), and National Marine Fisheries Service (1981). The general requirements for these measurements are that they be quantitative, intercomparable among sites and times, statistically valid, and repeatable.

1. Rationale for Using Size of Organisms

The traditional approach used to define aquatic community structure has been taxonomic description. Species composition can portray community structure in relatively static terms, but the process is time consuming, labor intensive, and hence expensive. For monitoring systems for areas as extensive as the oceans, more conservative methods should be investigated.

The size distribution within a community has been used by several investigators (Sheldon et al., 1972, 1977; Sprules and Holtby, 1979) to define the dynamics of community structure and pelagic food webs. Community size structure is important in energy exchange between trophic levels; lack of appropriately sized food particles at particular stages of development can inhibit adult reproduction or development of larvae from eggs. Steele and Frost (1977) concluded that "size structure is at least as important and probably more significant than total biomass of a population" in understanding energy flow between trophic levels.

Growth rate at any trophic level determines production rates. Particle size determines growth rate according to Sheldon and his coworkers. Sheldon et al. (1972, 1977) observed size structure of marine pelagic communities. They

found definite geographic variations in particle size spectra that can characterize certain areas of the ocean, such as the Sargasso Sea. Predator and prey populations universally maintain the same logarithmic variation in size.

Sheldon and his coworkers also observed nearly equal concentrations of material within equal logarithmic size intervals. The ecological implications of this observation are of considerable significance. Sheldon et al. measured frequency of particles between 1 and 100 µm, but the results can be used to estimate (within a factor of 2) concentrations of particles outside this size range. Standing stocks of bacteria or baleen whales may be estimated with the method. Sheldon et al. (1977) uses the relationship to predict both phytoplankton from fish stock and fish from phytoplankton occurrence.

2. Methods

Sprules and Holtby (1979) used an image analyzing computer to size particles. Samples were stained, washed, and photographed on high contrast film. The Quantimet 720 image analyzer counted particles in 15 size classes in the range 0.05-2.00 mm.

Sheldon and his coworkers measured particle size distribution with a model T Coulter counter. Equivalent spherical diameters from 0.63 to about 100 µm were measured. Sample size must allow for the upper size limit chosen. According to the hypothesis, if there is only one particle of 100 µm diameter in 500 ml of water, only one 1-mm diameter particle will likely be found in 500 liters.

The Coulter counter is unable to determine particle composition. Sheldon's group examined samples microscopically to determine that inorganic particles not associated with organisms did occur but were uncommon.

Sampling strategy must account for seasonality. Menzel and Ryther (1960) found seasonal variation in the total amount of particulate material up to a factor of 5. Sheldon's Sargasso Sea data (1972) showed greater variance in particle size during January than in November.

A combination of acoustic and netting techniques for biomass measurements and monitoring of zooplankton and nekton should be used. Only netting techniques are appropriate for neuston, since sonars are not effective at the near surface. Net samples are much more expensive of ship time than are acoustic measurements; thus efficient monitoring methods of the large areas should use acoustic surveys combined with selective net samples for calibration and faunal identification.

Measurements of pelagic fauna should be made at least quarterly. Even this will be too infrequent to follow the dynamics of zooplankton communities. Equal effort should be given to day and night sampling. The commercial and sport fishery catch data should be used when possible, but many species and sizes of nekton are not caught or enumerated. All fish sampling gears are selective (Pope et al., 1977). For certain trawl gear, estimates of efficiency are as low as 50 percent. To be quantitative, catch per unit effort (CPUE) must be from nets used in a standard manner for a standard time with standardized mesh sizes. Zooplankton gear is less selective, but, again, selectivity must be considered in the choice of gear and the evaluation of results.

Owing to the major effort required to process zooplankton samples, serious consideration should be given to analyzing the fauna on the basis of body size.

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H. Monitoring the Intertidal Environment

Of all the environments of the sea, the most accessible to verifiable observation is that between the tides. It is also the most complex and variable; the forms that live between the levels of the tides represent an in situ integration of the physical circumstances, the hydrographic events, and the biological interactions for at least several years before the time of any specific observation. On open sandy shores, this environment changes with the level of the tide, the season, and longer intervals of time in a state of dynamic equilibrium between the sand and the sea; in the sheltered areas of shores of lagoons and bays this equilibrium action is dampened so that the environment is more stable, although it is subject to the variations in stream flow, where such exists, that, combined with tidal action, produce complicated regimes of varying salinity in estuarine reaches. On rocky shores, the dynamic changes in the condition of the substrate are reduced, but in their stead there are the many variations in degree of exposure, especially on vertical slopes; intensity of wave action, at times so brutal as to tear off large patches of organisms; and the movement of sand against the immovable rock. Yet this environment is among the most densely populated by plants and animals of all of the environments of the sea.

Despite all of these complications, the intertidal environment, whether of rock surfaces on the open coast or of sheltered tidal flats, provides us with the best opportunity to make continuous observations of the conditions of life in the sea. Such observations, to be meaningful contributions to our understanding of the ecological interactions involved and to recognize the effect of changes introduced by the activities of man, must include some numerical, quantitative information.

This need was recognized early in our present century and stated clearly by Herdman (1920) and Elmhirst (1932), but the decades of the 1930's and 1940's were the high times of the artistic, subjective approach to seashore ecology as exemplified by T. A. Stephenson, whose life work was summarized from his notes by his wife after his death (Stephenson and Stephenson, 1972). For most of the time between the pioneer observations of the French shore naturalists and Edward Forbes and the studies of interactions (inspired in part by the static-artistic approach) that began to flower in the 1970's, we simply looked at this complicated interface and tried to describe it, preferably without numbers. There are mountains of descriptive papers on the intertidal ecology of this or that part of the world, many of them very useful for those interested in drawing up comparative pictures of various parts of the world. It is not without significance that numerical reinforcement of observations began in that part of the world where quantitative observations are more difficult

to make; the shallow, sand and mud bordered shores of the lowland seas of Holland, Friesland, Germany, and Denmark. Here in the lands of the Waddensees, where there are no rocky shores, people began to count to reinforce their observations. References to occurances in terms of numbers per square meter first appeared in the 1890's, notably with Friedrich Dahl's account, "Untersuchungen uber die Thierwelt der Urterelbe" published in 1893 (Ber. Komm. wiss. Unters. dt. Meere Kiel, 6:1510185), and most resoundingly with the famous work on the bottom fauna of Danish seas of Carl Georg Johannes Petersen in Denmark, published in the Reports of the Danish Biological Station from 1911 to 1918.

Of course these are not intertidal observations, but the lesson exemplified has been very hard to learn.

1. Rocky Surfaces

The rocky intertidal regions are in some ways the best sites for monitoring because they are the areas least subject to change (except when the landscape itself falls apart), and exact sites can be identified by individual differences in the surfaces and can be easily revisited. However the dense growth of plants and animals, especially at mid- and lower intertidal levels, presents difficulties in counting and ready identification during the short periods of accessibility especially at the lowest tides. Enough work has been done on recolonization and observation of new surfaces on sea walls and jetties to indicate that it requires several years for the biota to become established or to recolonize an area denuded by storm or accident or scraped bare as an experiment. While most of the plants that occur on rocky intertidal surfaces are short-lived or annuals, the large animals may in general be much longer lived; some herbivorous snails, for example, may live as long as 25 years, and seastars may live 5 to 15 years. Obviously this type of environment cannot be monitored on the basis of a single isolated sampling station, be it a unit area at a particular level or a transect from the highest reach of the spray of winter storms to the lowest level of the tides of the solstice. Nor is it possible to find a "control" area for observation against one to be subjected to repeated destructive sampling, since no two areas are enough alike to satisfy the concept of a control situation.

