Deep Seabed Stable Reference Areas

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Report of a Study

Board on Ocean Science and Policy
Commission on Physical Sciences, Mathematics, and Resources
National Research Council

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Meetings Code:

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BOARD ON OCEAN SCIENCE AND POLICY

COMMISSION ON PHYSICAL SCIENCES, MATHEMATICS, AND RESOURCES

CONTENTS

PREFACE

Section 109(f) of the Deep Seabed Hard Minerals Resources Act of 1980 (P.L. 96-283) requires the Secretary of State, in cooperation with the administrator of the National Oceanic and Atmospheric Administration (NOAA), to negotiate the establishment of international "stable reference areas" (SRAs) where no mining of the deep seabed will occur. The SRAs are to be used as "a reference zone or zones for purposes of resource evaluation and environmental assessment of deep seabed mining," and include "the designation of appropriate zones to insure a representative and stable biota of the deep seabed." As a result of this requirement, the Office of Ocean Minerals and Energy of NOAA in February 1982 asked the National Research Council's Ocean Policy Committee (as of July 1, 1983, Board on Ocean Science and Policy) to undertake a study of the stable reference area provision. The objectives of the study were as follows:

1. To determine the scientific validity of the SRA concept.
2. If the concept is found to be valid, to outline a cost-effective program to address the major scientific issues involved in establishing SRAs.
3. If the concept is found not to be valid, to outline alternative cost-effective ways to address the scientific issues that led Congress to adopt Section 109(f).

To meet these objectives, four meetings were held. At the first meeting, the scientific validity of the concept was discussed and general implementation principles were defined. At the second meeting, the biological problems associated with assessing the effects of deep seabed mining were discussed, and cost-effective ways to define "representative and stable biota" were considered. At the third meeting, the term "characteristic environment," a phrase used during the first meeting to represent a suite of environmental conditions and associated fauna in an area to be mined, was further defined, and a cost-effective research program to identify such areas and to assess mining impacts was developed. A fourth meeting was held to focus on the details of the highest priority research need for answering many of the scientific questions associated with identifying stable reference areas. The meeting reports are given in Appendixes A, B, C, and D.

Appendix E is the text of a background paper prepared for the fourth meeting.

This report summarizes the deliberations at the four meetings and reflects the views of the participants. Their individual and collective efforts, both before and during the meeting and in reviewing the report, are greatly appreciated.

G. Ross Heath, Chairman

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FINDINGS AND RECOMMENDATIONS

The dwindling of the world's stock of land-based mineral resources has prompted increasing interest among mining companies in exploiting the so-called manganese (or ferromanganese) nodules that are found in large quantities on many parts of the deep seabed. In addition to manganese and iron, these natural concretions contain more than 1 percent nickel, cobalt, and copper.

No attempts have been made to recover the useful metals in the nodules, however, primarily because no agreement has been reached on an international legal structure that would protect the interests of countries or private firms engaged in such deep-sea mining, most of which would take place beyond territorial waters. A secondary factor in delaying these mining operations has been the generally weak market for metals resulting from the current world-wide economic recession. In addition, current U.S. law prohibits recovery before 1988.

Deep-sea mining of these deposits is likely, eventually, to become economically attractive, and an international legal regime specifying rights and privileges will be put into place. Once mining of the nodules commences, it will have an impact on the biological organisms living in or near the mined regions. Just how serious this impact will be is still a matter for speculation.

Concern about the effect of deep seabed mining on the benthic community of the ocean bottom led Congress to include in the Deep Seabed Hard Minerals Resources Act of 1980 (P.L. 96-283) a clause requiring the establishment of stable reference areas (SRAs). These areas are to "preserve" representative deep-sea biota and to provide areas against which the extent of mining's impact on biological organisms can be determined.

After the 1980 law was passed, the National Oceanic and Atmospheric Administration (NOAA) asked the National Research Council's Ocean Policy Committee to examine the scientific validity of the SRA concept and, assuming the concept is valid, to outline a program for establishing SRAs. The following findings and recommendations represent the consensus of the committee, although not all were supported unanimously.

1. The concept of stable reference areas (SRAs) as outlined in P.L. 96-283 is scientifically valid if two types of SRAs are designated: one type, the preservational reference area (PRA), must be located to ensure that the biota is not affected by mining activities or other anthropogenic activities; the other type, the impact reference area (IRA), must be located close enough to mining to minimize inherent environmental differences so that statistically valid assessments of the impacts of mining can be made.

2. A small-scale resuspension experiment is required to identify the biological parameters that record the impact of mining most reliably. This is the highest priority near-term research need.

3. Present knowledge of the distributions of physical properties suggests that division of the Clarion-Clipperton region into three east-west units separated by boundaries at about 130°W and 140°W and three north-south units with equally spaced boundaries parallel to the fracture zones would define a set of nine "characteristic environments" within which the regional variability of environmental parameters is minimized. Each characteristic environment should contain at least one provisional PRA. Analysis of faunal distribution patterns in relation to characteristic environments may modify this approach, however (see pp. 00-00).

4. Bottom drifters, when available as routine research tools (probably within 5 years), should be used to map the drift of the bottom waters in the Clarion-Clipperton region so that PRAs can be sited upstream from mine sites.

5. Trial mining tests within licensed exploration areas should be used to assess the area likely to be affected by the plume of resuspended sediment from the mining collector to help define the appropriate separation of PRAs from mine sites.

6. Industrial groups should be encouraged to collect good-quality environmental data and samples during their exploratory cruises and submit them to recognized repositories so that these data can be used in the designations of provisional PRAs.

7. Studies of existing bottom photographs and good-quality benthic samples, together with additional data from ships of opportunity can provide a cost-effective means of increasing the knowledge of the benthos of the Clarion-Clipperton region. Such knowledge will aid in defining the number, size, and location of provisional PRAs.

8. The initial designation of provisional PRAs should be made as soon as possible. Refinement of these sites should be based on results from the controlled impact experiment (#2), from trial mining tests (#5), from bottom drifter deployments (#4), and from analysis of existing samples (#7).

9. Permanent PRAs should be designated when the first commercial recovery permits are issued. The preferred size of PRAs will depend on the results of the trial mining tests (#5), industrial data (#6), and provisional PRA studies (#8). Results from the experiment (#2) and provisional PRA studies (#8) should be assessed to better define the number of "characteristic environments" and, consequently, the number of permanent PRAs that should be designated.

10. Long-term biological monitoring of a subset of PRAs should begin as soon as mining operations begin to allow the detection of faunal changes due to effects too subtle to be recognized during the monitoring phase of a mining operation.

11. One IRA per mining site should be designated simultaneously with the issuance of each commercial recovery permit. Studies in IRAs should be based on the results of the experiment (#2) and should form part of the permittee's monitoring program. Studies similar to the experiment (#2) should begin with the development of a sound theoretical base and should be continued long enough to assess both short-term and possible intermediate-term impacts of mining activities. Shapes and locations of the IRAs should be designed to minimize the likelihood of null experiments (i.e., those detecting no impact), so as to maximize the statistical power of the comparison.

12. International consultation to promote acceptance of the PRA/IRA concept and to refine the characteristics and locations of such areas should be undertaken immediately to maximize the collection of complementary field data and to minimize potential conflicts between reference and mining areas.

13. Because of the large uncertainties still associated with plans to process nodules, this committee devoted little time to considering the environmental consequences of on-site processing. However, should such on-site processing result in the dumping of process rejects at mine sites, additional controlled experiments and on-site biological observations will be required to assess the impact of such discharges on the pelagic and benthic biota downstream from the processing vessel.

INTRODUCTION

BACKGROUND

Vast quantities of ferromanganese are found on the sea floors of the world's oceans. In certain regions, such as the area between the Clarion and Clipperton fracture zones in the eastern tropical Pacific, the deposits contain sufficient quantities of nickel, cobalt, copper, and manganese to interest mining companies. Although studies of mining and nodules have been under way for more than a decade, serious investment in seabed mining has awaited the development of a legal structure that would provide companies with exclusive rights to a mine site over a long period of time. Development of such a legal structure has been complicated by the fact that the nodule deposits are, in general, beyond the limits of jurisdiction of any nation.

The Third United Nations Conference on the Law of the Sea (UNCLOS III) has been attempting to reach agreement on a new international legal structure for managing the exploitation of the sea's resources since it convened in 1974. While a consensus has been reached on most of the other issues with which the conference is dealing, global agreement on a seabed regime has not been achieved.

LEGISLATION

Before the start of UNCLOS III, legislation was introduced in the U.S. Congress to license U.S. firms wishing to explore for nodule deposits and ultimately to exploit them. The legislation was based on the view that nodule mining, like fishing, was a high seas freedom permitted under the 1958 Geneva Convention of the High Seas. After UNCLOS III began, the proposed legislation was modified to make it interim in nature, pending U.S. ratification of a Law of the Sea treaty and its entry into force.

The legislation underwent other changes as well before it was passed by Congress. In early 1979, several months before the law's enactment, a provision calling for the establishment of SRAs was added. The impetus for this provision came in part from a resolution passed at the 14th Session of the General Assembly of the International Union for Conservation of Nature and Natural Resources (IUCNNR) in 1978. The resolution stated:

AWARE that deep sea mining activities are being undertaken by several nations that will disturb or destroy natural systems that have developed without the adverse influence of mankind;

FURTHER AWARE that such disturbance of the deep sea bed affects adjacent water masses from the sea bed to the surface and relates to the stability of the ocean environment as a whole;

RECOGNIZING that undisturbed natural systems in the deep sea can provide insight into the processes by which valuable mineralized nodules develop;

NOTING THAT even incomplete knowledge of deep sea organisms and deep sea ecology confirms great diversity of life and the existence of unique forms of life hitherto unknown;

CONCERNED because both species and systems have been shown to develop very slowly and thus are especially vulnerable to the impact of mining and activity;

BEARING IN MIND that any meaningful evaluation of the effects of ocean mining on marine life requires comparison with areas in which no mining has occurred;

The General Assembly of IUCNNR, at its 14th Session, Ashkhabad, USSR, 26 September-5 October 1978: URGES all nations engaged in, or considering, deep sea mining activities to:

(a) precede commercial mining operations by commissioning a comprehensive ecological survey to determine the impact of such mining activity;

(b) designate appropriate areas of the deep sea bed as baseline reference and resource zones in which no mining will be allowed;

(c) designate the size and shape of such area or areas to ensure that their stability will be maintained; and

(d) establish guidelines for scientific research to ensure minimum disruption of the natural state of such areas.

The seabed mining legislation became law when President Carter signed the Deep Seabed Hard Minerals Resources Act (P.L. 96-283) on June 28, 1980. Section 109(f) of the act states:

(1) Within one year after the enactment of this Act the Secretary of State shall, in cooperation with the Administrator as part of the international consultations pursuant to subsection 118(f), negotiate with all nations that are

identified in such subsection for the purpose of establishing international stable reference areas in which no mining shall take place: Provided, however, that this subsection shall not be construed as requiring any substantial withdrawal of deep seabed areas from deep seabed mining authorized by this Act.

(2) Nothing in this Act shall be construed as authorizing the United States to unilaterally establish such reference area or areas nor shall the United States recognize the unilateral claim of such reference area or areas by any State.

(3) Within four years after the enactment of this Act, the Secretary of State shall submit a report to Congress on the progress of establishing such stable reference areas, including the designation of appropriate zones to insure a representative and stable biota of the deep seabed.

(4) For purposes of this section "stable reference areas" shall mean an area or areas of deep seabed to be used as a reference zone or zones for purposes of resource evaluation and environmental assessment of deep seabed mining in which no mining will occur.

Implementation of the legislation was assigned principally to the National Oceanic and Atmospheric Administration (NOAA) in the Department of Commerce. NOAA established the Office of Ocean Minerals and Energy for this purpose and has begun preparation of the required policy and regulatory framework. Regulations pertaining to exploration licenses were issued in September 1981 (46 Federal Register 45890-45920).

At the time the regulations were issued, the U.S. government began negotiating for mutual license recognition with the three other nations (Federal Republic of Germany, France, and the United Kingdom) that had passed legislation similar to that of the United States. Since agreement on a basic reciprocal arrangement dealing with licensing is near, negotiations regarding SRAs could begin in the near future. In preparation for those discussions, NOAA asked the National Research Council's Ocean Policy Committee (OPC) to undertake a study of the stable reference area provision and its validity and intent.

The committee concluded that the concept of SRAs as outlined in P.L. 96-283 is scientifically valid. Given the current state of knowledge, however, the committee also concluded that the goals of P.L. 96-283 (designation of appropriate zones "to insure a representative and stable biota of the deep seabed" and "to be used as a reference zone or zones for purposes of resource evaluation and environmental assessment of deep seabed mining") could be met only by designating two types of SRAs. One type, the preservational reference area (PRA), must be sufficiently distant from mining sites and large enough to ensure that its biota is not affected. These areas should also be protected from other anthropogenic impacts, such as dumping of wastes. The other type, the impact reference area (IRA), must be close enough to mining areas to minimize environmental differences and thereby allow statistically valid assessments of the impact of mining activities.

MINING PROGRAM

Regulatory Program

The act allows the administrator of NOAA to issue licenses for the exploration and permits for the commercial exploitation of manganese nodules in the deep sea to qualified U.S. citizens. Commercial recovery is prohibited by law prior to January 1, 1988; however, test mining can occur prior to that time under a license.

NOAA has received applications for exploration license sites in the tropical Pacific from four international consortia with U.S. members. It is expected that these licenses will be issued in mid-1984, following the resolution of differences between the applicants over the sites to be explored. These licenses will allow the applicants to delineate the nodule resource at a site, determine environmental characteristics of the site that will affect the mining technology to be used, and conduct tests of mining equipment. A license will also entitle the applicant to seek a permit to mine an area within the exploration zone if the company can meet permit requirements. Licenses will be issued for periods of 10 years, which may be extended in 5-year increments.

Preparations for the issuance of mining permits have also begun. In December 1982, NOAA issued an Advance Notice of Proposed Rulemaking in the Federal Register soliciting comments on proposed regulations governing the exploitation of manganese nodules. It is expected that these regulations will be issued in mid-1984 and become effective shortly thereafter. Mining permits will be issued for initial periods of 20 years that can be extended by the administrator as long as commercial quantities of nodules are being recovered.

No policy was stated in the license regulations on the implementation of the stable reference area section of the law since it was felt to be premature; however, acknowledgment of this concept and NOAA's intent to implement it will be made in the individual license terms, conditions, and restrictions (TCR). The commercial regulations are expected to include information on NOAA's implementing strategy with specific TCR attached to individual permits, as appropriate.

The law requires licensees and permittees to monitor the environmental effects of their activities. Both licenses and permits will contain terms, conditions, and restrictions designed to prevent a "significant adverse effect on the quality of the environment." Permit applications will be required to include specific baseline information submitted in accordance with NOAA guidelines. No baseline information will have to be submitted prior to permit application for a mining permit, however, if no equipment tests are planned. If tests are planned under a license, applicants will be required to submit baseline data and a monitoring plan, developed in consultation with NOAA, one year prior to such tests.

NOAA can also place observers on company vessels to monitor conformance with license and permit TCR. If adverse environmental effects result from exploration or commercial recovery activities, the licensee or permittee will be required to develop and evaluate methods of mitigating such effects. NOAA also has the authority to suspend or modify operations if significant adverse effects are detected.

Few environmental data, and only skeletal monitoring plans, have been submitted to NOAA by the consortia, since both at-sea, demonstration-scale testing and commercial recovery are some years away. More comprehensive monitoring plans will be developed as the date for at-sea tests or commercial recovery draws closer and will be incorporated into license or permit TCR.

Industry Development Scenario

Since the concept of mining ferromanganese nodules in the deep ocean was first conceived, mining consortia have estimated the abundance and metal contents of nodules in the tropical Pacific, designed and tested prototype mining systems, and tested and evaluated bench-scale nodule-processing systems. Although these activities strongly suggest that deep seabed mining is technologically feasible, many other activities must be undertaken before major capital investments are made and mining actually begins.

Initial at-sea equipment tests have already occurred, and further testing under a license or permit may occur as early as 1986. Some consortia have indicated that they may conduct further tests of processing technologies during the license period, while others will scale up processing technologies during the permit phase. Major activities for most consortia during the license period, however, will be finer delineation of the distribution and grade of nodules and definition of those areas that can support commercial recovery of nodules over a period of 20 years. At the end of the 10-year license period, all of the consortia plan to apply for permits to mine commercially.

The problems inhibiting aggressive action by the mining consortia are (1) the unsettled state of international law regarding the mining of nodules and (2) the depression in world metal prices. Until these problems begin to resolve themselves, it is doubtful the industry will move very rapidly.