In the context of monitoring for impact purposes, a semi-quantitative abundance scale procedure has been developed in Britain. This procedure was expanded from an abundance scale technique developed by W.J. Ballantine (1961). This is essentially an eyeball appraisal of the abundances by percent of area according to standards set by the investigator. It was developed initially to assess the differences in intertidal abundances attributable to degree of exposure. As the title of Ballantine's paper suggests, the purpose of this method is

to facilitate comparative description. The most serious problem with this procedure is that of consistent application, especially from one investigator to the next.

A baseline study of intertidal biota was begun at Milford Haven in 1961 by Nelson-Smith (1967) to provide information assessment of changes that might result from the development of the region as a major oil port and from heavy industrialization. This is a narrow, rocky-shored estuary, and abundances of intertidal life were estimated when possible according to the Ballantine method and regularly spaced transects along the estuary. This survey was followed up a decade later by Crapp (1971), using the same methods and frequent reference to the raw data of Nelson-Smith.

In a later baseline study of a similar nature at Bantry Bay, Crapp also studied the population ecology of limpets as potential indicators of "subtle changes."

In their monograph on Procedures for Quantitative Ecological Assessments in Intertidal Environments, prepared for the EPA (EPA 600/3-78-087, September 1978), Gonor and Kemp dismiss these methods without describing them because they are not reproducible and because publication of graphs and diagrams that suggest quantitative results are misleading. A more serious drawback, in the context of monitoring by unskilled persons, is that they are too easy to misuse. While this report by Gonor and Kemp "does not necessarily reflect the views and policies of the Environmental Protection Agency," this document appears to be the best available treatment of quantitative assessment procedures in the various intertidal substrates.

The most attractive and practical nondestructive sampling and monitoring procedure is that employing photography. Photographic assessment methods have recently been used by Littler for baseline study of rocky intertidal systems in the Channel Islands and the Southern California Bight (Littler, 1971, 1980a, 1980b), as part of the environmental assessment studies funded by the Bureau of Land Management in connection with anticipated offshore oil lease development. This technique has also been developed for rocky subtidal situations (Lundalv, 1971; Torlegard and Lundalv, 1974).

Gonor and Kemp (p. 80) urge the use of standard frames to reduce problems of camera lens distance and parallax problems. In view of the details supplied in this monograph, it does not seem necessary to go into detail about the type of camera, lens systems, etc. In some cases the circumstances of the field will determine or modify this. Furthermore, the day may not be far off when present photographic systems may be obsolete for research requirements of this type. Images can be transmitted over millions of miles with remarkable resolution directly into computers and called out at will. Of course, the danger of systems like this is that it would

be too easy to accumulate vast amounts of information, and one would have to go back to the seashore to see what is really going on after all. The essential thing to emphasize is that photographic and image storing techniques make it possible to have information over extended periods of time of the same place. But it also has to be emphasized that no such remote sensing system (even a few millimeters away can be "remote") can eliminate the need for "ground truth" and stored samples. We have "photographs" of the rocks on Mars, but we still need the rocks.

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I. The Voucher Specimen Issue

Facilities and funding must be provided for storage of specimens of fishes, invertebrates, and aquatic plants (including phytoplankton). There is, at the present time, only one institution on the Pacific coast attempting to provide this service for monitoring programs: The California Academy of Sciences. It is inadequately funded, although State law requires permanent storage of specimens from baseline and monitoring programs. One problem is that the costs were underestimated; there should be stipulated funds for processing and preserving these specimens.

The Allan Hancock Foundation in Los Angeles has an uncertain future, and there are no museums of record in Oregon, Washington, or Alaska.

The National Museum of Natural History is overloaded and understaffed and not adapted to the specific task of preserving material by location or project. Obviously, part of any national monitoring program must include storage facilities and appropriate personnel. There are collections of expedition and research material at many places. Much of this is potential documentation of "baseline" conditions. There should be a national registry of these collections.

J. Suggested Areas for Monitoring

It is impossible to carry on a long-term monitoring program that would cover variables and conditions over the entire area of the seas within the jurisdiction of the United States, from low tide to the 200-mile limit. Such a program, even at the most cursory level, would involve great costs and effort. Although many analytical procedures have been simplified so that much more information can be obtained in less time, the resulting printouts still must be interpreted and reduced to understandable numbers. Obviously, monitoring everything in the sea, even the small fraction within the jurisdiction of the United States, is out of the question. There are some critical regions outside our territorial limits that should be monitored to detect the effects of environmental perturbations within the nation's boundaries. The most significant example of such a region is the sea off the Gulf of St. Lawrence, into which potentially deleterious substances may ultimately go; another is the area between Alaska and the State of Washington, frequently omitted from environmental impact studies of transporting oil from Valdez to Bellingham. Another critical area is that along the Pacific Ocean south of San Diego, where American-based or financed firms produce chemicals that may be prohibited or restricted north of the border, but which may nevertheless pollute territorial seas in the Los Angeles Bight.

The experience of the California Cooperative Fisheries Investigations, which includes sampling stations along the region west of Baja California, indicates the considerable expense of a continuous monitoring program. Efforts are being made to simplify this program, but such simplifications as reducing the number of stations or readjustment of effort according to season can only be achieved confidently in the light of a massive data-gathering base. At the very least, any proposed monitoring program must depend on previous data, a known baseline, where such exist. A selection of such areas depends on extant facilities that have produced the baselines in the first place and on the ability to conduct another important aspect of a monitoring program. Observation and data gathering of conditions induced by a short-term phenomenon, such as a volcanic erruption or lava flow in Hawaii, a severe hurricane on the southeast Atlantic or Gulf Coasts and several Caribbean localities, and heavy floods from rivers almost everywhere, are important to a monitoring program. This also means that funding for such emergency or catastrophe-watching should be anticipated. A critical aspect of this situation is the scheduling, several years in advance, of ship time for the oceanographic fleet. However, since most sampling for short-term phenomena will be surface and shallow depth, comparatively unspecialized gear that can be used on short-term charter vessels may resolve this need.

The areas of concentrated research by oceanographic institutions and federal agencies are fairly well-known. They include the Gulf of Maine and Cape region, Long Island Sound, the New York Bight, and the Hatteras region along the North Atlantic. One tropical region immediately accessible to large-scale monitoring is Southern Florida, thanks to the Rosenstiel School of Marine and Atmospheric Sciences, University of Miami. The Gulf of Mexico is served primarily out of Galveston, the base port of the Texas A & M oceanographic effort.

On the Pacific, Scripps Institution of Oceanography and other agencies have conducted intensive sampling programs for the past 30 years, ranging from Cabo San Lucas to the Strait of Juan de Fuca. The sampling program has been reduced, especially in the frequency of occupying the stations farthest from San Diego. The University of Southern California has maintained research vessels that from time to time have participated in the California Cooperative Fisheries Investigations (CalCOFI) program and in State and local baseline monitoring efforts. Monitoring, however, has been less intensive than desirable along northern California, north of San Francisco, especially in light of current needs to evaluate potential effects of oil exploration and production. A good base has been established along the Oregon and southern Washington coasts because of the program to monitor the dispersion and concentration of radioactive material from the Columbia River.

The areas around San Francisco and southern Alaska have not received much attention, and more intensive monitoring, at least at the start, may be required there. Hawaii has a good oceanographic effort.

All of this suggests that the most useful regions for establishing a monitoring program are those within the usual range of established oceanographic institutions, where there is already a body of information. Any addition to established programs of these institutions must be arranged according to what has already been done, and what may feasibly be added or continued. Hence, the details of establishing any sort of monitoring program will vary with each institution. Yet it is desirable that the factors and organisms to be studied be as uniform or as similar as possible.

Most sampling will emphasize shallow water and pelagic organisms and factors. Where there are rocky shores, however, monitoring of intertidal complexes may yield the most useful and informative results. This is because of the fixed population (although some of the conspicuous algae are annuals) and ease of sampling or photographing a variable complex. Open sandy beaches, however, are the poorest environments for continuous monitoring, except in a most general way, because the beach itself fluctuates seasonally, and there are few organisms that live for more than a year in such situations. Recruitment is not from local populations but conveyed by longshore currents from other beaches. Some of the organisms have larval cycles lasting several months. Food is allochthonous and unpredictable. Thus, there are too many inherent variables to be separated from any potential or possible environmental insult except massive oil spills, in which case any reestablishment of life tells us at least of the power and rate of reestablishment. One possible exception would be regular censusing of nesting turtle populations, as all of these species are endangered, and any information about them will tell us about conditions at sea as well as population dynamics of the species.

K. Suggested Methods for Monitoring

Because of the increasing interest in the potential utilization of both acoustical monitoring and remote sensing, this report includes more extensive discussion of these two techniques. It should be noted that reference has been made to other significant monitoring methods throughout the report.

1. The Application of Acoustics in Marine Monitoring

Although the actual applications of acoustic techniques date back to the days of Galileo, only in the post World War II era has the science of acoustics burgeoned into an extremely important research tool for modern marine biology and geology. The early work of the second half of the 20th century has lead to increasing development and rapid expansion of acoustics in all phases of marine research.

Early research with underwater acoustics was aimed primarily at elucidating the causes of sound scattering in the oceans. After rejecting various hypotheses about the physical and chemical nature of sound scattering, scientists became increasingly aware of, and more interested in, the nature of sound in the ocean, especially that reflected from the deep scattering layers, now widely known as the DSL. Subsequent investigations have shown that marine organisms are the principal sources of sound scattering. Further research concentrated on relating acoustic signals to the size and distributions of the organism(s) causing the scattering. Most of the recent work relating acoustics and biology is found in Andersen and Zahuranec (1977), a volume that was produced by bringing together acousticians, marine biologists, marine chemists, and engineers at Alisomar in Monterey, California, in 1975.

Recent investigations have expanded the uses of acoustics into many different facets of marine biology and geology. Acoustic surveys of fishery stocks, high frequency acoustic investigation of vertical distributions of planktonic organisms, low frequency studies of sediment deposition (both rates and composition), field studies of waste discharge plumes, and a myriad of other applications have made acoustics a valuable and increasingly applied tool of the marine sciences. As the applications of acoustics became better understood, the breadth of the problems acousticians began to examine increased in complexity and variety. With the growth of computers, programs integrating the facilities of both acoustics and rapid processing have developed. Now, not only are qualitative studies of distribution routinely handled, but quantitative studies of individual specimens and collections of organisms are beginning to develop.

a. Sound Propagation and Scattering in the Ocean

The theory and mathematics of acoustics is sufficiently complex that only a brief overview will be provided. In discussing the uses of acoustics in marine biological measurements, Holliday (1980) defined scattering as:

> "...... a change in the direction of a wave due to an encounter with an inhomogeneity in the medium in which the wave is propagating. This change in direction is usually accompanied by a change in the intensity of the wave field around the scattering object. The difference between the wave pattern which would have existed had the inhomogeneity not been there and the waves which are observed with the inhomogeneity present is called the scattered wave. The energy which is reflected 180°, i.e., toward the original wave source, is termed the backscattering wave."

The characteristics of the backscattered wave, and a few assumptions following from empirical work, can be mathematically formulated into information about the size of the object responsible for distorting the wave. For a more rigorous explanation of the theory of acoustics, calibration of acoustic systems, and development of models of oceanic sound scattering see Albers (1965), Bobber (1970), Urick (1975), and Clay and Medwin (1977).

Biological sound scatterers can be divided into two classes based upon the inclusion or exclusion of a gas bladder. For the first of these groups, sound scattering and target strength are a function of the characteristics of the air bladder that causes resonance below about 50 kHz. For those organisms not containing air bladders, the sound scattering is mainly a function of their size, sound speed, density contrasts, and the acoustic frequency used. Figure 1 shows the frequency dependent target strength of several types of marine organisms (Holliday and Pieper, 1980) and illustrates the theoretical relationship between size of organism, the acoustic frequency used, and the predicted target strength from several acoustic models. Table 3 (after Clay and Medwin, 1977) shows the appropriate acoustic frequencies used to investigate the different size classes present (from the largest to the smallest) in the ocean.

b. Current Utilization of Acoustic Techniques

i. Biological Oceanography and Fisheries

By far, the major emphasis of acoustics in marine research has been that dealing with biological oceanography and fisheries. As early as 1966, the State of California (and later the National Marine Fisheries Service) was routinely, acoustically surveying the smaller pelagic fish resources in the California Current System (Mais, 1974; Hewitt et al., 1976).

A combination of net trawling and acoustic transducers operating underway provided researchers with the size, distribution, and identification of the species that made up the large school groups living in the area. This survey technique provided an adequate, cost effective means for measuring fish stocks over large areas of the Southern California Bight with a fair degree of accuracy. The new methods corroborated and then supplanted earlier methods of obtaining the survey information much more quickly, accurately, and cheaply than ever before.

A symposium convened in Bergen, Norway by ICES (International Counsel for Exploration of the Seas) in 1973 dealt exclusively with the applications of acoustic techniques to fishery research. The symposium drew over 125 ocean scientists from

Table 3. Optimum detection frequency for bodies with resonant bubbles and minimum effective detection frequency for non-resonant bodies in marine animals and plants. (After figure 1.6.1 from Clay and Medwin, 1977.)