As a consequence, NOAA will find it difficult to designate SRAs, since such designations will rely in part on actions taken by private companies. The development of criteria for designating SRAs, for example, will depend in part on the results of testing. It is not certain, however, that any of the consortia will conduct further at-sea tests before being granted a permit. This means that baseline data collected by the consortia probably will not be submitted to NOAA until applications for permits are made. Consequently, these additional data, which could be used to help determine the number and location of PRAs, will be available only a short time prior to the awarding of permits when SRA designation should be made. Nor is it known exactly when various consortia will apply for mining permits. If permits are not issued until approximately 10 years after the issuance of licenses, the designation of SRAs will be delayed. Thus it is not possible to project the time of SRA actions with certainty because of the dependence on industry's activities and progress. Figure 5.1 represents a best estimate of future activities by mining consortia and the required interrelationship between these actions and those of NOAA for implementing the proposed SRA strategy.

INTERNATIONAL DEVELOPMENTS

The designation of SRAs will have to be done through negotiations with other mining nations, but it is uncertain which nations will be granting licenses or permits to conduct mining activities and what the legal framework governing these activities in international waters will be. Two legal regimes are developing simultaneously. The success of either one, and the interrelationships between the two, cannot be predicted at this time.

United Nations Law of the Sea

On April 30, 1982, the United States voted against adopting the text negotiated by the Third U.N. Conference on the Law of the Sea (UNCLOS III) because it found seabed mining provisions unacceptable. The United States believed, for example, that these provisions would prevent the success of unsubsidized, market-oriented, free enterprise mining operations. The United States therefore refused to sign the Convention when it was opened for signature in December 1982. The signing of the Convention by the required 50 nations established the Preparatory Commission, which is to develop the regulations implementing the Convention. Some nations, although signing the Convention, have withheld ratification (i.e., final approval) pending the development of draft regulations by the Preparatory Commission. One year after ratification of the Convention by 60 nations, it will enter into force. Of the major western mining nations, only France and Japan have signed the Convention at this time. Whether other mining nations will sign the Convention in the near future is unknown.

The Convention established December 31, 1984, as the deadline for nations to determine whether they will sign the Convention, thereby entitling mining operations by their nationals to international legal protection. Consequently, the mining consortia and mining nations must decide by that date whether to sign the Convention or participate in an alternative legal regime.

Reciprocating States Regime

Prior to the signing of the Convention by the necessary 50 nations, the United States and other major mining nations were working together to create an interim legal regime that would allow pioneer mining operations (those under development prior to the signing of UNCLOS) to proceed with some degree of security until an acceptable UNCLOS text was ratified. On September 2, 1982, the United States, United Kingdom, Federal Republic of Germany, and France signed an agreement that provides for consultation on issues relating to seabed mining. The agreement is considered preliminary, since it does not yet provide for mutual recognition of seabed mining licenses issued by the nations that have signed the agreement. The consortia, however, have been holding discussions among themselves to resolve differences arising from the fact that they wish to explore areas that overlap each other. Once these conflicts are resolved, the major mining nations will find themselves under pressure to provide for mutual recognition of licenses.

Up to this time, the United States has had few discussions with other mining nations regarding the establishment of SRAs. Because of uncertainty regarding the international legal framework, the nations with which the United States would have to negotiate to establish SRAs are undetermined. With the exception of the United Kingdom, no other nation has legislation providing for the establishment of such areas. Since the United States has not yet proposed a strategy for designating SRAs, other nations have been noncommittal toward the idea. NOAA is required to report to the Congress in 1984 on progress toward the establishment of such areas, however, and it is expected that the agency will begin discussions with other nations in the near future. Although other nations are not required by domestic legislation to set up SRAs, there is general agreement among most mining nations that licenses and permits should have compatible environmental requirements.

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PRESERVATIONAL REFERENCE AREAS

Preservational reference areas (PRAs) are SRAs that are distant enough from deep seabed mining sites to be unaffected by mining activities, yet representative of the environments to be mined. In addition to preserving areas of the seabed, the designation of PRAs provides sites where deep ocean processes can be studied to support the design of postmining monitoring studies and interpretation of the resulting data. Because the diversity of the environments to be mined is unknown, present knowledge suggests that a division of the Clarion-Clipperton region into three east-west units separated by boundaries at about 130°W and 140°W and three north-south units with equally spaced boundaries parallel to the fracture zones would create a set of nine "characteristic environments" within which large-scale variability of environmental parameters would be minimized. Each unit should contain at least one provisional PRA, which should be identified as soon as possible to embed the concept into the regulatory process and the reciprocating states framework and focus future fieldwork. Within each characteristic environment, properties such as sediment type, bottom currents, nodule coverage, extent of erosion, bottom slope, and nodule chemistry can be expected to vary markedly (i.e., on a scale of meters to kilometers). Existing detailed study sites should be incorporated into PRAs, if at all possible (e.g., MANOP Site S), since they represent a major investment of field and laboratory effort and in some cases provide an initial data base for time series studies spanning more than a decade.

Concurrently with the designation of provisional PRAs, research should be initiated to address the specific ecological concerns underlying the SRA concept. The results of this research would provide the basis for refining provisional PRAs and ultimately lead to designation of permanent PRAs. Specifically, the following tasks should be undertaken:

1. Highest priority should be given to the conduct of an experiment designed to assess effects of resedimentation on areas outside the path of a mining device in order to select locations for either IRAs or PRAs.
2. After resedimentation effects have been determined, planned sampling and environmental surveying programs should be designed and

implemented to determine the siting, size, and number of PRAs. This should include the use of bottom drifters to determine the flow of bottom waters in the Clarion-Clipperton region.

3. Maximum effort should be placed on utilizing ships of opportunity and analyzing existing data, samples, and photos, especially if funds are insufficient to support sampling programs focused on designation of PRAs.

4. Industry equipment tests should be carefully monitored to track the extent and effect of the benthic plume.

RESEDIMENTATION EXPERIMENT

To pick locations for either IRAs or PRAs, it is necessary to determine the effect of the benthic plume on areas away from the path of a mining device. Such a determination can take the form of an experiment in which the amount of resedimentation is controlled. The experiment should take place at a depth, accessible by a submersible, that affords an environment comparable to that expected at an actual mining area. It is recognized that at ALVIN's operating depth of 4000 m it will not be possible to duplicate exactly potential mining areas, which lie deeper than 5000 m. However, the advantages of working at shallower depths outweigh the limitations. While the results may not be fully applicable to nodule fields, they will establish sound criteria for monitoring and assessing impacts once actual mining begins. An acceptable experimental design can address the effect of resedimentation on several ecological parameters and can include a variety of methods for looking at total faunal composition, sediment mixed layer processes, and other characteristics. The experiment should rigorously address the following questions:

1. What is the effect of different amounts of resedimentation upon the species and functional group composition?
2. To what extent is any effect due to mortality, immigration, larval and adult recruitment, or alteration of demographic parameters?
3. What is the rate and sequence of recovery as measured by the faunal composition and the nature of the sediment mixed layer?

Since formal experimentation is the most effective means of producing an unambiguous answer as to how changes in the physical environment affect the biological components, such an approach must have first priority whenever it is technically and logistically feasible. Second, but much lower, priority must be assigned to planned sampling that seeks relationships between fauna and physical factors about which we have sufficient prior knowledge. Third priority is assigned to general multivariate analysis of survey data to identify additional questions important for more detailed experimentation. In general, second- and third-priority studies should be undertaken only when experimentation is not possible, or when other factors markedly reduce the cost of such studies.

It must also be stressed that the premature adoption of an experimental approach can prevent the final objectives of a project from being achieved. This is especially the case in ecological field experiments where the researcher controls the variation of only a small subset of all the factors in the environment. When there is not sufficient information about the biotic-environmental system to allow for identification of the most important factors, an experimental approach can be misleading. In most instances, deep-sea systems are poorly understood. However, to address SRAs, the panel advocates experimentation to determine the effect of one critical factor--sediment outfall from the plume. The problem is not to determine which natural factors are the most important in controlling community change, but rather to determine whether there is a measurable effect on the environment from an artificial disturbance that simulates an effect associated with mining. For this reason, an experimental approach should be adopted to answer this one question.

The development, execution, and interpretation of such an experiment will take about 7 years. Planning for it should therefore begin immediately. Such an experiment could also be used to test techniques to minimize the ecological impact of mining, and could contribute to the development of the site-specific environmental impact statements that are a prerequisite for commercial mining. Appendixes C, D, and E present more details on this experiment.

PLANNED SAMPLING AND ENVIRONMENTAL SURVEYING PROGRAMS

The use of PRAs as unimpacted reference areas, not as preserves against extinction, offers the best initial criteria for their siting. Island-zoogeographic theory or other developing theories for terrestrial preserve design do not offer useful criteria at this time. The rarity and sparsity of the deep-sea fauna make it highly unlikely that sufficient life history information could be gathered to suggest a scientific rationale by which to determine the size and number of PRAs. For the smaller size classes of animals, which make up the great bulk of the diversity, less than 28 percent of the species have an abundance of one individual over a 4-m^2 area (based on DOMES macrofauna studies). The diversity and paucity of the fauna in potential mining sites will result in a low analytical precision unless much larger numbers of samples are taken than is usual in basic deep-sea research efforts. It will be difficult to obtain numerous specimens of any species either for faunal comparisons or for direct examination. Thus biological studies to characterize provisional PRAs should be carried out in a gradual fashion since such studies will be costly and the theoretical framework for such studies needs to be strengthened. To maximize the effectiveness of programs that must gain information on deep-sea ecology, it is necessary to focus funding resources on programs that have highly specific goals supported by carefully planned sampling and analytical efforts.

The following PRA guidance and required sampling program is suggested for identifying PRAs. Until resedimentation effects have been determined, however, it is not even possible to determine where PRAs should be relative to potential mining areas.

1. A PRA should have biotic and environmental characteristics similar to those of the potential mining areas. Similarity can be determined by comparative sampling of a potential mining site and a provisional reference area. In practice, the necessary faunal survey will require extensive sampling, but only low-resolution comparisons can be expected. Because of their costs and the need for a stronger theoretical framework for such studies, the exhaustive biological characterization of sites should be undertaken in a measured rather than a hurried way. The sparseness of macrofauna in potential mining areas makes the collection of statistically useful samples difficult, if not impossible, using the best existing technology. Serious consideration should be given to assessing the more numerous meiofaunas and microfaunas as potential biological monitors. Comparisons should include dominant species including meiofauna and microfauna, diversity, standing crop biomass, photo-surveying of topography and megafauna, descriptive sediment analyses, near-bottom current structure, sedimentary mixed layer structure and mixing, and benthic metabolism. The use of metabolic data (oxygen consumption and ATP activity) should help to assess the spatial and temporal variability of biological activity. Natural short-lived and fallout radionuclide distribution can help to quantify near-surface bioturbation. Field surveys should not place too much emphasis upon direct or indirect measures of community processes because we do not know how to relate such findings to questions about specific animal populations.

Long-term current measurements as well as bottom photography (long time series) should be employed if erosion is suspected. Nephelometry and particle flux measurements will further define the depositional environment. If, as seems reasonable, the interaction between bottom topography and bottom currents affects food sources and hence faunal patterns, the minimum diameter of a PRA is likely to be tens of kilometers. This size may have to be increased to minimize the likelihood of alteration of a PRA by the plume from a mine site. Modelers may be able to assist in choosing the PRA size required for population maintenance. Models can also guide sampling strategy and allow subsets of taxa from the total fauna to be used for characterization.

To designate enough PRAs to include the range of environments threatened by mining, it will be necessary to undertake wide-scale environmental surveying. It is recognized that a comparable biological survey would be prohibitively expensive. However, it has not been established that the nonbiological characterization of nodule field benthic environments reflects faunal distributions. Therefore it is necessary to establish the relations that exist between the physical environment and the associated fauna. Such a project could take the form of an analysis of variance. Biological samples would be taken from sites with known differences in specific physical factors. Future descriptive surveying could then make extensive use of those factors that prove to correlate significantly with faunal composition. Such a planned sampling program, however, should be given lower priority than an experimental look at resedimentation effects.

Preliminary environmental characterization of the provisional PRAs should make use of the most economically effective techniques so that the greatest number of areas can be assessed. Approaches could include Seabeam surveys of selected portions of PRAs; coordinated time-series measurements of near-bottom currents, particle fluxes, and particle concentrations; and discrete determinations of the spatial and temporal variability of selected biological parameters. Bottom drifters, when available as a routine research tool, should be used to track near-bottom currents to improve predictions of benthic plume drift in the Clarion-Clipperton region. Such data will help locate PRAs upstream of mine sites. Because of the difficulty in recognizing and correcting for local topographic steering, progressive vectors derived from moored current meters yield much less reliable estimates of the mean regional bottom flow.

The mining consortia should be strongly encouraged to collect high-quality data and samples during their exploration activities, which would be submitted to recognized repositories. Such information would increase the data base on which provisional PRA identifications would be made.

2. <u>To resolve conflicts between mining interests and the establishment of PRAs, a planned sampling program should be designed to determine whether a prime mining area coincides with a distinct fauna.</u> It is anticipated that some conflicts may arise if PRAs are perceived to remove substantial areas from exploitation. The deciding factor must lie in a determination of whether the fauna in a contested area is unique. In part, this can be done by establishing whether those factors that determine the desirability of an area for mining also coincide with a distinct fauna. This could be addressed in a planned sampling program similar to that described above, but in which the physical parameters are restricted to those also used to find prime mining areas. These include topography, nodule cover, and nickel content.

ANALYSIS OF EXISTING DATA, SAMPLES, AND PHOTOGRAPHS

Analysis of existing information provides a cost-effective means to obtain additional insight into some of the ecological issues. In addition, such analyses can be initiated immediately, whereas conduct of the resuspension experiment is at least years off due to required planning, and results from test mining are likewise several years away since industry's development schedule has slowed down. Mining consortia should be urged to give NOAA nonproprietary, unpublished environmental data so that additional analyses can be made of these data. The following projects, which can be initiated immediately, will contribute to the base of knowledge on the variability in the DOMES region and thus support decisions on the number, size, and location of PRAs:

1. Assessment of the correlation between extreme local variations in the physical environment at DOMES Site A (which are well known) and the benthic biota in existing, good-quality biological samples, supplemented by photo traverses, community respiration rate measurements, and, where necessary, additional core samples to be collected from ships of opportunity. Such a comparison should include hills versus valleys, nodule-covered areas versus nodule-free areas, Tertiary versus Quaternary surface outcrops, and copper- and nickel-rich nodule areas versus copper- and nickel-poor nodule areas. This task is prompted by the existing state of ignorance of the correlations between small-scale variations in the benthic environment, and faunal variations. In this context, the environmental properties with high spatial variability should be tested to determine the extent to which they are statistically independent so as to minimize the number of measurements required in the future.

2. Evaluation of existing bottom photographs supplemented by additional transects to be collected from ships of opportunity and, where possible, calibrated by bottom samples, to determine whether (a) macrobenthic taxa are uniformly distributed over the Clarion-Clipperton region, (b) these taxa vary from characteristic environment to characteristic environment, or (c) they follow some other coherent pattern in the region. The number and distribution of provisional PRAs should be reassessed if the third possibility is found to be the case.

3. Synthesis of existing quantitative benthic faunal data from the Clarion-Clipperton region (principally from the DOMES sites) to determine which organisms are consistently abundant enough for their absence from a sample to be indicative of a deviation from a homogeneous population.

TEST MINING

Because of the importance in determining the benthic plume effects to the location of PRAs relative to mine sites, future test mining should be carefully monitored to define the area affected by the benthic plume. Such an assessment should be based on measurements from moored sediment traps, nephelometers, and current meters, as well as "before" and "after" core samples and bottom photographs. Better information on the behavior of the plume of resuspended sediments will contribute to the determination of the location and minimum size of PRAs required to preserve a benthic area.

4

IMPACT REFERENCE AREAS

At least one impact reference area (IRA) should be designated simultaneously with the issuance of each commercial recovery permit. Research on the designation of IRAs should be modeled on the techniques developed to characterize PRAs and should form part of the monitoring program carried out by the permit holder. To the extent that IRAs within areas covered by commercial recovery permits are mined within 20 to 30 years, they will not have the permanence sought for PRAs. Studies of IRAs should continue long enough to assess both the short-term and the intermediate-term impacts of mining. The shape and location of IRAs should be designed to minimize the likelihood of detecting no impact.