Marine Plants and Animals	Equivalent Spherical Diameter	Optimum detection Frequency for Bodies with Resonant Bubbles	Minimum Effective Detection Frequency for Non-Resonant Bodies
Largest Nekton: whales and sharks	2 to 6 m	10 to 3 Hz	250 to 75 Hz
Larger nekton and Largest Plankton: rat-tails, deep sea cods, tuna and scyphozoa	0.2 to 2 m	100 to 10 Hz	2500 to 250 Hz
Small Nekton and Larger Plankton: myctophids, stomiatoids and hatchet fishes	2 to 20 cm	1000 to 100 Hz	25 to 2.5 kHz
Megaplankton: euphausiids, amphipods, chaetognaths, juvenile and larval fishes	2 to 20 mm	10 to 1 kHz	250 to 25 kHz
Macroplankton: copepods	0.2 to 2 mm	100 to 10 kHz	2500 to 250 kHz
Microphytoplankton: dinoflagellates and diatoms. Microzooplankton: radiolarians, foramineferan and ciliates	20 to 200 u	1000 to 100 kHz	25 to 2.5 MHz
Nanoplankton: flagellates, coccolithophores and diatoms	2 to 20 u	10 to 1 MHz	250 to 25 MHz
Ultrananoplankton: bacterioplankton	< 2 u	> 10 MHz	> 250 MHz

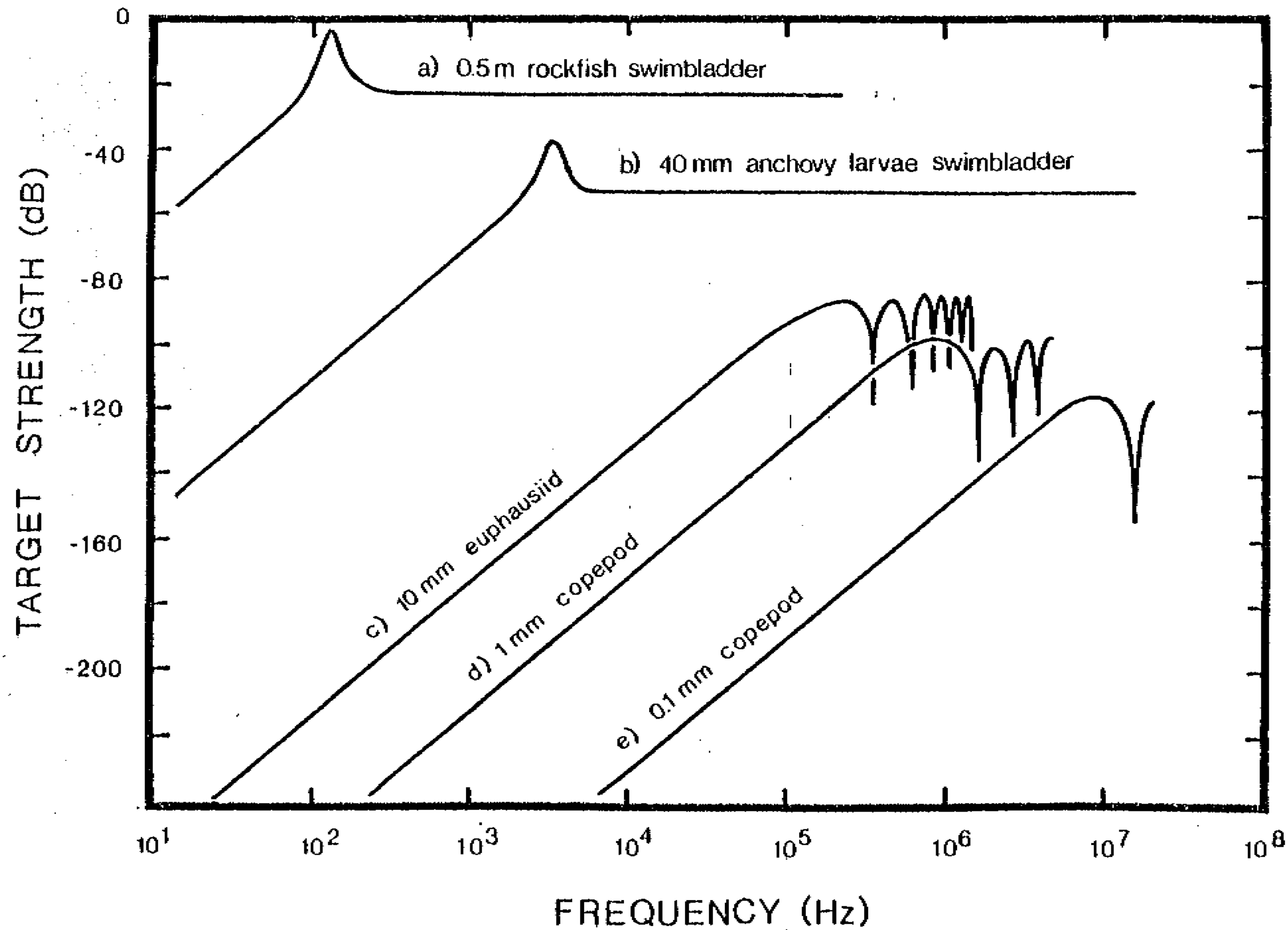


Figure 1. Theoretical acoustic signatures of several common types of marine organisms. (From Holliday and Pieper, 1980)

many fields to address the applications and problems and future development of acoustics to be used for fish stock assessment (Margetts, 1977).

Similar symposia on the more general topics of oceanic acoustic scattering of all types can be found in proceedings edited by Farquhar (1970) and Andersen and Zahuranec (1977). From reports given at these conferences and research independent of those participants, it is clear that one emphasis of acoustic research in recent times has been the identification of the organisms primarily responsible for sound scattering. We now know that fishes and physonectid siphonophores are the major scatterers in the frequency range used in most shipboard echo sounders (frequencies from around 11 to 40 kHz).

More recently high-frequency (greater than 50 kHz) acoustics have been used to record scattering from planktonic organisms. Barraclough, LeBrasseur, and Kennedy (1969) found that a large shallow subsurface concentration of the copepod, Calanus cristatus, was correlated with an observed scattering layer at 200 kHz. Studies in Saanich Inlet, British Columbia, Canada, by Bary and Pieper (1970) have shown that diffuse scattering layers at 42, 107, and 200 kHz corresponded to the depth distribution of high euphausiid concentrations (Figure 2). Sonic scattering at 100 kHz in Puget Sound and the St. Lawrence Estuary, by Cooney (1971) and Sameoto (1972, 1973), respectively, was associated with high euphausiid concentrations. Pieper (1979) recorded 102 kHz scattering in the San Pedro and Santa Catalina Basins off southern California and correlated the acoustic measurements with the biomass and distributions of euphausiids, predominantly Euphausia pacifica. Figure 3 shows the echo sounder trace of a highly patchy area encountered with a profile of calculated scattering strengths of the euphausiids in the patch.

Most recently, work with suites of ultra-high frequency acoustics have been used to try to differentiate various components of zooplankton assemblages. Working with frequencies in the 0.5 to 3.0 MHz region, Holliday and Pieper (1980) have examined the complex vertical structure of thin scattering layers in the upper 100 meters of the ocean. Their work demonstrates the relationship between fine scale thermal structure and the vertical distribution of zooplankton (Figure 4).

ii. Marine Geology, Physics, and Engineering

Marine geologists have used the characteristics of sound propagation and density differences to examine the sea floor. Much of the seismic work done on marine sediments is based on the velocity of sound increasing as it goes deeper in sediments due to the compressibility of lower lying sediments by the weight of those above them. Comparison of acoustic data and core samples taken on the bottom show, as with biological specimens, that geological sediments have their own particular

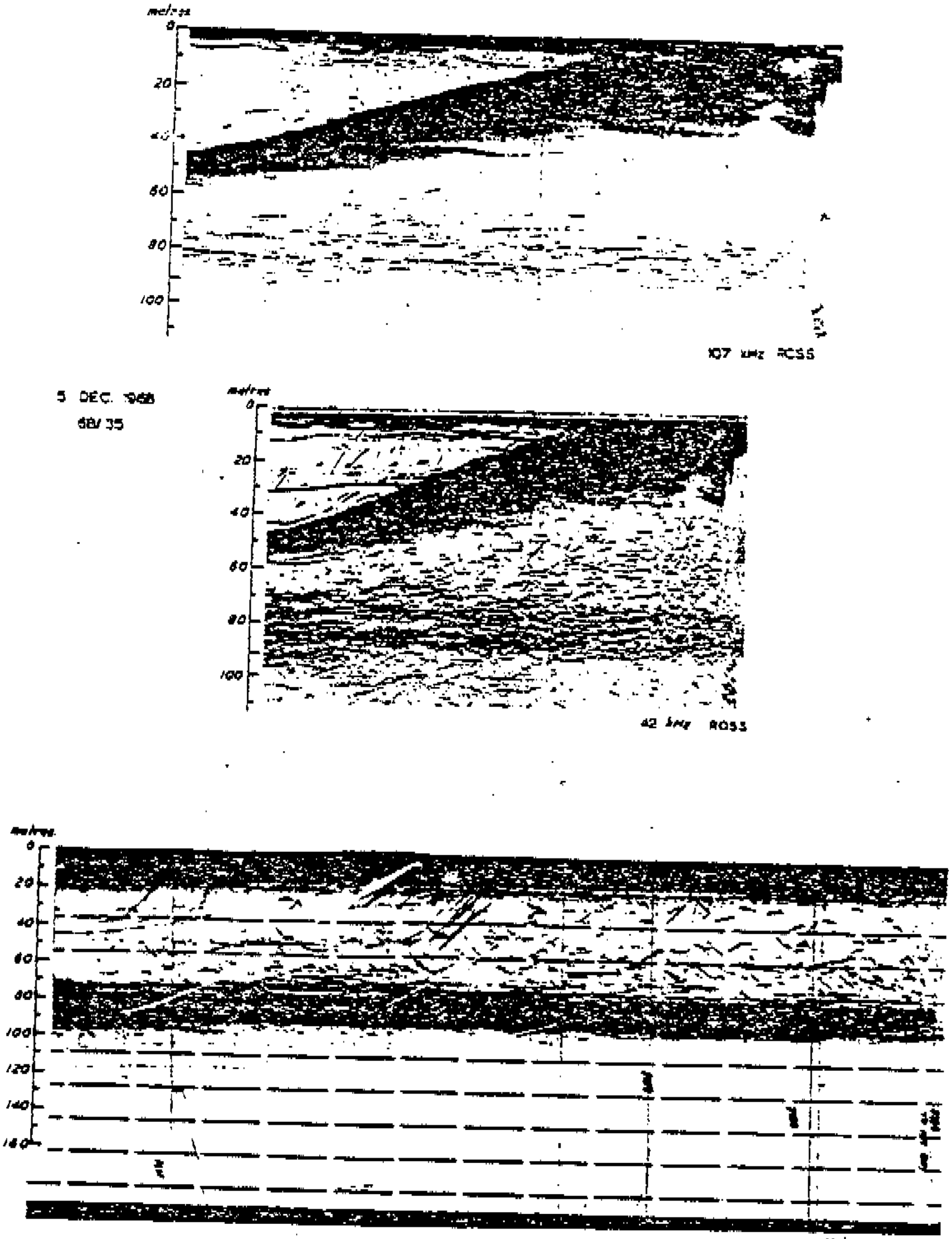


Figure 2. Echograms recorded at frequencies of 11, 42, and 102 kHz (from bottom to top) from Saanich Inlet, British Columbia, Canada. The fish scattering layer (primarily lantern fishes) from 70 to 90 m is strongest at the lower frequencies. The signal level of the migrating scattering layer is strongest at the higher frequencies and is due to euphausiids migrating to the surface during evening twilight. (From Pieper, unpublished)