Because of the "control" aspect of IRAs, they should adjoin or even overlap commercial recovery areas to minimize the spatial variability that might be wrongly assessed as an impact from mining. Many, if not most, of the studies of IRAs should be part of the monitoring activities that accompany mining. There is a clear need to assess both the immediate impacts of mining, where cause-effect relationships are likely to be obvious, and delayed (or longer-term) impacts, where the chain of cause and effect may be obscure and scientific understanding depends on knowledge developed from studies of PRAs. Long-term monitoring of a subset of PRAs should begin in conjunction with the initiation of commercial mining and IRA studies so that subtle natural changes in the benthic environment can be recognized.

It is premature to suggest a program of impact assessment and monitoring in areas where there has been commercial-scale mining. However, the criteria developed and the important parameters identified during the experimental program should form the basis of postmining studies. It is anticipated that such programs will focus on recolonization and return of the biota to a stable state, possibly unlike the premining state.

5

IMPLEMENTATION

Identification of provisional PRAs should occur prior to the award of preenactment licenses in order to embed the concept into the domestic legal framework. Discussions with members of the reciprocating states on the implementation of the SRA concept should begin immediately, with the goal of agreeing on the number, size, and location of provisional PRAs.

Designation of permanent PRAs should occur no later than at the time of permit issuance. Prior to permanent designation, a panel of international experts should be convened to assess the data from

1. Provisional PRA studies.
2. Monitoring of test mining.
3. Mining consortia.
4. The resuspension experiment.
5. Any other samples or studies that would contribute to PRA designation.

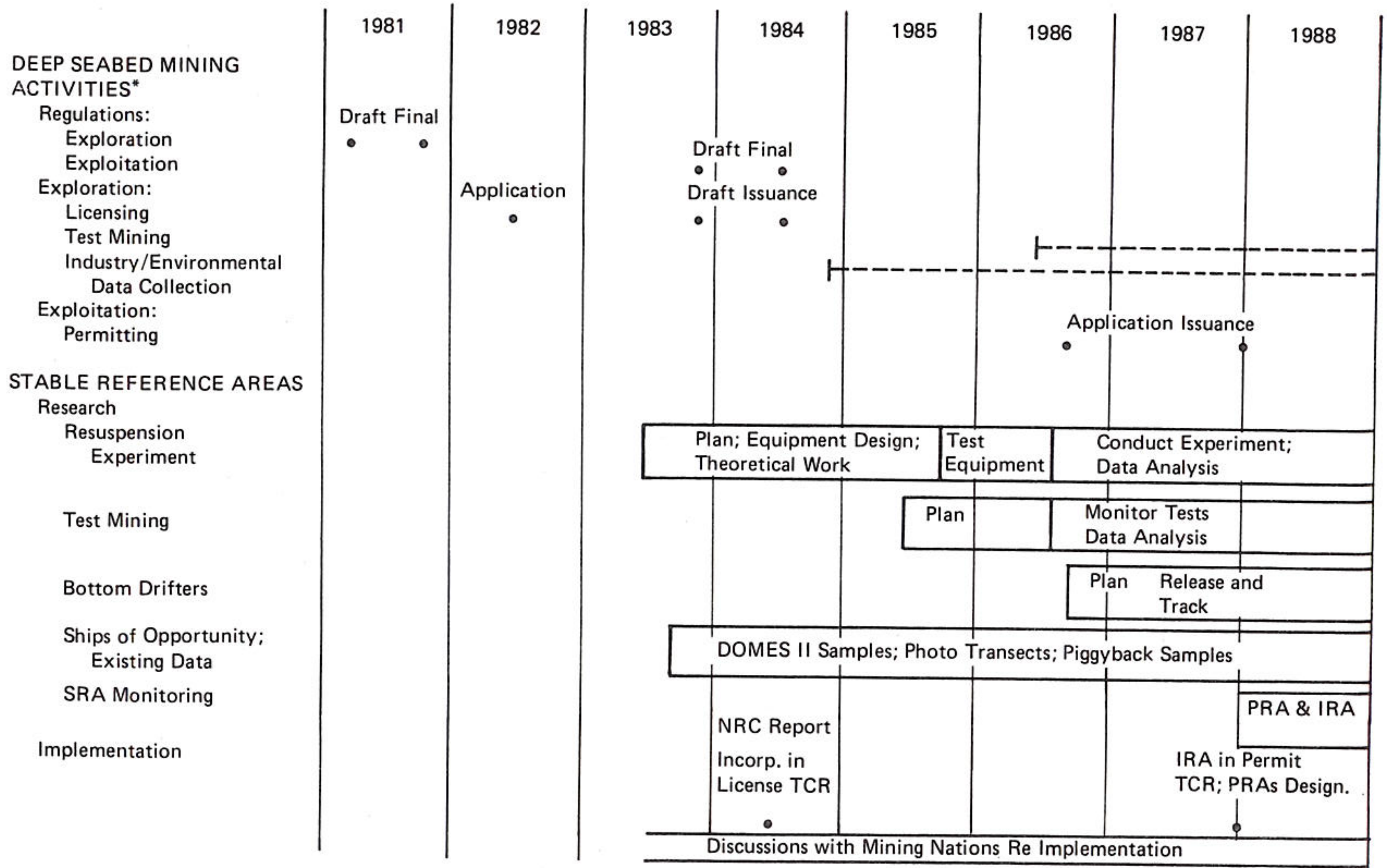
Based on such an analysis, the panel should evaluate the adequacy of provisional PRAs in meeting defined scientific criteria for permanent designation and make appropriate recommendations on the size, location, and number of permanent PRAs. This assessment could result in the continuation, modification, discarding, or addition of PRAs.

IRAs should likewise be designated at the time of permit issuance, and their study should be part of a permittee's responsibility for impact monitoring.

As a rough guide to the appropriate schedule for research activities, near-term projects should be started as licenses are granted, and the initiation of long-term monitoring projects should coincide with the beginning of commercial mining. Because of uncertainties as to how fast industry will progress toward full-scale mining activities, only a rough schedule, based largely on research priorities, can be suggested.

Near term

- Initiation of experimental study of resedimentation effects in order to establish valid criteria.



*Dates are tentative due to uncertainties in date of conflict resolution, economic situation, and international discussions.

FIGURE 5.1 Interrelationships among the regulatory actions, SRA actions, and timing of research efforts.

Appendix A

INTERIM REPORT ON STABLE REFERENCE AREAS
REPORT OF A MEETING
MARCH 28-29, 1982

CONTENTS

INTRODUCTION

Vast quantities of manganese nodules cover the seafloors of the world's oceans. In certain regions, such as the area between the Clarion and Clipperton fracture zones in the eastern Pacific, the deposits appear to consist of sufficient quantities of high-grade nodules (nodules with relatively high concentrations of nickel, cobalt, copper, and manganese) to interest mining companies in the possibility of their commercial recovery. Although studies have been under way for more than a decade, serious investment in seabed mining has awaited the development of a legal system that would provide companies with exclusive rights to a mine site and with the necessary security of tenure. The problem is complicated by the fact that deep ocean nodule deposits are, in general, beyond the limits of jurisdiction of any nation.

The Third United Nations Conference on the Law of the Sea (UNCLOS III) has been attempting to reach agreement on a new international legal system for managing the exploitation of seabed minerals since it convened in 1974. While an impressive consensus has been reached on almost all of the other ocean issues the conference is dealing with, agreement on a seabed regime has so far been elusive.

Before the start of UNCLOS III, domestic legislation had been introduced into the U.S. Congress to license U.S. firms wishing to explore for nodule deposits and ultimately to exploit them commercially. The legislation was based on the concept that nodule mining, like fishing, was a high seas freedom permitted under the 1958 Geneva Convention of the High Seas. After UNCLOS III negotiations began, the legislation was modified to make it interim in nature, pending U.S. ratification of a Law of the Sea treaty and its entry into force.

The seabed mining legislation underwent other changes as well before it was passed by Congress. In early 1979, several months before its enactment, a provision calling for the establishment of "stable reference areas" (SRAs) was added. The impetus for this provision came in part from a resolution passed at the 14th Session of the General Assembly of the International Union for Conservation of Nature and Natural Resources (IUCN), meeting in Ashkhabad, USSR, in the fall of 1978. The resolution stated:

> AWARE that deep sea mining activities are being undertaken by several nations that will disturb or destroy natural systems that have developed without the adverse influence of mankind;
> FURTHER AWARE that such disturbance of the deep sea bed affects adjacent water masses from the sea bed to the surface and relates to the stability of the ocean environment as a whole;
> RECOGNIZING that undisturbed natural systems in the deep sea can provide insight into the processes by which valuable mineralized nodules develop;

NOTING THAT even incomplete knowledge of deep sea organisms and deep sea ecology confirms great diversity of life and the existence of unique forms of life hitherto unknown;
CONCERNED because both species and systems have been shown to develop very slowly and thus are especially vulnerable to the impact of mining activity;
BEARING IN MIND that any meaningful evaluation of the effects of ocean mining on marine life requires comparison with areas in which no mining has occurred;

The General Assembly of IUCN, at its 14th Session, Ashkhabad, USSR, 26 September-5 October 1978:

URGES all nations engaged in, or considering, deep sea mining activities to:

(a) precede commercial mining operations by commissioning a comprehensive ecological survey to determine the impact of such mining activity;
(b) designate appropriate areas of the deep sea bed as baseline reference and resource zones in which no mining will be allowed;
(c) designate the size and shape of such area or areas to ensure that their stability will be maintained;
(d) establish guidelines for scientific research to ensure minimum disruption of the natural state of such areas.

After reconciliation of several different versions, the seabed mining legislation became law when the President signed the Deep Seabed Hard Minerals Resources Act (Public Law 96-283) on June 28, 1980. Section 109(f) of the act states:

STABLE REFERENCE AREAS

(1) Within one year after the enactment of this Act the Secretary of State shall, in cooperation with the Administrator and as part of the international consultations pursuant to subsection 118(f), negotiate with all nations that are identified in such subsection for the purpose of establishing international stable reference areas in which no mining shall take place: Provided, however, That this subsection shall not be construed as requiring any substantial withdrawal of deep seabed areas from deep seabed mining authorized by this Act.

(2) Nothing in this Act shall be construed as authorizing the United States to unilaterally establish such reference area or areas nor shall the United States recognize the unilateral claim to such reference area or areas by any State.

(3) Within four years after the enactment of this Act, the Secretary of State shall submit a report to Congress on the progress of establishing such stable reference areas, including the designation of appropriate zones to insure a representative and stable biota of the deep seabed.

(4) For purposes of this section "stable reference areas" shall mean an area or areas of the deep seabed to be used as a reference zone or zones for purposes of resource evaluation and environmental assessment of deep seabed mining in which no mining will occur.

Implementation of the legislation was assigned principally to the National Oceanic and Atmospheric Administration (NOAA) in the Department of Commerce. NOAA established the Office of Ocean Minerals and Energy for this purpose and has begun preparation of the required policy and regulatory framework. Regulations pertaining to exploration licenses were issued in September 1981 (46 Federal Register 45890-45920).

At the time of the issuance of domestic licensing regulations, the U.S. government, represented by NOAA and the Department of State, began negotiating for mutual license recognition with the three other nations (Federal Republic of Germany, France, and the United Kingdom) that had passed similar domestic seabed mining legislation shortly after the United States. Since agreement on the basic reciprocal arrangement dealing with licensing is now near, negotiations regarding stable reference areas could begin later this year.

In preparation for those discussions, NOAA requested that the National Research Council's Ocean Policy Committee (OPC) undertake a short scientific study of the stable reference area provision and its validity and intent in order to provide a basis for NOAA's actions with respect to this portion of the seabed law. The objectives of the OPC study were as follows:

1. To determine the scientific validity of the SRA concept;

2. To define, if the concept is found to be scientifically valid, a cost-effective program to address the major scientific questions involved in establishing SRAs; and

3. To define, if the concept is not found to be scientifically valid, alternative, cost-effective approaches to addressing the scientific issues prompting the insertion of this section into the law.

To undertake the study, the Ocean Policy Committee requested G. Ross Heath, dean of Oregon State University's School of Oceanography, to organize and serve as chairman of a meeting of experts on March 28-29, 1982. This interim report contains the findings arrived at by the participants in that meeting. Additional review and appropriate revision of these findings will take place before the final report is submitted to NOAA in September.

FINDINGS

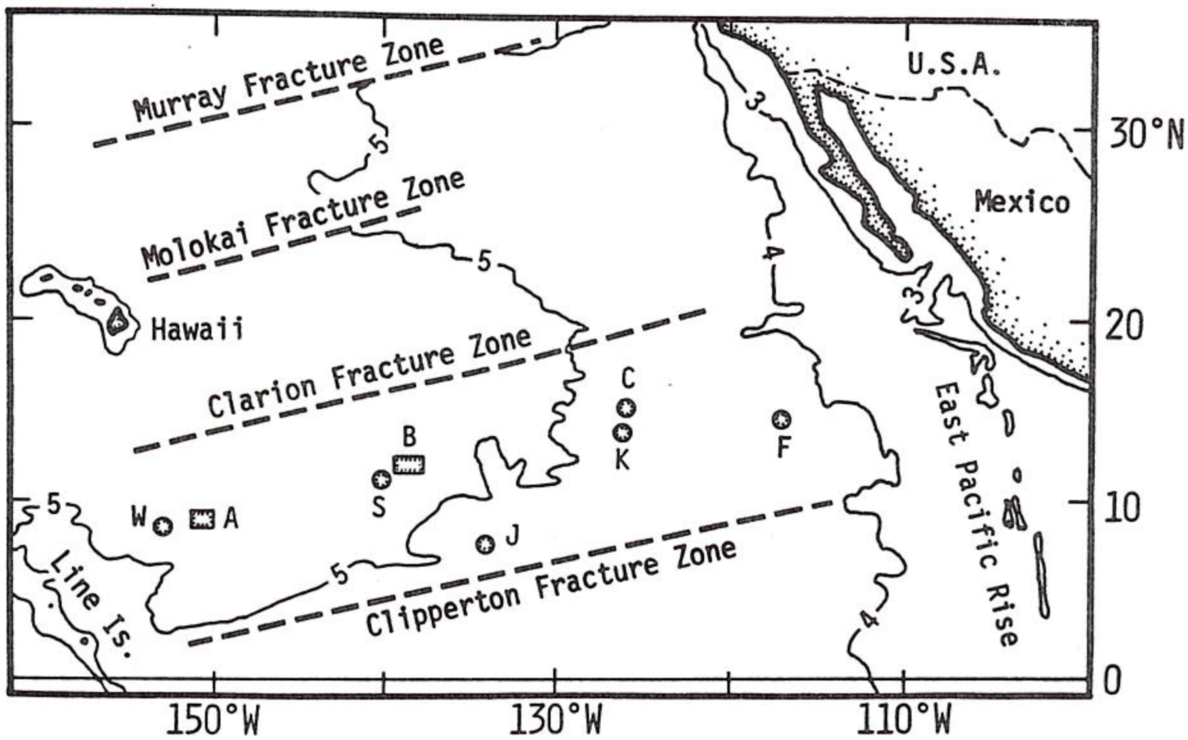
The findings that follow represent a consensus of the participants in the March meeting, but not all the findings were supported unanimously.

1. The concept of stable reference areas (SRAs) as outlined in P.L. 96-283 is scientifically valid. With the current state of knowledge, however, the goals of P.L. 96-283 (designation of appropriate zones "to insure a representative and stable biota of the deep seabed" and "to be used as a reference zone or zones for purposes of resource evaluation and environmental assessment of deep seabed mining") can be met only by designating two types of SRAs. One type, the "preservational" reference area (PRA), must be sufficiently distant from mining sites to ensure that the biota is not affected by mining activities. These areas should also be protected from other anthropogenic impacts, such as dumping of wastes. The other type, the "impact" reference area (IRA), must be close enough to a mining area to minimize inherent environmental differences and thereby allow statistically valid assessments of the impact of mining activities.
2. Development of a cost-effective program to address the major scientific questions involves several technical and institutional considerations and could follow this possible sequence of actions:

(a) A panel of deep-sea ecologists would design an economical means of measuring the gross temporal and spatial variability of benthic communities in areas for which the variability of the physical environment is relatively well known. A comprehensive biotic-abiotic description is needed to select SRAs that meet the requirements of the legislation. Measurements will be needed to examine community processes, such as oxygen consumption, bioaccumulation, and sediment mixing, as well as community structure. Although total faunal inventories during this early stage would not be cost effective and might well be impossible, this shortcoming could be minimized by concentrating on the distribution of a small number of sentinel organisms. These organisms, which might reflect overall faunal patterns, should be reliably sampled and should be organisms for which ecological expertise exists. Further, the current search for field methods for measuring pollutant-induced stress in coastal marine organisms should be monitored closely to ascertain whether any techniques are transferable to the deep-sea environment.