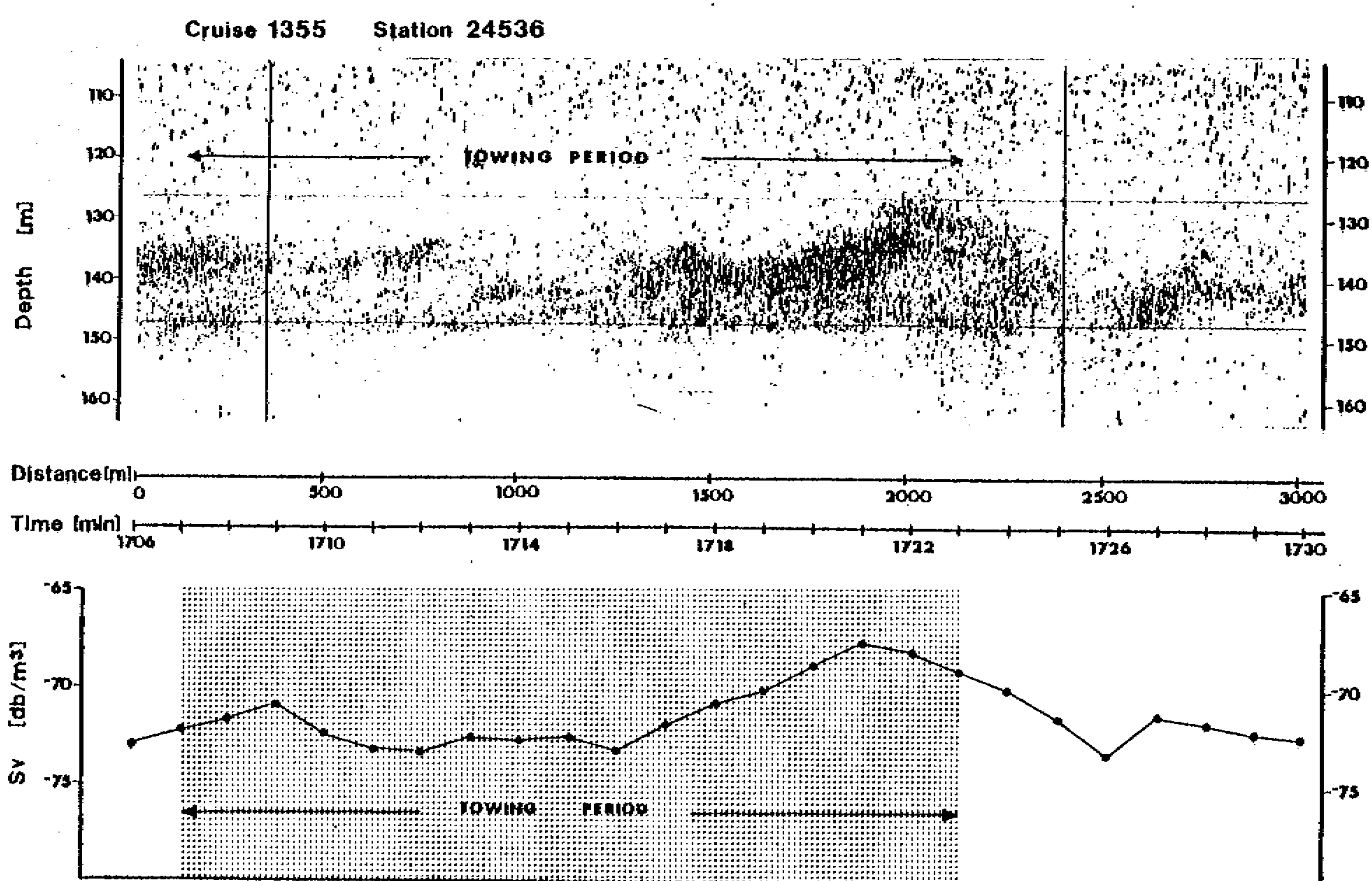
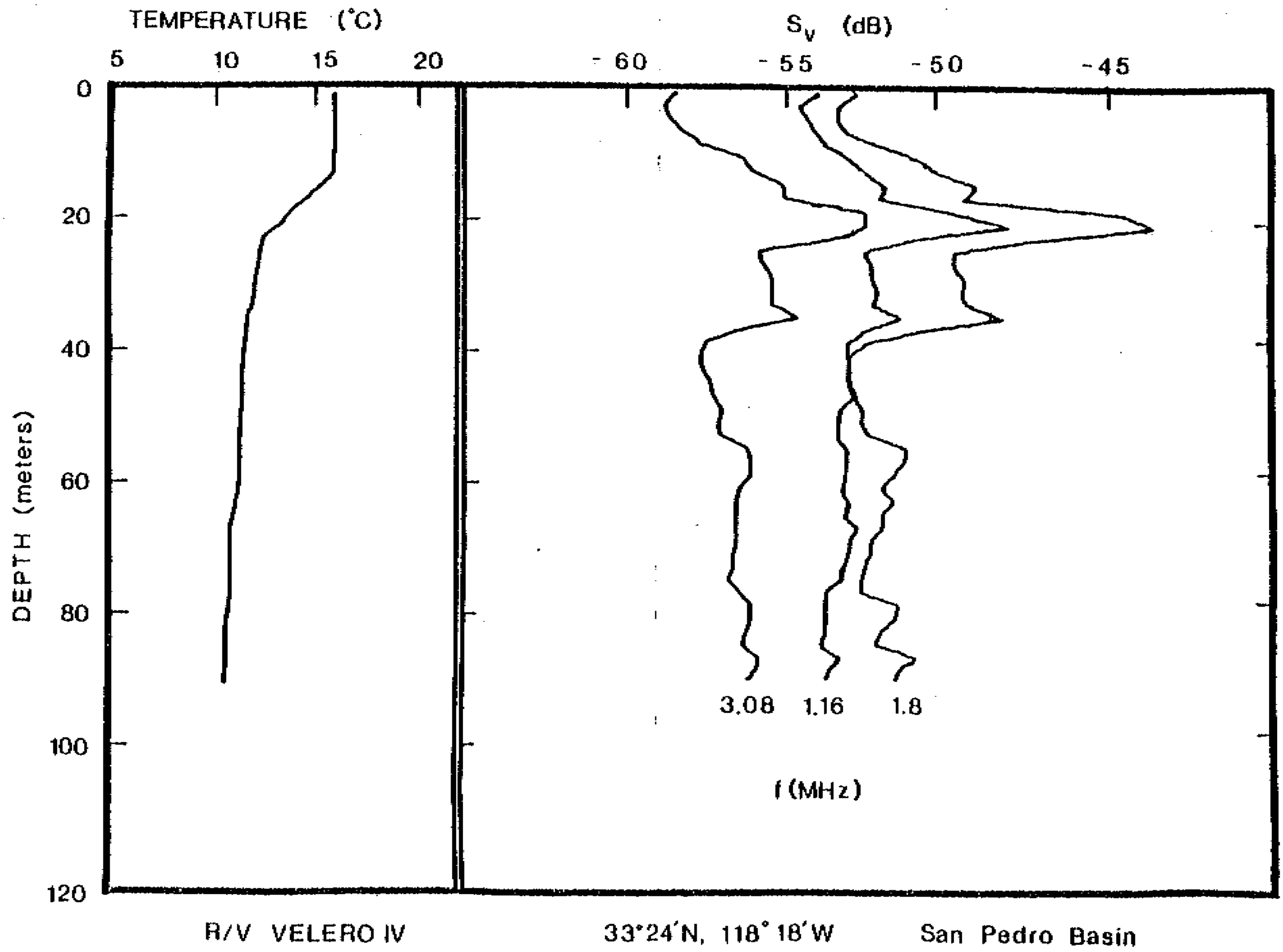


Figure 3. A qualitative echogram showing a patchy, 102 kHz scattering layer from euphausiids at a depth of 127 to 147 m in the San Pedro basin off southern California, and the calculated volume scattering strength for each minute over the 20 m interval shown. (From Pieper, 1979)

Figure 4. Acoustic scattering strength and temperature profiles from a station in the San Pedro basin off southern California. The acoustic scattering at these frequencies (1.16, 1.80, and 3.08 MHz) was from zooplankton, primarily copepods. (From Holliday and Pieper, 1980)



signature (Hamilton, 1970). Further work on seismic surveys and bottom profiling can be found in the text edited by Hampton (1974) and the article by Embley et al. (1970).

Physical oceanographers have used acoustics to study the size and extent of various oceanic phenomena, including internal gravity waves and warm water cores, as well as to explore the paths of currents by deploying SONAR buoys and monitoring their movements. Low frequency acoustics are presently being used to develop a technique, called "ocean acoustic tomography," to measure large-scale physical features (mesoscale processes; scales of about 100 km and two months) in the ocean (Munk and Wunsch, 1979).

Practical application of acoustics includes simple SONAR applications, doppler speed logs, and other telemetry devices for deployment and relocation of oceanic equipment.

iii. Ocean Monitoring

Acoustics have also been used in field studies relative to ocean monitoring. Proni et al. (1976) reported on their use of a 200 kHz echo sounder to trace the dilution and subsequent plume of sewage dumped into the ocean off the New York Bight sewage sludge area.

In a study to estimate the run of sockeye salmon (<u>Onchorhyncus nerka</u>), Thorne and Dawson (1974) compared their hydroacoustic transect data to weir counts of adult salmon moving out of their spawning areas of Lake Washington. Their goal was to establish a procedure for accurately assessing abundance to provide a harvesting limit so that reproductive stock of salmon would not be diminished because of overfishing.

In another study, Thorne et al. (1979) reported using acoustics to examine fish behavior around the cooling water intake of the Redondo Beach (California) generating station and the effects of thermal discharge on fish distributions and abundance in the vicinity of the San Onofre Nuclear Generating Plant. The first study fixed an acoustic sensor on the bottom near the intake, and the latter study used a shipboard transducer on a transect line to survey the development and extent of the thermal plume and the response of fishes to the plume.

c. Advantages of Acoustics

Acoustics provide several distinct advantages over conventional sampling schemes. The first, and probably most significant as far as monitoring is concerned, is the instantaneous procurement of significant data. Scientists can use the information independently or integrate it into a more comprehensive program. When combining acoustic information with net or trawl assessments, directed sampling can be based

upon acoustic patterns rather than a predetermined arbitrary selection of sampling depths. In addition, the trawl or net will provide information on the number and type of scatterer(s) present.

Acoustic techniques provide data in both the vertical and horizontal (cruise track or time) dimensions. Previous methods were limited to differences in either one dimension or the other, and repeated sampling was necessary to develop a less than adequate picture of zooplankton or fish distributions. Recent acoustic research has led the way for reassessment of the ways organisms distribute themselves in space and time in the ocean.

d. Problems with Acoustical Assessment

The major impediment with acoustical techniques is the paucity of information about which specific organisms are responsible for the sound scattering. While this problem is currently the focus of several research programs (for instance, Holliday and Pieper, 1980), it has yet to be resolved definitively. The multifrequency suite of echo sounders may be one of the primary mechanisms for differentiating various components of the zooplankton and fish assemblages (Greenlaw, 1979; Holliday, 1980). An example of scattering records using different frequencies is shown in Figure 3. Additional problems also occur when strong scatterers (e.g., fishes) are associated with numerically dominant, but weaker scatterers (e.g., zooplankton). In some of these instances, the fish scattering may obscure the scattering from the zooplankton. These problems eventually may be resolvable in light of current research.

The second problem most often associated with acoustic techniques is that of resolution. The resolution possible from acoustics is affected by the population density of organisms, their size, and the distance the acoustic signal must travel, mindful that most transducers are operated at or near the surface. When transducers operate near the surface, attenuation losses of acoustical signal, due to spreading and absorption of the sound wave by the oceanic medium, become significant when examining a deep population.

e. Conclusion

At the present time, most of the work with underwater acoustics in ocean monitoring-type studies is in the fields of biological oceanography and fisheries. Currently, echo sounders are routinely used for qualitative and quantitative assessment of fish and zooplankton stocks. Most of the quantitative investigations using echo sounders to assess sizes of individuals and numbers of various fishery stocks and euphausiid populations have been combined with more

conventional, supplemental information such as that from nets or trawls. Private, commercial, and scientific utilization of echo sounders attest to the reliability and convenience as well as cost effective means of gathering data. While at this time insufficient work for quantitative studies of mixed assemblages of organisms has been completed, it should be available in the future. As more information becomes available and the combination of computer processing and acoustic modeling develop together, it is not unreasonable to assume that some day acoustics will supplant other means of qualifying and quantifying distributional information in the ocean.

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2. Remote Sensing in Marine Monitoring

a. Introduction

Remote sensing, the acquistion of information about characteristics of objects or areas without coming into physical contact with them, is a relatively recent addition to the array of technologies for oceanographical and biological monitoring. One of the most pervasive problems in monitoring has been the obtaining of synoptic measurements or samples over areas larger than those which can practicably be sampled by one ship, a group of ships, or by in situ recording devices, such as buoys. Also, some important environments are not readily accessible to oceanographic vessels. These range from mudflats to arctic ice; such hostile environments could be monitored for at least some parameters by remote sensing.

There are several major drawbacks to monitoring by remote sensing. The first is the limitation of sensing to surface phenomena because depth penetration is minimal. The second limitation lies in the problem of interpreting the data derived, for extensive "ground truth" field data must be obtained via ships or buoys in order to calibrate the remote sensing images derived. A third limitation is the enormous volume of data generated, with concomitant difficulties in data reduction, and finally, a limitation is the capital investment required for satellite monitoring, although comparable scopes of in situ monitoring would be logistically impossible and/or prohibitively expensive.

An increasing array of remote sensing devices is available; these range from cameras to multi-spectral scanners, passive microwave systems, radar, thermal infrared senors, and laser systems. Platforms for the devices range from booms mounted on boats through low altitutde, medium altitude, and very high altitude aircraft, to spacecraft satellites.

The physical parameters which can be successfully measured include sea surface temperatures, sea ice, sea surface topography, oceanic wave energy, sea surface vector winds, turbidity, coastal erosion, waste plumes, and oil spills. Of the major biological processes only chlorophyll a can be measured by optical sensors.

The present realities of using remote sensing data are that they are not yet readily assimilated into oceanographic research because they may be difficult to obtain and difficult to comprehend (Goody, 1981) due to problems in tape formats, calibration (or lack thereof), and image processing methods.

b. Methods of Remote Sensing

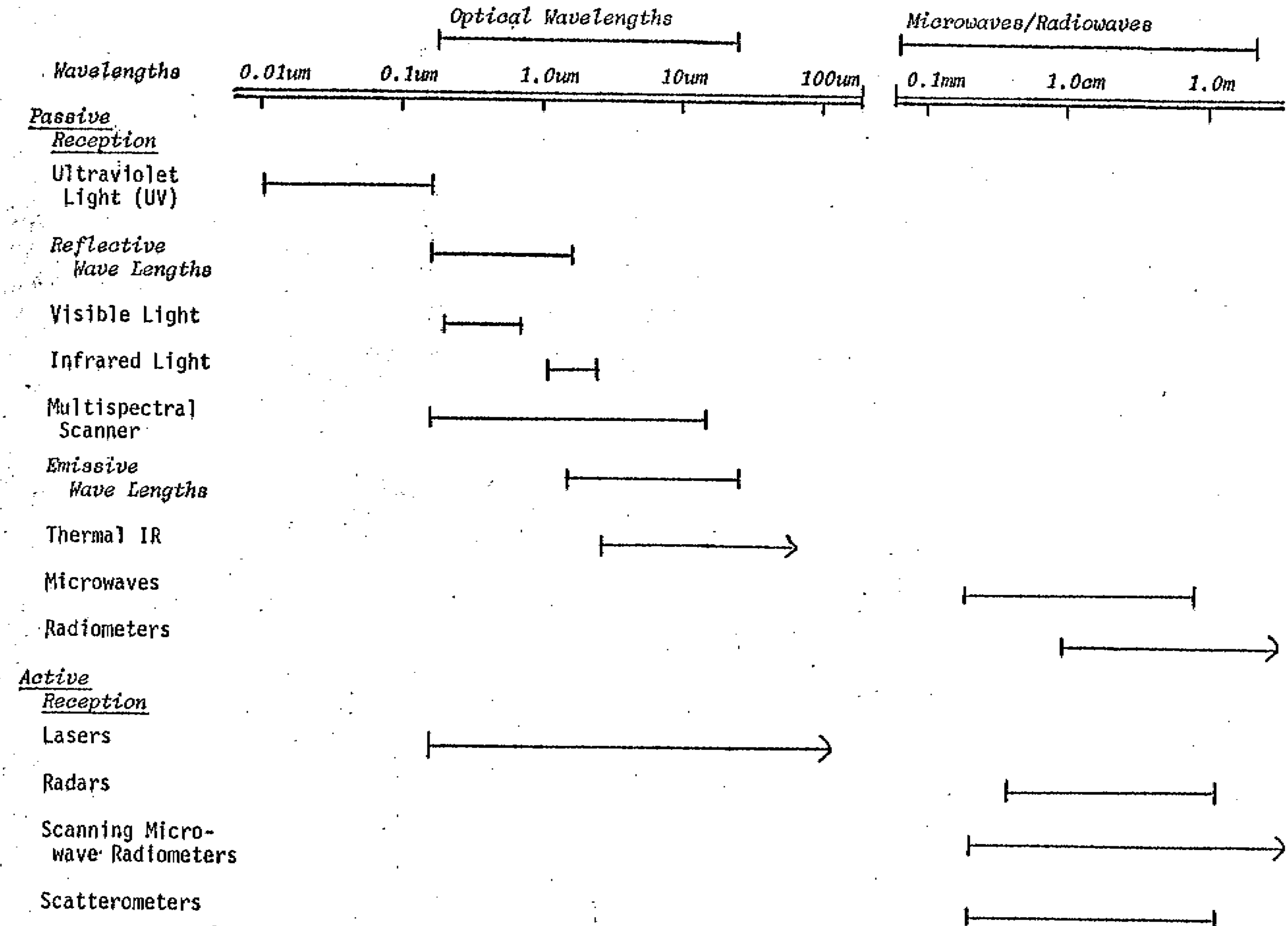
Remote sensing measurements are almost always translated into the production of images which are instantaneous views of some area of the earth. Remote sensors measure interactions of radiation with matter (Coulson et al., 1980) and may include reflected solar radiation, thermal emissions from the earth, and artificially produced radiation (radar). In Figure 5, some of the major divisions of the electromagnetic spectrum are shown, along with the types of remote sensing that are appropriate to the various wave lengths.