(b) A panel of experts would develop a U.S. position on the initial number and locations of PRAs in the region covered by pre-enactment exploration license applications. There should be at least one such PRA per "characteristic environment," and it should be large enough to remain significantly unaffected by the sediment plume from a mining operation. The term "characteristic environment" would be defined by the panel on the basis of such parameters as water depth, primary productivity, surface and deep currents, topography, and substrate character/nodule coverage. PRAs should be located to incorporate and make maximum use of existing intensively studied benthic areas (such as DOMES sites, MANOP sites, WAHINE areas, and Deep-Tow sites) whenever possible (Figure 1).

(c) Negotiation of an international (reciprocating states regime) agreement on the number and locations of the provisional



A = DOMES Site A (Bischoff and Piper, 1979)

B = DOMES Site B (Bischoff and Piper, 1979)

C = DOMES Site C (Bischoff and Piper, 1979)

*F = BENTHIFACE area (Johnson, 1974)

*J = D. Johnson's area (Johnson, 1972)

*K = Deep-Tow area K (Johnson, 1972)

*S = MANOP Site S (Karas, 1978)

W = WAHINE area (Calvert et al., 1978; Moore, 1970; Moore and Heath, 1967)

* Near-bottom (deep-tow) bathymetric survey available

FIGURE 1 Locations within the Clarion-Clipperton region that have been studied in detail. Depths (isobaths) are in kilometers.

PRAs and on the need for IRAs should occur in conjunction with and prior to the award of the pre-enactment licenses. The agreement should be considered interim in that it could provide an opportunity for other nations to join in the agreement and participate in its further development once a Law of the Sea treaty enters into force.

(d) Preliminary environmental characterization of the provisional PRAs should make use of the most economically effective techniques so that the greatest number of areas can be assessed. Approaches could include Seabeam surveys of selected portions of PRAs; coordinated time-series measurements of near-bottom currents, particle fluxes, and particle concentrations; and discrete determination of the spatial and temporal variability of the parameters mentioned in paragraph (2a) above.

(e) Assessment, by an international panel of experts, of the provisional PRAs should take place before the award of commercial recovery permits. Such an assessment could result in the continuation, discarding, modification, or addition of PRAs, with the expectation that agreed upon PRAs would no longer be treated as "provisional."

(f) A course of research should be developed to seek specific ecological bases for the number, location, and size of preservational areas needed to maintain deep-sea communities. This research might involve the development and testing of theories of population maintenance and life history adaptation. High cost or constraining scientific factors may limit such follow-on studies to a subset of PRAs.

(g) One IRA per mining site should be designated simultaneously with the issuance of commercial recovery permits. Studies in these areas should be modeled on paragraph (2d) above and should form part of the monitoring program to be carried out by the permit holder. To the extent that IRAs within areas covered by commercial recovery permits are mined within 20 to 30 years, they will not have the permanence sought for PRAs. Studies of the type described in paragraph (2f) should begin as soon as a sound theoretical basis is developed. IRA studies should be continued long enough to assess both short-term and possible long-term impacts of mining activities. Shapes and locations of the IRAs should be designed to minimize the likelihood of null experiments (i.e., those detecting no impact).

DISCUSSION AT THE MEETING

Following introductory remarks by R. Heath, who suggested that the participants concentrate on scientific issues rather than questions of policy, organization, or specific research activities, R. Wicklund and S. Earle described the evolution of the SRA concept (see Introduction). Subsequent discussion made it clear that both the "preservational" and the "impact" aspects of SRAs are important. Formal international acceptance of the concept (even within the reciprocating states regime) does not yet exist, and it has been discussed only in the context of broader environmental questions (see Center for Law and Social Policy, 1981). There is a sense that other nations are waiting to react to a U.S. proposal.

M. Wimbush emphasized the need for effective integration of international scientific work to support the credibility of the SRA concept and to help control costs to individual countries. R. Knecht felt that the framework for such work exists in the current wording of the Draft Convention on the Law of the Sea.

Scope. P.L. 96-283 concerns the mining of deep-sea nodules. The act will have to be amended to cover polymetallic sulfides or nodules on the Blake Plateau.

As the meeting progressed, concerns over the apparent incompatability of the preservational and impact aspects of SRAs led the participants to the conclusion that the goals of P.L. 96-283 could be met only by the designation of two types of SRAs.

Preservational reference areas (PRAs). Preservational reference areas are SRAs that are far enough from mine sites to be unaffected by mining activities. In addition to preserving an area of the seabed, PRAs would provide sites for study of deep ocean processes to guide study design and data interpretation in impact reference areas. R. Carney emphasized the need to work with modelers in choosing the PRA size required for population maintenance. Models can also guide sampling strategy and allow subsets of taxa from the total fauna to be used for characterization.

M. Wimbush supported long-term current measurements as well as bottom photography (long time series) if erosion is suspected. J. Dymond added nephelometry and flux measurements to Wimbush's suggestions. J. Dymond also suggested the use of metabolic data (oxygen consumption and ATP activity) to help assess spatial and temporal variability of biological activity. J. Dymond and R. Heath both proposed the use of natural short-lived and fallout radionuclides to quantify near-surface bioturbation. R. Carney expressed concern that field surveys not place too much emphasis upon direct or indirect measures of community processes because of an inability to relate such findings to questions about specific animal populations. However, because a total faunal survey on the necessary spatial scale might prove impossible, it was suggested that a limited set of taxa might be studied. These "pet beasts" would be species that were reliably sampled and might reflect overall faunal patterns.

S. Earle emphasized the need for comprehensive biological studies (as described, for example, by P. Jumars in Appendix A.B). Because of their cost and the need for a stronger theoretical framework for such studies, most participants favored a measured rather than crash implementation of this approach.

Impact reference areas (IRAs). Because of the "control" aspect of IRAs, the participants felt that IRAs should adjoin or even overlap commercial recovery permit areas to minimize the effect of inherent spatial variability. C. Morgan indicated that many, if not most IRA studies might well be included in the monitoring activities that will accompany mining. R. Carney pointed out the need to assess both immediate impacts, where cause-effect relationships are likely to be obvious, and delayed (or long-term) impacts, where the chain of cause and effect may be obscure and may depend on understanding developed in PRAs for its interpretation.

M. Wimbush, J. Dymond, and C. Hollister suggested that because of initial uncertainties in plume dispersal, annular IRAs may be required around some sites to avoid the possibility of a null experiment. In general, the IRA studies should follow those proposed for PRAs.

C. Morgan expressed concern over early distinction and designation of PRAs and IRAs. He suggested deferring decisions on these issues and on size as long as possible (perhaps until the commercial recovery permit phase) so that environmental data developed by the consortia during their explorations could be used to better define SRAs.

Rationale. S. Earle pointed out that the need for SRAs extends far beyond scientific studies or mining controls. Stable reference areas should serve as "bank accounts" for the future. P.L. 96-283 provides a rationale and focus to get the designation process started. S. Earle also pointed to the rapid development of small submersibles that should greatly enhance the accessibility of the abyssal seafloor in the next decade. C. Curtis reiterated the need to protect portions of abyssal environments, which are now poorly understood.

The participants felt that the concept of limited "exploited" areas in a matrix of "preserved" ocean floor (rather than the reverse implied in P.L. 96-283) was an ideal that would be difficult to maintain in practice. The tendency would be toward continuous erosion of preserved areas.

Size of SRAs. As is clear from the Jumars paper (Appendix A.B), there is too little information or too few tested concepts about the deep sea to provide a sound scientific basis for choosing an optimum size for an SRA at this time. Based on an intuitive sense of the area needed to ensure protection from a mine site plume (M. Wimbush) and on the concept that SRAs should approximate commercial recovery permit areas, there was some support for initial designation of an area in the range of 20,000 km^2. This figure should be reassessed as knowledge of population theory and spatial variability of deep-sea biota expands. R. Carney pointed out that determination of an ecological basis for designating the size of SRAs should be a high-priority topic for research. Similar problems are being addressed in terrestrial ecology, and the conceptual framework might be similar. The upper bound on size is likely to be determined by a balance between environmentalist desires for the largest possible SRA and the requirement under P.L. 96-283 that "substantial withdrawal of deep seabed areas from deep seabed mining" be avoided.

Number of SRAs. Suggestions centered, arbitrarily, on either a total of ten SRAs or one SRA per commercial recovery permit area. Subsequent discussion led to a preference for at least one per "characteristic environment" in the Clarion-Clipperton region. The lack of benthic biological data will require that the number and location of provisional PRAs be specified on the basis of surface productivity and physical, geological, and geomorphological properties. C. Morgan emphasized the importance of calling on environmental expertise in the mining consortia because of the huge pool of unpublished data that they hold.

Several participants emphasized the benefits of incorporating existing detailed study sites into PRAs, if at all possible. Such sites represent a major investment of field and laboratory effort, and in some cases they provide initial data for time-series studies that go back a decade or more.

Still unclear is the extent of funding that will be available for SRA studies. To get around the difficulty of creating realistic scientific plans in such a vacuum, the participants favored development of a minimum-cost credible program to determine gross environmental, temporal, and spatial variability, as well as a comprehensive, model-based program to be focused, as it is perfected, on a few SRAs.

Because there is a statistical chance that provisional PRAs will coincide with commercial recovery permit areas based on pre-enactment license applications, a large enough number of provisional PRAs should be defined to ensure the long-term survival of at least one per characteristic environment.

Timing. Suggestions regarding the timing of SRA designations ranged from immediate designations at arbitrary locations to designations a decade or more in the future. Possibilities include the initial designation of more sites than necessary, with culling as a data base is developed. The participants preferred the position outlined by C. Curtis, which would tie PRA designations and agreement on the IRA concept to the initial negotiations of pre-enactment exploration licenses (so that the the SRA concept would be embedded in the reciprocating states regime from the start) while tying IRA designations to the award of commercial recovery permits.

REFERENCES

Bischoff, J.L. and D.Z. Piper, eds. (1979) Marine Geology and Oceanography of the Pacific Manganese Nodule Province. New York: Plenum.

Calvert, S.E., N.B. Price, G.R. Heath, and T.C. Moore, Jr. (1978) Relationship between ferromanganese nodule compositions and sedimentation in a small survey area of the equatorial Pacific. J. Mar. Res. 36:161-183.

Center for Law and Social Policy (1981) Report and Recommendations from the Deep Seabed Mining Workshops, Paris, December 8-10, 1980, and Luxembourg, February 10-12, 1981. Washington, D.C.: Center for Law and Social Policy.

Johnson, D.A. (1972) Ocean floor erosion in the equatorial Pacific. Geol. Soc. Am. Bull. 83:3121-3144.

Johnson, T.C. (1974) The dissolution of siliceous microfossils in surface sediments of the eastern tropical Pacific. Deep Sea Res. 21:851-864.

Karas, M.C. (1978) Studies of manganese nodules using deep-tow photographs and side-looking sonars. La Jolla, Calif., Scripps Inst. Oceanography, Ref. 78-20.

Moore, T.C., Jr. (1970) Abyssal hills in the central equatorial Pacific: Sedimentation and stratigraphy. Deep Sea Res. 17:573-593.

Moore, T.C., Jr. and G.R. Heath (1967) Abyssal hills in the central equatorial Pacific: Detailed structure of the sea floor and sub-bottom reflectors. Mar. Geol. 5:161-179.

APPENDIX A.A: LIST OF PARTICIPANTS

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APPENDIX A.B

Limits in Predicting and Detecting Benthic Community Responses to Manganese Nodule Mining*

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Abstract There are severe problems both in predicting and in detecting the responses of benthic communities to manganese nodule mining. Predictions are hampered by the basic lack of natural history information for deep-sea organisms; in all but a few instances, crucial data on dietary habits, population dynamics, modes and rates of dispersal, food-web relationships, and natural successional sequences and rates are lacking. Detection is further impeded by sampling problems. Besides the obvious logistic problems encountered in sampling under miles of water, the extremely low areal densities at which most deep-sea species live enforce wide confidence limits about their estimated mean abundances. The rarest species in any deep-sea community have yet to be sampled.

Nonetheless, some predictions can be made. Animals in the path of the nodule collector will suffer high mortalities. Populations dependent upon manganese nodules as attachment substrata will be very slow to recover (> 10^3 yr), as will food-web members dependent on this encrusting epifauna. Mobile scavengers (i.e., fishes, amphipods,

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> and shrimps) will find a new, temporary food source in the form of injured and displaced animals, but they may be forced to switch to carnivory when a given mining effort ceases. Suspension and surface deposit feeders will be most heavily impacted by mining-induced resuspension and redeposition, the extent of this effect depending on the (unknown) food value of the resuspended material. Substantial narrowing of uncertainty in mining effects, however, will require continuing iteration among predictive ecological modeling, *in situ* experimentation, and carefully designed monitoring of actual, full-scale mining operations.

The aim of this paper is, within the realm of conceivable impacts of manganese nodule mining, to identify the somewhat smaller region of likely responses within deep-sea benthic communities. From the outset, I will set the limits of resolution at the level of effects leading to the appearance or disappearance of individuals, to actual changes in community composition. Physiological changes that are not likely to lead to altered population birth or mortality rates will not be addressed. I hope to make two problems apparent: one is the shortage of verified theory concerning deep-sea community structure, and the other is the imprecision with which deep-sea community spatial structure and changes in it have been and can be measured. To accomplish these goals within a limited space, I will draw freely upon several recent, more specialized, yet more comprehensive reviews. Rather than redescribing the biota of the DOMES area, I will rely on the extensive baseline of Hecker and Paul (1979). Pertinent theory regarding the mechanisms controlling deep-sea community structure will be abstracted from Jumars and Gallagher (1981), while conclusions about spatial structure and sampling variability within deep-sea communities will be extracted from Jumars and Eckman (1981). Comments on conservation strategies largely will reflect the landmark collection on this topic by Soulé and Wilcox (1980), although opinions on optimal procedures are far from unanimous.

While the lack of verified theory and of data on deep-sea community structure is serious, it does permit straightforward presentation of this chapter. In a "connect-the-dots" approach to outlining the likely outcomes of mining, I will simply present contrasting scenarios of likely results. Following the more detailed, and less specific to manganese nodule mining, approach of Jumars and Gallagher (1981), I will choose dots or pairs of dots at the individual, population, and community levels of ecological organization. I sincerely hope that neither member of the respective pairs will be extracted from context and considered alone. If the approach is sound, it will serve to box in the effects that require controlled experimentation and monitoring as mining proceeds. The size of the box alone attests that monitoring and experimentation will be needed to determine where (hopefully) within this figure the truth will lie.

I will endeavor not to make value judgments, but policymakers may find it difficult to form such evaluations without familiarizing themselves with the kinds of organisms that frequent the deep sea. Contrary to the plates in volumes describing early voyages of discovery, the numerically dominant members of the deep-sea benthic community are tiny (a few millimeters or less in length) nematode and polychaete worms and test-building protozoans (Foraminifera) of varying sizes (but again mostly smaller than a few millimeters in diameter). Most of these animals inhabit the uppermost centimeter of deep-sea sediments. More thorough and less diminutive illustrated descriptions can be found in Gage (1978), Grassle (1978), Hessler (1972), Hessler and Jumars (1974), and Jumars and Gallagher (1981). Many of the surprisingly numerous species are as yet not even described, much less well known, so that it clearly is impossible to estimate how valuable these organisms might someday become, for example as sources of natural pharmaceuticals (e.g., the once nearly worthless horseshoe crab) or as model systems for addressing scientifically and medically important questions (as sea urchins have been in studying fertilization and early embryonic development). Because the smaller species (meiofauna and microbiota) are so poorly known, I will limit my discussion to those species that are (if only barely) visible to the naked eye (i.e., macrofauna and megafauna).

Because the questions of tightness of organization and interdependency of the various components of communities are still matters of debate, even for much more accessible communities (e.g., Levin, 1975), it is worth attempting prediction of several levels of ecological organization. The truth falls somewhere between the extreme view that a community can be understood simply by summing the behaviors of its smallest component parts (individuals, at the aforementioned level of resolution) and the opposing view that the interactions among these parts are so strong that communities can be understood only by studying the whole. Numerical abundances given below, unless otherwise stated, are quoted from the extensive baseline studies of Hecker and Paul (1979) in the DOMES region. Mining rates are taken from Ozturgut *et al.* (1981, Appendix).

Likely Impacts

Individual Level

It is hardly worth arguing about the fate of individuals directly in the path of the nodule collector. Those that are not killed outright by the fluid shear produced in the dredge or by the combination of abrasion and temperature rise in traveling up the pipe will be ejected helter-skelter with sediments in the near-bottom plume. Technical difficulties, including ones of experimental design, would argue against attempting to monitor whether mortality amounts to 95% or 99.999% of the total individuals taken. With 168 (macrofaunal) individuals per m^2 and assuming 100% mortality, that amounts to 3.36×10^3 individuals per second, 2.9×10^8 per day, or 1.06×10^{11} individuals per mining ship per year. At roughly 0.3 g of wet weight per m^2, that equates with 1×10^8 g per year.

From this point, predictions become decidedly less precise. Impacts on individuals outside the collector zone surely will depend upon the guild to which they belong—upon their life-styles. (An ecological guild is defined as a group of species that utilizes the same resource in similar ways.) Specifically, impacts on swimming scavengers, walking–crawling scavengers, surface deposit feeders, subsurface deposit feeders, and suspension feeders are likely to differ.

The scavengers are the most active lot, and the fishes, shrimps, and larger lysianassid amphipods are likely to be able to avoid local regions of high redeposition rates and high turbidity. The non-swimming scavengers observed to date are among the larger benthos, so we might expect them to be relatively immune from mortality due to burial. Both kinds of scavengers are likely to experience a short-term increase in rate of food supply in the form of animals injured by mining, with the swimming forms obviously being first to arrive at the windfall.

Subsurface deposit feeders are likely to be the least affected of all feeding guilds on the short term because of their relative isolation from resedimentation effects. Presumably they are dependent upon continued bacterial growth for their food, and it is not known how subsurface bacterial growth will vary as a function of time and thickness of the overlying resedimented layer. Because of the low standing stocks of animals, the scavenger activity, and the high concentration of oxygen in bottom water, there seems to be little opportunity for anaerobic conditions to develop, even for the subsurface dwellers; no mass mortality due to anoxia is anticipated.

Surface deposit feeders and suspension feeders, on the other hand, will be affected much sooner and perhaps in similar ways. The rate of supply of surface deposits and of suspended material certainly will be increased, but its net food value is likely to be altered substantially over the normal surface deposit and suspended load. Very little is known about the organic chemistry of deep-sea clays under deep-sea conditions, but adsorption of materials onto suspended clays may be a major effect (e.g., Moore, 1977). If the average food value of these resuspended and redeposited particulates is still lower than that of their normal supplies, then the net rate of energy gain to members of surface deposit-feeding and suspension-feeding guilds is likely to fall. It is conceivable, alternatively, that the net rate of energy gain within these guilds might be increased if, during resuspension, the clays chemically scavenge sufficient organic matter from the overlying water.

Assuming no fatality beyond the collector path, Figure 1 summarizes these predictions of net rates of energy gain by individuals within various guilds. How likely is fatality? If net rate of energy gain falls below maintenance levels for an appreciable period, mortality would result. I find little basis for predicting the actual time scales in Figure 1, except that suspension feeders will be affected only so long as the cloud of resuspended material remains in their vicinity or so long as their feeding mechanism remains affected. Deep-sea suspension feeders are likely to be especially sensitive to clogging of their filtration apparatus, which after all has evolved to operate at ambient suspensate levels of a few micrograms per liter; even 20 km from the mining site, suspensate levels may rise by two orders of magnitude (Ozturgut *et al.*, 1981).

Burial under a few centimeters of sediment may seem and be innocuous enough to one accustomed both to the large amounts of sediment transport and to the strong burrowers often seen in the intertidal. Most

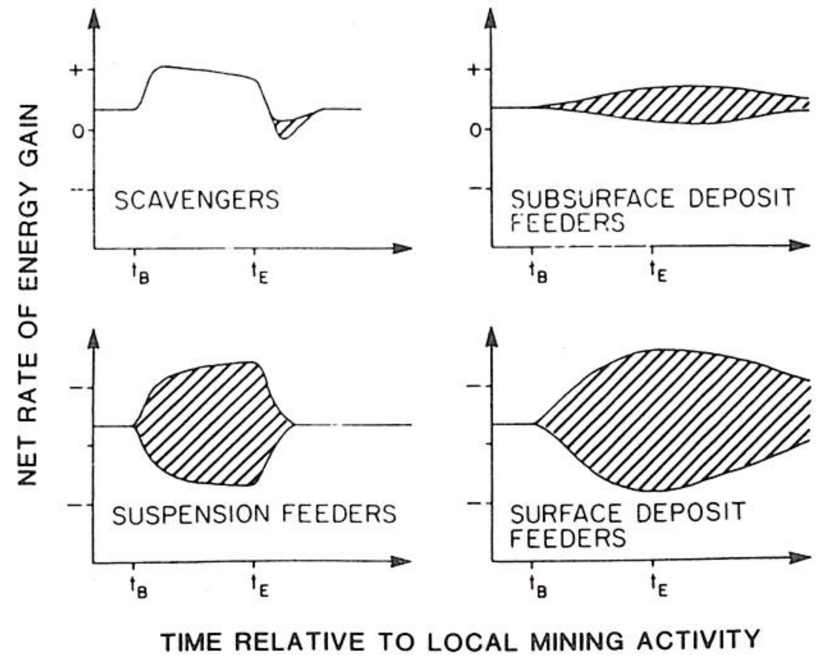

FIGURE 1. Crude predictions of net rate of energy gain as a function of time by feeding guild for those individuals (as opposed to populations) not suffering immediate mortality from mining effects. t_B: local mining begins; t_E: local mining ends; shaded area: major region of uncertainty in predictions. Predictions at the level of numerical responses of populations are more difficult.

deep-sea animals living near the sediment–water interface of nodule fields have limited burrowing abilities, however, because sedimentation proceeds at rates of millimeters per 10^3 yr. In an accidental burial of a small region ($\sim 10\ m^2$) of a bathyal community living at 1,200 m (where sedimentation rates are roughly 10 cm per 10^3 yr), for example, I have observed substantial mortality (unpublished observations of an unsuccessful particle tracer experiment attempted during Expedition Quagmire; Thiel and Hessler, 1974) of numerous sedentary animals after only one day's burial. Suspension feeders were too rare to be censused with adequate statistical precision, but most of the mortality was evident (as autolysis or bacterial decay) in surface deposit feeders. Although linear extrapolation is hazardous at best, these results suggest that burial depths of millimeters may cause substantial mortality among the faunas of the DOMES area. For animals adapted to feeding at the sediment–water interface, it is conceivable that burial of their normal food resources under a millimeter or less might be critical, depending on the time scale over which these food resources recover. The sessile suspension feeders attached to nodules are likely to be the most severely affected, however, even by an exceedingly thin veneer of sediments.

Population Level

Two extreme views are tenable at the population level. One of them may prove true generally, or each may hold for some subset of the populations encountered. The most optimistic view would hold that little mortality would ensue outside the collector tracks, so that in a year some 170 km^2 of the 30-km by 30-km mining claim would remain inhabited by members of the population. If they were not completely sessile, these survivors would begin to diffuse to produce something like 80% of their initial areal density. (A majority of abyssal species seem to be slowly moving deposit feeders; Hecker and Paul, 1979; Hessler and Jumars, 1974.) If this density is high enough for reproductive success, recruitment will complement the diffusive recovery. If, on the other hand, the population were completely eliminated within the mining claim and for some distance outside it, recruitment to the center of the site would require either many generations of slow, diffusion-like movement or some more rapid means of adult, juvenile, or larval dispersal. Given the seemingly low dispersal abilities of the majority of deep-sea species, this case likely would resemble the slow healing of a deep wound, while the more optimistic first case would be more like the healing of a series of scratches.

To carry this metaphor perhaps too far, both cases are likely to result in ''infection'' by opportunistic species. Within months, azoic sediments placed on the sea floor in the deep sea are colonized by populations with high dispersal abilities. In the two experimental programs whose results have been published to date (Grassle, 1978; Desbruyères *et al.*, 1980), the most spectacularly successful initial colonists are species that are either absent or very rare in the ambient, undisturbed community.

It is thus reasonable to anticipate a strong, mining-produced selection for high dispersal abilities, coupled with relatively rapid reproductive rates, to fill the gaps produced by the tracks or by the combination of tracks plus resedimentation. In essence, one expects a suite of weed species to recruit to, and to evolve with, the mining activity. Beyond the edges of the mining site, however, selection may favor rather different life-history tactics. Suppose, for example, that the resedimentation near the periphery causes greater or more variable mortality in larvae and juveniles than in adults. Jumars and Gallagher (1981) summarize a simple stochastic model which suggests that, under such circumstances, selection will act to lengthen the less susceptible adult life stage and to lead toward multiple reproductive events (iteroparity), features normally not associated with populations of stressed or disturbed habitats.

Besides varying with proximity to the disturbance, population responses probably will also depend on the feeding guilds under consideration. I already have mentioned the rapid functional response of scavengers to deep-sea windfalls. Especially because of the relative continuity of this new food resource, mining is likely to result in a numerical (reproductive) response as well. Given the high motility of many deep-sea scavengers, though, this numerical response may be especially difficult to resolve from pure attraction. But what will these locally elevated (in abundance) populations do when mining ceases? For energetic reasons suggested by Jumars and Gallagher (1981), this guild is likely to be comprised of generalists which may survive by a combination of dispersal and carnivory when mining ceases.

Much less likely to be so malleable are the populations dependent on nodule-associated microhabitats for their existence (e.g., Bernstein *et* *al.*, 1978). Most obviously, the fouling community of nodule surfaces will probably suffer most and longest. Simply because of the slow growth rates of deep-sea manganese nodules and the fact that nodules will be both removed and buried, these populations are unlikely to recover to natural levels in less than 10^4 yr. Time scales for recovery of other populations cannot be predicted because generation times of nearly all deep-sea species are unknown.

Community Level

Implicit in many of the above population-level effects is the potential for interpopulation interactions. Will the scavengers have substantial predatory impacts on particular prey populations after the source of easier game is removed? Will subsequent invasion of the newly opened territory be facilitated, unaffected, or impeded by the initial colonists (Connell and Slatyer, 1977)? If populations of suspension and surface deposit feeders are reduced, will burrowing deposit feeders encroach on food resources that would have been taken by these two guilds? Very basic natural history information is needed to answer these questions regarding the precise nature of the resources now used by suspension and deposit feeders and the identity of existing predatory–prey links. These data are missing for all deep-sea areas.

The value of this lacking information can be seen by analogy with the diverse communities of tropical rain forest, where at least part of such information has been collected. Gilbert (1980, p. 32), for example, finds that "The system consists of many parallel, structurally similar but taxonomically different, food webs based on particular groups of plants." Similar organization also seems likely in the deep sea, and while it may seem reasonable to predict that predators dependent upon nodule-associated prey will be impacted seriously, this prediction is vitiated because the predators have not been identified, and thus their abilities to utilize alternate prey are completely unknown.

A theme reiterated throughout the anthology by Soulé and Wilcox (1980), *Conservation Biology*, is the need to know the sources, rates, and intensities of natural disturbances in order to predict and manipulate the effects of anthropogenic disturbances. Further, the less similar are these two types of disturbances (if the more frequent and severe type is anthropogenic), the more severe will be the effects of the man-made variety. No natural disturbance of the magnitude to be produced by full-scale mining has been identified for communities of geologically stable mid-ocean regions; all conceivable natural disturbances are much smaller in spatial scale (Jumars and Eckman, 1981) and presumably are less intense.

There is no validity whatsoever, then, in examining community structure and life-history tactics of communities that are exposed relatively frequently to major disturbances such as turbidity flows and using them (Gerard, 1976) to predict the short-term consequences of nodule mining. The comparison is just as ludicrous as suggesting that tropical rain forest will respond to a blizzard in the same way as will tundra. If mining continues at an appreciable rate, selection may lead in the direction followed in areas where turbidity flows are frequent and severe, but this would be a long-term (evolutionary time scale) prediction. Even on this longer time scale, the analogy is imprecise because any one mining plot likely will be mined only once and because the native sediments of nodule areas and continental margins (where turbidity flows are more common) differ substantially.

The events following mining also are difficult to put into the context of the most recent synthesis of successional theory (Connell and Slatyer, 1977). Beyond the suggestion (above) that opportunists will recruit to the mined region within one or a few months, neither the time scales nor the specific directions of succession can be predicted. The initial colonists may alter environmental conditions (e.g., effective sediment porosity and permeability), either accelerating or impeding subsequent colonization, and the initial colonists may be removed via predation, competition, or their own modifications of the sediments. No deep-sea colonization experiments reported have yet shown close approach to the ambient community composition. Given the apparently long lifetime of some deep-sea, sediment-dwelling species (e.g., Turekian *et al.*, 1975), such nearly complete recovery would take decades to tens of decades. Again, simply because of the slow growth rates of nodules, any community components dependent directly or indirectly upon nodules would take more than 10^3 years to begin approaching natural abundance levels in the area of the collector track.

A wide variety of theories dealing with succession and (dynamic) equilibrium community composition lead to similar predictions (Figure 1) concerning the relation of species diversity with the frequency and intensity of disturbance. Both of the two extreme Markov models presented by Jumars and Gallagher (1981), for example, predict a relationship like that of Figure 2. While it seems likely, especially given removal of the nodule microhabitat, that mining at the proposed levels will drive the curve toward the lower diversities of its right-hand tail, the position of the natural community along the abscissa is unknown. Extant theories (Jumars and Gallagher, 1981) differ substantially in the importance, frequency, and intensity they ascribe to such natural disturbances as predation and windfalls of food.

It is possible, then, that some low level of mining activity might actually increase species diversity on an appropriately measured spatial scale. The simplest such scenario is that in which opportunistic species (new to the local community) take up residence in the tracks of the dredge, and the community outside the tracks is unaffected, increasing local community diversity by the difference between the number of new opportunistic community members and the (small) number of species that chanced to be present locally only in the path of the dredge. Considering the magnitude of the disturbance (relative to natural ones), a much more likely scenario, however, involves a dramatic local decrease in species diversity. Besides the obvious disturbance effect (viz., Figure 2), a correlate and possible cause of high deep-sea species diversity is small-scale environmental heterogeneity (e.g., tubes and burrows) created by the animals themselves (Jumars and Gallagher, 1981). The net effect of nodule removal and burial of the surrounding bottom of resedimenting clay would almost surely be to make the new environment more homogeneous on these smaller spatial scales.

Extrapolation to Multiple Mining Sites

Implicit in all the above predictions is their limitation to a single mining site approximately 30 km by 30 km in area, mined for a topical mining year (estimated at 300 days). The impossibility of extrapolating these predictions with any set accuracy to multiple mining sites needs to be pointed out. The ability to make analogous extrapolations is just now being approached in the obviously much better known forest ecosystems through successional models (summarized by Shugart and West, 1980). Such models are heavily dependent upon detailed autecological information—detail unavailable in the deep sea.

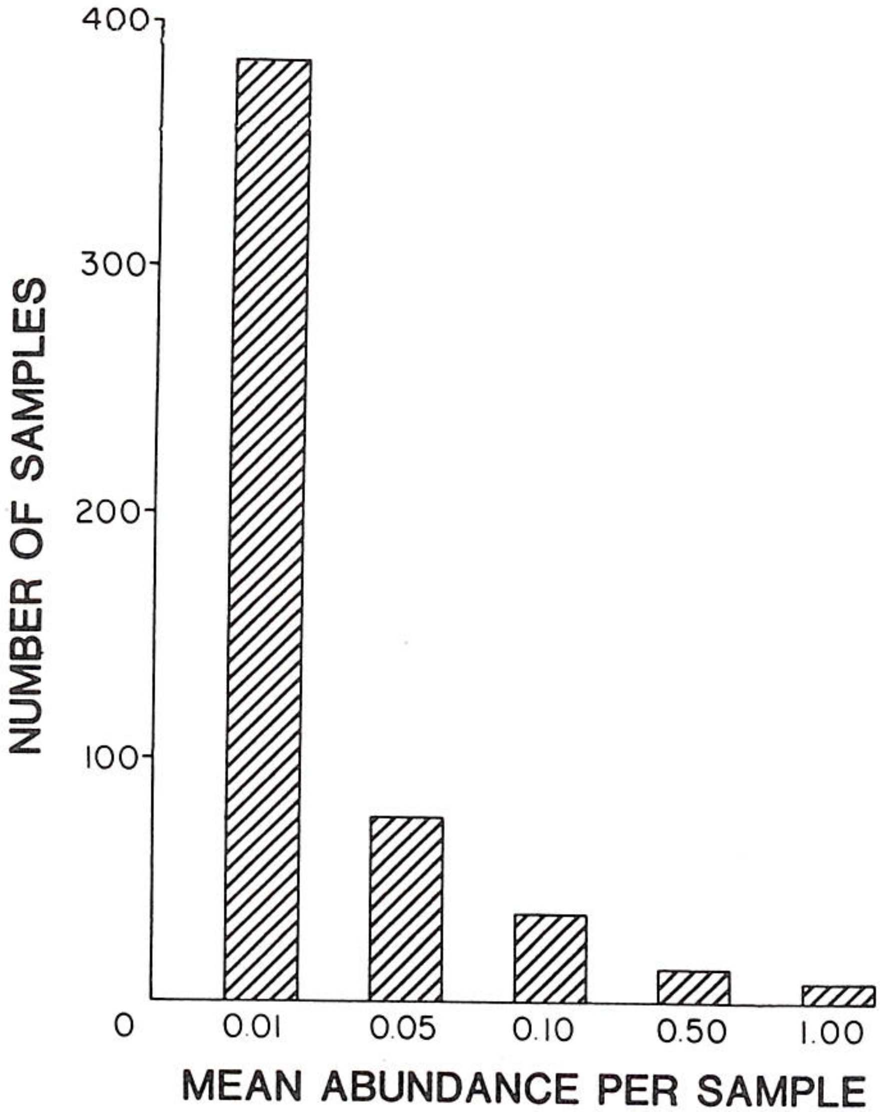

FIGURE 2. General predictions from a wide diversity of models (e.g., Horn, 1975; Huston, 1979; Levin and Paine, 1975) concerning the species diversity likely to result from different rates of mortality-causing disturbances. Without manipulations (cf. Paine, 1977) such as carefully monitored mining, the position of natural deep-sea communities along the abscissa will remain unknown.