c. Passive Emissions

Reflective wavelengths are those that are passive; as the sun shines on the earth, sunlight is reflected as ultraviolet light, visible light, and infrared light in wavebands that can be sensed by a camera. As indicated in Coulson et al. (1980), the "color" film consists of three layers of gray which are later dyed; there is no color sensor as such. Yet the Coastal Zone Color Scanner (CZCS) has been used to produce spectacular pictures of chlorophyll a distributions, but requires extensive processing of data on reflectance values from the multiple sensor array (Multi-Spectral Scanner, MSS). Each area sensed for reflectance becomes a picture element, or "pixel," in an image which can be displayed on a video screen or printed as a simulated photograph. False color composites (FCC) of the green, red, and infrared scans can be digitized and computer-enhanced for creating false color photographs, but results of true color simulation are poor as yet. MSS temperature values will differ from "bucket" temperatures because of the difference in depth of sample, and calibration may be difficult to achieve.

The infrared sounder records thermal radiation from the surficial millimeter of the sea surface, and data can be converted to sea temperatures, which have in turn been used to produce striking images of the Gulf Stream, with warm rings and cold core rings. The latter, for example, have subsequently been studied in situ by multidisciplinary groups (the Ring Group, 1981). Only intensive and extensive surface investigations in biology, chemistry, and physics coupled with satellite data can reveal the importance of such phenomena, which are most probably linked to large-scale variations in fisheries stocks and reductions in fisheries such as those due to the El Nino diversions off Peru. The OPUS study of upwelling off California is an example of such multifaceted investigations (Dugdale et al., 1982).

Figure 5. Major Remote Sensing Ranges in the Electromagnetic Spectrum[1]



[1] Compiled from various sources (Soule, unpublished)

d. Active Radar Scatterometry

The NOAA Seasat satellite, which operated from June to October 1978 (Goody, 1981), flew an active radar scatterometer (SASS or SCAT) which measured return signals as they were scattered by surface capillary waves. It was possible to infer from these signals the surface wind stress, wind velocity, and direction, with some indeterminacy. It did measure, for the first time, the wind vectors in a hurricane off Hawaii, as well.

Microwave altimeters use radar beams to measure the distance between the earth and spacecraft. Early operators of radar in World War II referred to the return signals as "clutter," to be considered unwanted (Ernst, 1981). In the SASS system, backscatter was used to indicate tilt in the facets of the sea surface and thus to interpret the surface waves. After comparative analysis with buoy data and shipboard data, SASS correlations could be developed that would ultimately benefit marine transportation, offshore industries, and fisheries. Synthetic aperture radar (SAR) on SeaSat was able to provide information on sea ice dynamics (Hussey, 1981). Unfortunately the present NIMBUS satellites are not equipped with such systems.

Important progress has been made in monitoring sea ice using the NIMBUS satellites 5, 6, and 7 equipped with scanning multichannel microwave radiometer (SMMR or MR), which is a passive system that yields microwave brightness temperatures. The data can be converted to estimate wind speed, water vapor, rain rates, and ice cover.

e. Promises and Problems

The suite of instruments on the SeaSat satellite, which suffered an untimely power failure, and on the NIMBUS satellites have demonstrated the remarkable potential for investigating large-scale oceanographic phenomena beyond any possible comparison with the data collected by buoy or ship investigations.

Yet there are severe problems and needs for improvement in utilization of these instruments. Data reduction is an enormous problem, for continously recording sensors, regardless of where they are placed, create voluminous records. Conversion of SeaSat data obtained in only a few months has taken years to process, and the data are expensive for investigators to obtain in digital format or photographic form. Satellites, as highly visible and large budget items, have been easy to delete in the recent period of cost reductions, whereas budgets for some portion of the traditional individual and multi-

institutional research efforts survive. The "ground-truth" investigations necessary to calibrate remote sensing data must be continued whereever they can be incorporated into existing monitoring efforts.

The limitations in biological monitoring measurements to those related to chlorophyll may ultimately be overcome to encompass at least some type of intertidal biomass estimates. Low-flying aircraft probably offer the most cost-effective alternative for obtaining fairly large-scale monitoring of sea surface temperature and phytoplankton at the present time, utilizing the visible light and infrared spectrum equipment. Coastal wetlands are particularly appropriate to such sampling methods since terrain may be inhospitable for traditional field sampling. Kish (1981) listed an impressive array of applied problems which could be dealt with, at least in part, by making use of remote sensing observations including land and sea satellites. These include: detection of chlorophyll a, turbidity and suspended sediments; depletion of dissolved oxygen (based on false color imaging); red tides; municipal, industrial, and pulp/paper effluent discharges; oil spills and seeps, plugged leachate fields of septic tanks, sanitary waste disposal siting; drainage and flood evaluations; dredge and fill monitoring; acid-iron waste ocean disposal; water depths (measured by laser); salmon spawning; kelp bed monitoring; aquatic vegetation mapping; groundwater mapping; tidal zone mapping; non-point source pollution; salinity, temperature, pH and dissolved oxygen measurements; irrigation runoff; and hazardous waste leaching. The implications for marine monitoring in the future are well indicated, provided that some momentum in remote sensing research is maintained.

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