One concern that already has surfaced is over the potential extinction of deep-sea populations and species at some (perhaps unrealistically high, but unknown) level of mining activity, and the suggestion has been made that some spatial and temporal patterns of mining would minimize the likelihood of extinction. Terborgh and Winter (1980), in their review of the causes of extinction in better studied systems, point to fragmentation, isolation of one part of a population from others, as a major cause of extinction. Assuming that a mined area does form an appreciable barrier for normal dispersal of at least some populations, the worst mining pattern would thus be one that would cut a more or less continuous, wide swath through the deep-sea habitat. Without more autecological information (e.g., on dispersal abilities of deep-sea species), however, the ecologically optimal mining pattern defies prediction.

Detection of Impacts

The specter of extinction of deep-sea populations carries with it its own "Catch 22" insofar as detection is concerned. Despite extensive and intensive sampling at the various DOMES sites (Hecker and Paul, 1979; Jumars and Self, unpublished), the point at which further sampling would yield few additional species has not been reached at any site within the DOMES region. It is precisely those species that have not yet been sampled which would be predicted to be most extinction prone since, "Rarity proves to be the best index of vulnerability" (Terborgh and Winter, 1980, p. 132). These rare species and their changing abundances with time and with mining activity could not be detected without monumental increases in sampling effort.

Nor will reductions even in those populations that have been sampled be easy to detect. The largest practicable, quantitative samples now taken from the deep sea are 50 cm by 50 cm ($0.25\ m^2$). Once the samples are retrieved and processed on shipboard, it requires roughly one person-month of microscopic sorting just to separate the animals from residual sediments in a single sample. Assuming (optimistically) a random (i.e., Poisson) distribution of individuals among samples, Figure 3 shows how many samples would be required to give reasonable certainty ($P \geqslant 0.95$) of detecting the most severe impact possible—complete mortality of the local population. It is virtually certain (Hecker

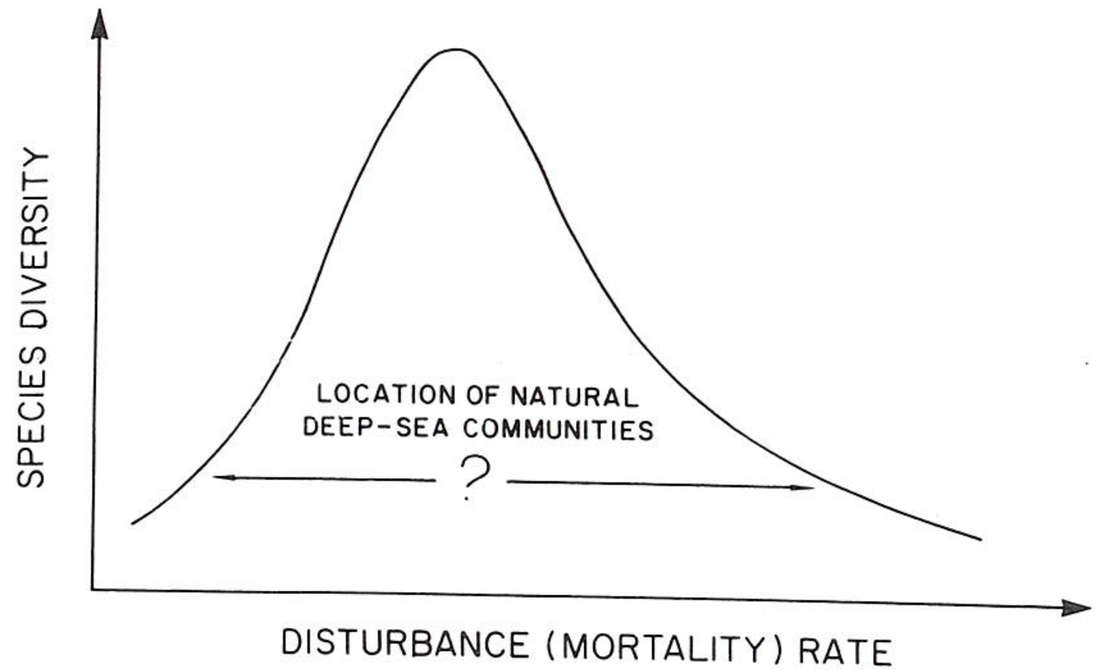

FIGURE 3. The number of 0.25-m² samples required to be reasonably certain of detecting any effect when the population has been decimated entirely (i.e., no individuals are found in any sample) versus natural mean abundance per sample. The χ^2 test of goodness-of-fit to a theoretical Poisson distribution with the specified mean was used to generate the figure, so that the estimates provide reasonable minima (cf. Jumars and Eckman, 1981). Most abyssal populations have mean densities below 0.05 individuals per 0.25-m² sample, making monitoring at the single population level generally impractical.

and Paul, 1979; Jumars and Self, unpublished) that most species in the DOMES region have mean abundances of fewer than 0.05 individuals per sample (< 0.20 individuals per m^2).

With the outlook so bleak for detecting impacts at the single-species level, monitoring will be practical only at the level of guilds or larger groupings, and one might ask what magnitude of impact could be detected for the fauna as a whole (i.e., the best case). Using total observed faunal abundance per sample within a 20-km by 20-km area at DOMES site A and employing the actual variance observed in that parameter (Jumars and Self, unpublished), the question can be answered relatively precisely. With a (manageable) sample size of 20 0.25-m^2 cores, total faunal abundance changes in excess of 50% over the entire sampling region would be necessary to assure ($P \geqslant 0.95$) detection of the impact, even in this grossest indicator of community condition.

Conclusions

These figures argue against placing great expectations in the results of routine monitoring efforts aimed at evaluating mining impacts. Even relatively large impacts can easily go undetected via traditional before–after comparisons based on random sampling via a surface vessel. This imprecision in sampling estimates is further coupled with the additional imprecision (and potential inaccuracy) of the above predictions; the theories used to make those predictions have not yet been verified in a deep-sea context.

The major reasons behind these problems are easier to identify than are the solutions. First, organisms are extremely sparse, aggravating the already major difficulties in the sheer mechanics of retrieving reliable bottom samples from several kilometers of water. This rarity sets definite limits on sampling precision (cf. Figure 3). Secondly, crucial data are lacking for the DOMES region as well as for other deep-sea areas. For example, generation times, predator–prey relationships, and both qualitative food requirements and feeding rates of deposit and suspension feeders are all but unknown for the animals living on this major fraction of the earth's surface.

No one approach is likely to bring deep-sea ecology quickly to the point where impact predictions can be as accurate and precise as they are in the longer, more thoroughly studied, and more accessible terrestrial ecosystems (e.g., Shugart and West, 1980). However, the most rapid and sure approach to this sort of knowledge is through iteration between theories and manipulative experiments (Paine, 1977); an accelerated program to couple the collection of essential natural history information with controlled experimentation in an accessible deep-sea environment is sorely needed. Because of the low population densities, high species diversities, and low population growth rates which characterize the deep sea, however, this coupling will not be complete before full-scale manganese nodule mining begins. The obvious challenge, then, is to develop both theories and monitoring schemes which make efficient use of the manipulative experiment provided by manganese nodule mining itself.

References

Bernstein, B. B., Hessler, R. R., Smith, R., and Jumars, P. A. 1978, Spatial dispersion of benthic Foraminifera in the abyssal central North Pacific. *Limnol. Oceanogr.* Vol. 23, pp. 401–416.

Connell, J. H., and Slatyer, R. O., 1977, Mechanisms of succession in natural communities and their role in community stability and organization. *Am. Nat.* Vol. 111, pp. 1119–1144.

Desbruyères, D., Bervas, J. Y., and Khripounoff, A., 1980, Un cas de colonisation rapide d'un sediment profond. *Oceanologica Acta,* Vol. 3, (in press).

Gage, J. D., 1978, Animals in deep sea sediments. *Proc. Roy. Soc. Edinburgh,* Vol. 76B, pp. 77–93.

Gerard, R., 1976, Environmental effects of deep-sea mining. *Marine Technological Society Journal,* Vol. 10(7), pp. 7–16.

Gilbert, L. E., 1980, Food web organization and the conservation of neotropical diversity. In: *Conservation Biology,* M. E. Soulé and B. Wilcox, ed. Sunderland, Mass.: Sinauer Associates, Inc., pp. 11–33.

Grassle, J. F., 1978, Diversity and population dynamics of benthic organisms. *Oceanus,* Vol. 21(1), pp. 42–49.

Hecker, B., and Paul, A. Z., 1979, Abyssal community structure of the benthic infauna of the eastern equatorial Pacific: DOMES sites A, B, and C. In: *Marine Geology and Oceanography of the Pacific Manganese Nodule Province,* Bischoff, J. L., and Piper, D. Z., ed. New York: Plenum Press, pp. 287–308.

Hessler, R. R., 1972, The structure of deep benthic communities from central oceanic waters. In: *The Biology of the Oceanic Pacific,* C. B. Miller, ed. Corvallis, Oregon: Oregon State Univ. Press, pp. 79–93.

Hessler, R. R., and Jumars, P. A., 1974, Abyssal community analysis from replicate box cores in the central North Pacific. *Deep-Sea Res.,* Vol. 21, pp. 185–209.

Horn, H. S., 1975, Markovian properties of forest succession. In: *Ecology and Evolution of Communities,* Cody, M. L., and Diamond, J. M., ed. Cambridge, Mass.: Belknap Press, pp. 196–211.

Huston, M., 1979, A general hypothesis of species diversity. *Am. Nat.*, Vol. 113, pp. 81–101.

Jumars, P. A., and Eckman, J. E., 1981, Spatial structure within deep-sea benthic communities. In: *The Sea, Vol. 8. Deep-Sea Biology*. Rowe, G. T., ed. New York: Wiley–Interscience, in press.

Jumars, P. A., and Gallagher, E. D., 1981, Deep-sea community structure: Three Plays on the benthic proscenium. In: *Ecosystem Processes in the Deep Ocean*, Ernst, W. G., and Morin, J., ed. Englewood Cliffs, N.J.: Prentice-Hall, (in press).

Levin, S. A., ed., 1975, *Ecosystem Analysis and Prediction*. Philadelphia, Pa.: Society for Industrial and Applied Mathematics, 337 pp.

Levin, S. A., and Paine, R. T., 1975, The role of disturbance in models of community structure. In: *Ecosystem Analysis and Prediction*, Levin, S. A., ed. Philadelphia, Pa.: Society for Industrial and Applied Mathematics, pp. 56–67.

Moore, P. G., 1977, Inorganic particulate suspensions in the sea and their effects on marine animals. *Oceanogr. Mar. Biol. Ann. Rev.*, Vol. 15, pp. 225–363.

Ozturgut, E., Lavelle, J. W., and Erickson, B. H., 1981, Estimated discharge characteristics of a commercial nodule mining operation. *Marine Mining*, Vol. 3 (1–2).

Paine, R. T., 1977, Controlled manipulations in the marine intertidal zone, and their contributions to ecological theory. *Acad. Nat. Sci., Spec. Publ.*, No. 12, pp. 245–270.

Shugart, H. H., and West, D. C., 1980, Forest succession models. *Bioscience*, Vol. 30, pp. 308–313.

Soulé, M. E., and Wilcox, B. A., ed., 1980, *Conservation Biology*. Sunderland, Mass.: Sinauer Associates, Inc., 395 pp.

Stearns, S. C., 1976, Life-history tactics: A review of the ideas. *Quart. Rev. Biol.*, Vol. 51, pp. 3–47.

Terborgh, J., and Winter, B., 1980, Some causes of extinction. In: *Conservation Biology*, Soulé, M. E., and Wilcox, B. A., ed. Sunderland, Mass.: Sinauer Associates, Inc., pp. 119–133.

Thiel, Hj., and Hessler, R. R., 1974, Ferngesteurtes Unterwasserfahrzeug erforscht Tjefseeboden. *UMSCHAU*, Vol. 14, pp. 451–453.

Turekian, K. K., Cochran, J. K., Kharkar, D. P., Cerrato, R. M., Vaisnys, J. R., Sanders, H. L., Grassle, J. F., and Allen, J. A., 1975, Slow growth rate of a deep-sea clam determined by ^{228}Ra chronology. *Proc. Nat. Acad. Sci. U.S.A.*, Vol. 72, pp. 2829–2832.

Appendix B

REPORT OF THE MEETING OF DEEP-SEA ECOLOGISTS CONCERNING STABLE REFERENCE AREAS: JULY 12-13, 1982 MEETING

Robert S. Carney
Moss Landing Marine Laboratory

INTRODUCTION

On March 28-29, 1982, in response to a request from NOAA, the Ocean Policy Committee of the National Research Council brought together a group of experts to discuss scientific aspects of the stable reference areas provision of the Deep Seabed Hard Minerals Resources Act (PL 96-283). Among the recommendations of this group in their interim report to NOAA of April 1982 was the recommendation that a panel of deep-sea ecologists and biological oceanographers meet subsequently to address the major scientific questions associated with the establishment of reference areas and the measurement of ecological impacts of deep-sea nodule mining. On July 12-13, 1982, the subsequent panel met, and this report summarizes their discussion and presents their recommendations. Essentially, the July panel took the following position: since little is known about abyssal fauna, and since study of them is extremely difficult but, to address this issue, necessary, <u>a program is recommended that will make maximum use of collected data by placing greater emphasis upon determining ecological relationships through field experimentation and less emphasis upon general surveying and environmental characterization</u>.

BACKGROUND

Findings of the March Panel

Before presenting the recommendations of the July panel in greater detail, it will be useful to review some of the relevant findings and recommendations of the March panel as stated in their interim report. The March panel addressed primarily two formal objectives:

1. To determine whether the Stable Reference Area concept is scientifically valid, or, if necessary, to define a scientifically valid alternative.

2. To describe for the initial or modified concept a cost-effective program for addressing the major scientific questions involved in the establishment of SRAs.

With respect to scientific validity, it was found that the concept of SRAs needed to be modified to achieve the dual purpose of serving as (a) reference areas for comparison with regions under impact, and (b) undisturbed areas for the preservation of deep-sea organisms and ecological systems. The problem with the original concept arose from the fact that in order to serve as a good control or baseline to assess impact, an area must be close to a mining site. The required closeness, however, could result in impacts on the reference area. On the other hand, if these areas were located at a distance sufficient to ensure no impact, they might bear too little resemblance to the mining sites to serve as a control. The conflict was resolved by recommending two types of reference areas: Preservational

Reference Areas (PRAs) to be established at a safe distance from mining sites; and Impact Reference Areas (IRAs) to be established in or near mining sites so that an area can be studied before and after mining.

With respect to defining a cost-effective program to address the major scientific questions, the panel that met in March suggested a course of action that called for subsequent meetings of deep-sea experts. The first meeting was to involve a panel of ecologists to address the biological needs, and the second meeting, involving a multidisciplinary panel of scientists, was to define criteria for PRAs and IRAs and the essential studies that need to be conducted. Specifically, the March panel recommended that: "A panel of deep-sea ecologists would design an economical means of measuring the gross temporal and spatial variability of benthic communities in areas for which the variability of the physical environment is relatively well known. A comprehensive biotic-abiotic description is needed to select SRAs that meet the requirements of the legislation...Although total faunal inventories during this early stage would not be cost effective and might well be impossible, this shortcoming could be minimized by concentrating on the distribution of a small number of sentinel organisms. These organisms, which might reflect overall faunal patterns, should be reliably sampled and should be the organisms for which ecological expertise exists ...."

The March panel also recommended that a panel of biologists needed to develop: "A course of research...to seek specific ecological bases for the number, location and size of preservational areas needed to maintain deep-sea communities. This research might involve the development of theories of population maintenance and life history adaptation..."

Recognizing the breadth of expertise on the March panel and the tentative nature of its recommendations concerning a scientific program, the deep-sea ecologists at the July meeting did not restrict discussion to these two tasks. Instead, they focused upon the major scientific questions that must be answered in establishing either type of reference area. Priorities were assigned to the suggested work to assure that answers would be produced in a cost-effective manner. As a result the recommendations of the deep-sea ecology committee differ from those of the March meeting, but the basic concept of reference areas, as modified by the earlier panel, remains valid.

The Problem of Cost Effectiveness in Deep-Sea Ecology

To appreciate why the panel considered certain questions more important than others, it is necessary to understand what types of ecological studies can be undertaken in the earth history context of oceanography and to see the complications imposed by the nature of deep-sea biota. Much of deep-sea oceanography is still in an exploratory stage, and any additions to empirical description can still be of considerable value. However, when it is possible for exploratory methods to be replaced by planned sampling or, better yet, by experimentation, specific questions about how components of the deep-sea ecosystem interact can be more effectively answered.

Direct control of environmental factors and measurement of response are essential components of the experimental method in the biological and other sciences. Before beginning the experiment, a statistical model is selected that meets the requirements and restrictions of the specific problem and also dictates the plan of execution. In the earth sciences, however, environmental factors of ecological interest often vary on time or spatial scales that cannot be duplicated in a formal experiment. In such cases, a sampling plan can be selected that takes advantage of prior knowledge of how the environment varies and looks for biological differences under different natural conditions. With this approach, however, there is no control over any environmental factors, and unambiguous cause and effect relationships are difficult to determine. When there is no prior knowledge of environmental variables, surveys can be undertaken with concurrent environmental and biological sampling. The resulting data can be examined through various techniques of multivariate pattern recognition and classification, but it is not possible to make unambiguous determinations of cause-effect relationships in this manner.

Since formal experimentation is the most effective means of producing an unambiguous answer as to how changes in the physical environment affect the biologial components, such an approach must have first priority whenever it is technically and logistically feasible. Second, but much lower, priority must be assigned to planned sampling which seeks relationships between fauna and physical factors about which we have sufficient prior knowledge. Third priority is assigned to general multivariate surveying followed by "going fishing" data analysis. In general, second and third priority studies should be undertaken only when experimentation is not possible, or when other factors markedly reduce the cost of such studies.

It must also be stressed that the premature adoption of an experimental approach can prevent the final objectives of a project from being achieved. This is especially the case in ecological field experiments where the researcher controls the variation of only a small subset of all the factors in the environment. When there is not sufficient information about the biotic-environmental system to allow for identification of the most important factors, an experimental approach can be misleading. In most instances, deep-sea systems fall into the category of poorly understood. However, to address SRAs, the panel advocates experimentation to determine the effect of one critical factor--sediment outfall from the plume. The problem is not to determine which natural factors are the most important in controlling community change, but rather to determine whether there is a measurable effect on the environment from an artificial disturbance that simulates an effect associated with mining. For this reason, an experimental approach should be adopted to answer this one question.

It is often stated that any policy concerning the deep sea must acknowledge how very little is known about the environment. One of the primary reasons this is true is that the deep sea is a system that is very difficult to study. The greatest difficulties lie not in the remoteness of the environment or the limits of sampling technology, but in the nature of the fauna. As discussed by Jumars (1981), it is an environment where most species are rare. For the smaller size classes of animals, which make up the great bulk of the diversity, at most 28 percent of the species have an abundance of one individual over a 4 m^2 area (based on DOMES macrofauna studies). The diversity and paucity of the fauna in potential mining sites will decrease analytical precision unless larger numbers of samples are taken than is usual in basic deep-sea research efforts. It will be difficult to obtain numerous specimens of any species either for faunal comparisons or for direct examination. To maximize the effectiveness of programs that must gain information on deep-sea ecology, it is necessary to focus funding resources on programs that have highly specific goals supported by carefully planned sampling and analytical efforts.

RECOMMENDATIONS

1. First priority: An experiment should be designed to assess effects of resedimentation on areas outside the path of a mining device in order to select locations for either IRAs or PRAs.

To pick locations for either IRAs or PRAs it is necessary to determine the effect of the benthic plume on areas away from the path of a mining device. Such a determination can take the form of an experiment in which the amount of resedimentation is controlled. The experiment should take place at a depth, accessible by a submersible, that affords a parallel environment to an actual mining area. It is recognized that at ALVIN's operating depth of 4000 m it will not be possible to duplicate exactly potential mining areas lying deeper than 5000 m. However, the advantages of working at shallower depths outweigh the limitations. While the results may not be fully applicable to nodule fields, they will establish sound criteria for monitoring and assessing impact once actual mining begins. An acceptable experimental design can address the effect of resedimentation on several ecological parameters and can include a variety of methods for looking at total faunal composition, sediment mixed layer processes, and other characteristics. The experiment should rigorously address the following questions:

(a) What is the effect of different amounts of resedimentation upon the species and functional group composition?

(b) To what extent is any effect due to mortality, immigration, larval and adult recruitment, or alteration of demographic parameters?

(c) What is the rate and sequence of recovery as measured by the faunal composition and the nature of the sediment mixed layer?

2. Second priority: After resedimentation effects have been determined, planned sampling and environmental surveying programs should be designed to determine the siting, size, and number of PRAs.

The use of PRAs as unimpacted reference areas, not as preserves against extinction, offers the best initial criteria for their siting. Island-zoogeographic theory or other developing theories for terrestrial preserve design do not offer useful criteria at this time. The rarity and sparsity of the deep-sea fauna make it highly unlikely that sufficient life history information could be gathered to suggest a scientific rationale by which to determine the size and number of PRAs. As discussed above, until resedimentation effects have been determined, it is not even possible to determine where PRAs should be relative to potential mining areas. These criteria are similar to those stated in the March report.

(a) A PRA should have biotic and environmental characteristics similar to those of the potential mining areas. Similarity can be determined by comparative sampling of a potential mining site and a provisional reference area. In practice, the necessary faunal survey will require extensive sampling, but only low resolution comparisons can be expected. Comparisons should include: dominant species comparison to include meiofauna, diversity, standing crop biomass, photosurveying of topography and megafauna, descriptive sediment analyses, near bottom current structure, sedimentary mixed layer structure and mixing, and benthic metabolism.

(b) To designate enough PRAs to include the range of environments threatened by mining, it will be necessary to undertake wide-scale environmental surveying. It is recognized that a comparable biological survey would be prohibitive. However, it has not been established that the characterization of nodule field benthic environments along non-biological lines would reflect faunal distributions. Therefore, it is necessary to establish the relations that exist between the physical environment and the associated fauna. Such a project could take the form of an analysis of variance. Biological samples would be taken from sites with known differences in specific physical factors. Future descriptive surveying could then make extensive use of those factors that prove to correlate significantly with faunal composition. Such a planned sampling program, however, should be given lower priority than an experimental look at resedimentation effects.

3. To resolve conflicts between mining interests and establishment of PRAs, a planned sampling program should be designed to determine whether a prime mining area coincides with a distinct fauna.

It is anticipated that some conflicts may arise over whether PRAs remove substantial areas from exploitation. The deciding factor must lie in a determination of whether the fauna in a contested area is unique. In part, this can be done by establishing whether those factors that determine the desirability of an area for mining also coincide with a distinct fauna. This could be addressed in a planned sampling program similar to that described above, but in which the physical parameters are restricted to those also used to find prime mining areas. Apparently these include topography, nodule cover, and nickel content.

4. <u>As a rough guide to scheduling research activities, near-term projects should be started as licenses are granted, and long-term projects should coincide with the beginning of commercial mining</u>.

Because of uncertainties as to how fast industry will progress towards full-scale mining activities, only a rough schedule, based largely upon research priorities, can be suggested. Near-term projects should be started at about the same time that exploration licenses are granted. Long-term projects should coincide with the beginning of commercial mining.

Near term
- Initiation of experimental study of resedimentation effects in order to establish valid criteria.
- Notification of industry of the need to cooperate in siting and criteria development.
- Selection of Provisional PRAs.

Mid term
- Refinement of siting and impact criteria on the basis of experimental evidence.
- Examination of initial PRAs with repect to those criteria.
- Application of impact criteria in trial mining tests.

Long term
- Assessment of impact on large scales as part of monitoring effort of actual mining operations.
- Continued review of provisional PRAs.

5. <u>The criteria developed and the parameters used in the experimental program should form the basis of post-mining monitoring studies</u>.

It is premature to suggest a program of impact assessment and monitoring in areas where there has been commercial scale mining. However, the criteria developed and the important parameters identified during the experimental program will serve to structure any post mining studies. It is anticipated that such programs will focus upon recolonization and return of the biota to a stable state, possibly unlike the pre-mining state.

6. <u>The next panel should be interdisciplinary in its make-up and, to meet the environmental concerns described in PL 96-283, should focus on the ecological importance of those parameters that can be measured with state-of-the-art technology.</u>

Since it is often much easier and faster to produce a descriptive survey of the physical parameters in the deep sea than it is to address specific ecological questions, there may be a predictable tendency to recommend a state-of-the-art environmental survey. However, such an undertaking will not address the obvious ecological concerns of the SRA concept as described in the legislation. Therefore, it is recommended that the next planning group be interdisciplinary in structure, and that it focus upon methods of determining the ecological importance of those environmental parameters that can be measured.

DISCUSSION AT THE MEETING

The reader will understand that any number of different ideas and concerns wove their way through the panel's discussions. For that reason, the specific topics that follow represent a somewhat artificial distillation of the days' talks; however, they should be a convenience to the reader in explaining the evolution of the recommendations presented above.

1. Preliminary Items

The purpose of the meeting and the results of the previous meeting were explained by R. Carney, who was the only member to be present at both. R. Wicklund then gave a brief account of the legislative history of the SRA concept and how it came to be included in the Deep Seabed Hard Mineral Resources Act. During questioning, he explained that progress towards creation of reference areas is not tied to the fate of the Law of the Sea Treaty. The SRA concept was included as part of the U.S. position, and it reflects the concerns held by a number of Congressmen. In the current fiscal climate, it is not likely that major funding will come in the near future. However, there is sufficient Congressional interest to suggest that some funds can be expected in the next two federal fiscal years.

2. Industrial Contribution to the Ecological Data Base

J. Nichols gave a brief account of the ecological work being undertaken by Lockheed Ocean Systems as part of the effort of the Ocean Minerals Company. To date, this work has focused upon zooplankton in the entire water column and benthic surveys of megafaunal organisms. Preliminary megafauna data showed some interesting trends, although a full appreciation was limited by the proprietary nature of the sample locations. Based on 34 camera transects, the megafauna was found to be dominated by species that are probably cosmopolitan or belong to cosmopolitan genera. Spatial autocorrelation suggested clustering of some taxa, but there were no conspicuous east-to-west trends in species composition. Minor east-west differences were found for macrofauna during the DOMES project (Hecker and Paul, 1979). It is possible that the location of the phototransects will become available once licenses have been let.

3. Determination of the Major Scientific Question and the Best Method of Investigation

It was initially pointed out by Jumars that a lack of knowledge of benthic plume effects away from the actual path of the mining device prevented formulation of criteria for both PRAs and IRAs. In addition, determination of any effect through a controlled experiment could serve as an encompassing effort that looked at faunal impact in many different ways: effect upon composition, functional groups, life history aspects of selected species, recolonization, structure of the sediment mixed layer, etc. Each of these aspects of impact had been mentioned separately by different panel members. It was generally felt that the benthic plume offered the greatest opportunity for impact to the benthos in that it could extend far downstream from the mining device. Abyssal communities are adapted to very low food input rates and very low rates of sedimentation; as such, the sudden addition of considerable new material settling from the plume may cause major alterations in the fauna that could be reflected in the functional group composition. Aller expressed the interesting opinion that resedimentation might not have a major impact, because it might not be appreciably different from the sediment mixing experienced by the animals due to bioturbation. This idea could be tested in a controlled experiment.

The relative merits of controlled experimentation, planned sampling across natural gradients, and general multivariate sampling were then discussed. Hessler cautioned that the experimental approach was often oversold in situations where it was premature, impossible, or impractical, and that the panel should not leave the impression that experimentation was the solution to all ecological problems. Endorsing these comments, Aller pointed out also a possible paradox in placing highest priority on experimental work and lowest on general descriptive work. In a poorly known environment like the deep sea, without a sound descriptive basis it is not possible to formulate meaningful experiments. These two cautions were generally accepted, but it was agreed that in the specific case of SRAs, plume effect experiments were possible and should have the highest priority, because such effects will determine the spacing criteria of mining and non-mining areas in the future.

4. Inapplicability of Terrestrial Concepts of Preserve Design and Management

It was suggested at the March meeting that the concepts being developed for terrestrial preserve siting and size might be helpful in establishing criteria for deep-sea SRAs. Caswell addressed this possibility and pointed out that preserve criteria have not progressed beyond the point of heated debate. In addition, the rarity of the deep-sea fauna would make it especially difficult to obtain the needed life history information. Jumars pointed out an additional difficulty: one of the major goals of terrestrial preserve design is to protect species from local or total extinction. Here again, the rarity of the abyssal fauna poses a major problem. Those deep-sea species most likely to be driven to extinction by the impact of mining are so rare that there is only a very low probability that they would ever be collected in any monitoring program.

5. The Relative Merits of Examining Impacts in a Controlled Experiment Versus Waiting for Trial Mining

The discussion of how to actually measure impact took the form of a debate on the relative merits of two different approaches. The first (proposed first by Hinga) would be to wait until industry began trial mining in nodule fields and to conduct a sampling program to follow changes. The other (suggested by Jumars) would be to construct a controlled experiment at depths accessible with current submersible technology. It was generally concluded that the considerable merits of the experimental approach outweighed its shortcomings and that it was not necessary to wait for test mining to begin studies. The approach has four major advantages:

(a) The amount of resedimented material can be varied and marked in a highly controlled manner. During DOMES trial mining, it was not possible to determine whether there was any resedimentation in the areas sampled.

(b) If the work is done at accessible depths (above 4000 m for the submersible ALVIN), a more abundant and better known fauna can be studied. Increased sample size will improve statistical resolution and make possible detailed studies of single species. Many of the species will be the same ones found deeper or of similar functional or phylogenetic groups.

(c) It will be possible to determine the response of several parameters to controlled levels of resedimentation in the same experiment. This will allow for a careful selection of those to be included in future monitoring studies.

(d) Research can be initiated prior to trial mining and can progress at a pace that is independent of industrial developments

Two principal shortcomings of the experimental approach are:

(a) Accessible environments will probably not be physically and biologically entirely like potential mining areas. This may limit the applicability of some results.

(b) The scales of disturbance in a controlled experiment cannot be as large as those produced by actual mining.

However, it was concluded that the experimental work would produce a sound set of initial criteria that could then be tested in nodule fields once trial mining began.

6. The Need to Establish the Nature of Faunal-Environmental Correlations Prior to Extensive Surveying

It was a tentative conclusion of the March panel that selection of PRAs will require extensive surveys of the fauna and physical parameters across the area subject to early mining. Because of the more extensive physical data base and the relative ease of producing charts of physical properties, it was also recommended that exhaustive faunal surveys be avoided. It was unanimously concluded at the July meeting that an exhaustive survey would be prohibitive. However, the opinion was strongly voiced by Jumars and Hessler that a physical survey cannot be used to determine which areas contain specific faunas. The correspondence between the variables that can be measured to produce a description of an environment and the fauna contained there have not been determined. It is not even evident that there is any ecological relevance to the descriptive parameters that are routinely measured. Carney, Aller, and Hinga argued in favor of using physical criteria alone for initial sites to be followed by ecological investigations to determine whether physically distinct sites had distinct faunas. It was finally concluded that by first establishing which descriptive parameters are associated with distinct faunas, surveys to locate probable faunal sites could be better planned and would be more likely to succeed in locating such sites. Jumars suggested that such a program could take the form of an analysis of variance following a stratified random sampling design. This design would require prior knowledge of the distribution of the physical parameters.

7. Inapplicability of Proxy Measurements in Place of Species Counts

Because of the tedium of comprehensive faunal surveys in the deep sea, the idea that species composition can somehow be replaced by a single parameter is a recurrent dream in the field of impact assessment. Unfortunately, however, it was the conclusion of the panel that there is no substitute for detailed faunal analysis. It is clearly the intent of the legislation to preserve the species that might otherwise be threatened by mining. Furthermore, there are no known measurements that allow determination of which species are present without an actual census. As pointed out by Aller and Hinga, measurement of the integrated effects of the biota can, however, provide information as to system functioning and could be used to monitor impact and recovery. However, the relationship between integrated measurements and specific changes in the fauna has not been established in the deep sea. These relationships could be investigated as part of a resedimentation experiment. Integrated measurements could include:

biogenic structure in the mixed layer (direct observation of water content), mixing as measured by natural and manmade radioisotopes, total benthic metabolism, and vertical profiles of bacterial metabolism.

8. The Need for Analysis of Functional Classifications of Organisms

Jumars pointed out that studying impact upon functional groups of organisms would reduce some of the problems inherent in working at the species level. First, there are theoretical grounds on which to predict types of impact upon functional groups that are defined according to feeding and locomotion characteristics. Predictions allow for experiments that entail hypothesis testing. Second, many of the rare species will be lumped into larger groups, facilitating statistical comparisons. Since the DOMES area megafauna was dominated by polychaetes and isopods, Jumars and Hessler were asked about the adequacy of functional classifications that exist now or could be easily applied. It was admitted that refinement would be needed, but it was felt that workable classifications could be made now. Carney noted that such functional classifications would require sorting to the species level as an initial step, but, as Jumars pointed out, it would not require the full taxonomic identification.

9. SRAs and the Changing Emphasis of Deep-Sea Biology

Because of the long-term nature of the recommended efforts (approximately 10 years), it is necessary to allow for changes in the field of deep-sea biology as poorly examined processes and parts of the environment are studied. While agreeing that such investigations should not be specifically included in the SRA program, the panelists did suggest areas that might bear upon impact assessment in the deep sea. Hessler pointed out that ocean scale distributions of species within the dominant faunal groups have not been determined, and that knowledge of these distributions will be needed in any effort that seeks to preserve species. Hinga suggested that the relationships between nutrient input, faunal composition, and community metabolism are just beginning to be established. Jumars noted that the relationships between physical parameters and the biota needed to be determined beyond the level of making purely empirical correlations. Caswell felt that developing concepts of non-equilibrium population models could be applied to the study of life history adaptation in the deep sea. Aller stressed that there was considerable opportunity to study the response of deep-sea animals to the natural changes that occur in that environment and to learn more about their overall abilities to accommodate to change.

10. Biological and Physical Parameters of Interest

Several different parameters were repeatedly mentioned as important parts of a controlled experiment, of a comparison of two sites, or during sampling to determine the relationship between environmental and biological variables. These were faunal composition, which should include meiofauna (since it is this small size class into which newly settled larvae will fall), a measure of diversity, standing stock; functional composition; integrated measures of faunal activity (community metabolism, mixing rate, etc.); near-bottom hydrodynamic regime; topography; sediment size analysis; nodule cover; nickel content of nodules; and descriptive measures of the state of the biologically mixed layer (radiographic examination of biogenic structure, interstitial water content, mixing rate, oxygen profiles, etc.).

11. Technical Requirements

Current technology will suffice to successfully undertake controlled experiments and precision core sampling of the bottom. The submersible ALVIN can work at 4000 m, and positioning systems coupled with transponders allow for precise sampling. However, SRA programs could take advantage of improved submersible technology as it becomes available. Of particular interest would be improved maneuverability, improved manipulator dexterity, and a depth limit of 6000 m. With respect to faunal surveys, Hessler suggested that even a traditional sampler, such as an epibenthic sledge, might suffice for some purposes. Jumars, however, argued in favor of box cores, which provide better information on the actual area sampled.

12. Impact of Commercial Scale Mining

The desirability of attempting to assess impacts of large-scale mining in the near term was discussed as a possible major question. Such a program would have to focus upon recolonization of large areas under direct impact from the mining device and the benthic plume. However, this was not given a high priority, since the opportunity will not afford itself until some time in the future, while the effects of the plume can be studied now. Hinga suggested that an impact study could be built into industrial test mining. However, Jumars felt that precise control of the miner and precise placement of cores in the track of the miner would not be practical. The value of putting recolonization boxes in mining areas was viewed favorably, but it was pointed out that the critical test showing that recolonization boxes reflected natural resettlement had not been performed. By placing highest priority on a resedimentation experiment, it will be possible to develop sound methods of assessing possible impact once mining begins.

13. Possible Methods of Reducing Impact

Obviously, little can be recommended before the nature of the impact has been studied. However, two possible methods came to light during discussion on benthic plume effects. Caswell suggested that once plume effects and geometry are known, a mining pattern that minimized plume spreading could be developed. Aller also noted that if the bite of the miner was restricted to the biologically mixed layer, the sediments thrown into the benthic plume would be chemically similar to those aleady experienced by the fauna.

REFERENCES

Hecker, B., and A.Z. Paul 1979. Abyssal community structure of the benthic infauna of the eastern equatorial Pacific: DOMES sites A, B, and C. In: Marine Geology and Oceanography of the Pacific Manganese Nodule Province, Bischoff, J.L., and D.Z. Piper, eds. New York: Plenum Press, pp. 287-308.

Jumars, P.A. 1981. Limits in predicting and detecting benthic community responses to manganese nodule mining. Marine Mining, Vol. 3(1-2).

Appendix C

"CHARACTERISTIC ENVIRONMENT" REPORT: OCTOBER 11-12, 1982 MEETING

The third SRA meeting (San Francisco, October 11-12, 1982) first reviewed the results of the prior two SRA sessions, particularly the biological concerns raised at the second session. Points discussed included the following:

1. The usefulness of meiofauna (greater areal abundance, but poorly known) relative to macrofauna (difficult to sample adequately, but reasonably well studied) in assessing the impact of mining.
2. The validity of "functional groups" as indicators of environmental perturbation (is there any basis for assuming uniform response within such groups?).
3. What submersibles are available for deep-ocean experiments? Although navy-operated submersibles are accessible to civilian scientists, experience suggests that ALVIN is the only credible tool currently available for complicated manipulative experiments.
4. The importance of a "controlled impact experiment" to determine whether changes in the makeup or health of a fauna due to burial by a sediment plume can be recognized in "functional group" counts or even in gross indicators of faunal activity such as metabolite consumption/production, or rates of bioturbation.

Most of the meeting, however, was taken up with discussions of the number and definition of "characteristic environments" in the Clarion-Clipperton region that should contain the initial provisional PRAs. In the absence of sufficient benthic samples to define the characteristic environments on biological grounds, we assessed other environmental properties that might allow a rational subdivision of the regions. Parameters considered included the following:

- Sediment types
- Nodule coverage
- Surface primary productivity
- Surface biomass
- Benthic biomass
- Nodule composition
- Bottom currents
- Bathymetric trends

- Local relief
- Proportion of rock outcrops
- Surface currents
- Occurrence of erosion

Based on existing knowledge, there is no basis for proposing any subdivision more complex than a 3 by 3 scheme in which the region would be divided by north-south boundaries along 130°W and 140°W and two equally spaced northeast-southwest boundaries parallel to the fracture zones. Within each such "environment," the topography, occurrence of erosion, sediment coverage, nodule properties and coverage, and bottom currents will be highly variable at scales of hundreds of meters to kilometers.

Mining groups (and ships of opportunity) should be encouraged to submit properly documented and preserved benthic samples and bottom photographs to recognized repositories as a relatively inexpensive way to augment our basic knowledge of the Clarion-Clipperton region. Such information may allow a more biologically meaningful set of characteristic environments to be defined prior to the designation of permanent PRAs.

At least one provisional PRA should be designated within each characteristic environment. The provisional PRAs should be large enough to sample the local variability and to guarantee some immunity from a mining plume if trajectory estimates are seriously in error. The designation of provisional PRAs as soon as possible (and definitely no later than the award of pre-enactment exploration licenses) will ensure that the SRA concept is embedded in NOAA regulations, and will serve to focus fieldwork in the coming years. Inasmuch as future work may result in some preliminary PRAs being discarded, this early designation may lead to some wasted effort. We believe, however, that the benefits of early designation outweigh the liabilities.

There was considerable discussion on the size of PRAs (certainly not less than 15 x 15 km, and conceivably 100 times this area), and on methods of relating faunal distributions to benthic environments. The comparison of faunas from contrasting subenvironments in a well-surveyed area like DOMES Site A (for example) was felt to be worthwhile. Such a comparison should include hills versus valleys, nodule-covered versus nodule-free areas, Tertiary versus Quarternary surface outcrops, and Cu-Ni-rich versus Cu-Ni-poor nodule occurrences.

The use of bottom drifters will be required to determine the regions upstream and downstream from mine sites. Maximum use should be made of trial mining to define the behavior of the plume of resuspended sediment. Tools for this should include more strings of current meters, (nephelometers), and sediment traps around the mining site.

Appendix D

REPORT ON REQUIREMENTS FOR A COST-EFFECTIVE PROGRAM FOR STABLE REFERENCE AREAS: MARCH 21, 1983 MEETING

INTRODUCTION

The fourth and final meeting on the stable reference area (SRA) concept was held to focus on the scientific and engineering requirements for conducting the "resuspension experiment" outlined in the previous meetings. Some concern had been expressed that the conduct of this experiment could be extremely difficult, and so a fourth meeting was convened to define possible technical constraints and approaches associated with this project.

A background paper prepared by Gary L. Taghon (given in Appendix E), was the basis for discussion. The basic concept of sampling to determine impacts following application of a labeled natural sediment was endorsed by the participants. The consensus, however, was that the effort should proceed slowly, with minimal investment, until some "paper" studies (i.e., theoretical and conceptual design studies) had been completed. Such early analyses could eliminate some alternatives and thus reduce expenditures and time spent in pursuing useless or costly approaches.

The following summary of the meeting reviews the pertinent discussion and then lists the preliminary steps (items for action) that should be taken prior to a major expenditure of funds (e.g., construction of the particle spreader). The panel felt that until these initial studies were conducted, it would be difficult to provide any further guidance on the conduct of the experiment.

DISCUSSION

Several issues arose that require further assessment before a final experimental design is approved:

1. Labeling the dumped sediment. How well can microbeads be mixed into a large mass of deep-sea sediment? Should the beads be activated? Can natural 210-Pb in sediments be used as a tracer? Could sediment be collected, spiked, and deposited by a sea-floor vehicle?

The "cement-mixer" approach for adding tracer to sediment on board ship is likely to be feasible but slow. Twin jets (one delivering slurry, the other tracer) could generate enough turbulence for good mixing, but the procedure would again be slow. The use of activated beads would allow gamma counting to speed up areal density estimates. For a large experiment, the total activity might be unacceptable, however. There was general agreement that natural 210-Pb would be too insensitive a tracer at the low load rates (less than 1 mm) of greatest interest to the SRA problem. Additional conceptual design work is required to assess the feasibility of a sea-floor "collect-mix-spread" vehicle.

2. Number of samples required. Further theoretical work on sampling strategies for very diverse, very depauperate faunas is needed to develop a statistically robust coring plan. Initially, such modeling should be general, and then it should be customized to the (limited) information on the deep-sea benthos in nodule-covered areas. Of particular interest is the number of functional groups that can be resolved by a given sampling strategy.

A study focused on meiofauna might reduce the number of samples required, due to the greater number of individuals per core, but the group felt that the expertise required to mount such a study does not now exist in the United States.

3. Relative benefits of ALVIN and surface ships as dumping and sampling platforms. Concerns over ALVIN's effectiveness resulted from the following:

(a) The substantial time that would be required to dump from a small hopper. This would be expensive and would face changing near-bottom circulation as the tidal currents rotated during the dumping runs.

(b) The severe disturbance of the bottom by ALVIN as cores are being collected.

(c) The excessive number of dives and coring operations required to collect a statistically useful area of surficial sediments.

An alternative, development of a separate wheeled bottom spreader (modeled after agricultural implements), combined with ALVIN sampling solves (a), but not (b) and (c).

Dumping and coring from a surface ship (using sea-floor acoustic transponders for navigation) has considerable appeal due to lower costs and fewer (but larger) cores. The much larger volume of sediment and impacted area required (to compensate for uncertainties in core placement and location) accentuate the problems of homogeneously mixing in a tracer and dumping the sediment in a well-defined pattern, however. One technique thought to be worthy of further study was mixing the sediment to be dumped into a large bag adjacent to the ship, then lowering the bag and bursting it some distance above the sea floor. The behavior of smoke plumes in the atmosphere as they strike an inversion and spread laterally could be a good analog of the behavior of the released slurry as it hit the sea floor.

Neither ALVIN nor the best surface-ship box cores are capable of collecting truly undisturbed (at a 1-mm scale) sediment-water interfaces. Thus the samples collected at the time of dumping will show the mass per unit area of added sediment at a location (based on tracer per unit area), but not the initial rate of bioturbation.

4. Site for initial studies. The relatively well-studied floor of the San Diego Trough is close to port facilities, and hence allows for developmental testing of sediment spreading and recovery techniques, and is populated by a known fauna. Because only a thin layer of added sediment will drive the existing surface anoxic, however, it is a poor model for oxic, nodule-covered regions. Despite this characteristic, which could result in qualitatively different responses of the two environments to dumping, the benefits of the San Diego Trough appear to outweigh its disadvantages for initial studies. MANOP Site H should be used as a more credible study area as soon as new hardware is working reliably. In the meantime, about five box cores from Site H for initial faunal characterization should be collected from a ship of opportunity.

5. Timing. The amount of time required to design, construct, and test the special equipment needed to carry out a credible controlled-impact experiment cannot be estimated with any confidence until good conceptual designs have been developed (a 1-year task if several options are to be compared). Our best guesses range from about 2 to about 5 years.

ITEMS FOR ACTION

Several theoretical or conceptual studies should be carried out before an effective controlled-impact experiment can be mounted.

1. What is the most statistically robust sampling strategy for the impacted area, based on the application of mathematical statistics to population systems theory?
2. What is the optimum tracer, and how can it be mixed homogeneously into the sediments to be dumped on a test area?
3. What is the cost and feasibility of a sea-floor sediment collector-mixer-spreader system?
4. Would release of a large volume of slurry from a point source above the sea floor produce an acceptable distribution of sediment on the sea floor?
5. Based on the best possible conceptual designs, what are the relative costs and benefits of ALVIN-deployed spreader and sampling systems versus transponder-navigated systems that could be deployed from a surface ship?

Appendix E

LOGISTICAL AND EXPERIMENTAL CONSIDERATIONS: CONTROLLED IMPACT EXPERIMENT

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The purpose of this appendix is to present logistical and technical considerations germane to conducting a controlled impact experiment as part of the stable reference area concept of the Deep Seabed Hard Minerals Resources Act. An earlier panel organized by the National Research Council, meeting to address questions of ecological impacts of deep-sea manganese nodule mining, recommended an experimental approach wherein selected bottom sites would be covered with known amounts of sediments to simulate resedimentation caused by nodule collectors. These impacted areas would be sampled to determine benthic community response, over time, to variable degrees of such burial.

The following areas, pertinent to conducting successfully such an experiment, are discussed:

1. Physical and engineering constraints on conducting the experiment.
2. Amount of sediment to be deposited and methods of quantifying the dose actually delivered.
3. Siting of the experiment.
4. Sampling considerations and analysis of results.

The discussion and recommendations made are based on conversations I have had with engineers in the ALVIN Group at Woods Hole Oceanographic Institution and in the School of Oceanography at Oregon State University, and my own experiences in conducting experiments on animal-sediment-flow interactions using exotic tracers.

1 and 2. The design of the experiment and consequent physical and logistical constraints convary, and therefore are considered jointly.

The committee of ecologists and biological oceanographers that met in July 1982 envisaged a resedimentation experiment conducted using DSRV ALVIN, in an area paralleling as much as possible proposed mining locations. Choice of ALVIN is based on the need for fine-scale, on-site control of the sediment dispersal stage, which rules out any dispersal mechanism relying on a surface ship. Several constraints are connected with the use of ALVIN. ALVIN's load capacity is determined by its weakest link, the safety release mechanism to drop external equipment in the event of an emergency. The mechanism's maximum capacity, as presently configured, is approximately 120 kg (in air). Thus, one "load" of sediment would only cover a relatively small area (3.5 m square, assuming a neutrally buoyant spreading mechanism, $\rho_{sediment} = 2\ g/cm^3$, and an average 1-cm-thick sediment layer). Rather than pursue design of a sediment spreader that will tax ALVIN's load capacity to the limit, and reduce maneuverability, ALVIN should be used to ferry smaller amounts of labeled sediment from a larger container lowered to the bottom from the surface ship. Under this scenario, a simple hopper would be mounted on ALVIN that could be filled, front-loader fashion, from the sediment container. ALVIN would then cruise to the experimental area and release the sediment.

It does not appear practical to make a large effort on designing a spreader that will dispense, precisely and accurately, thin layers of sediment over large areas. Practical experience in intertidal experiments, where a great deal of control can be exercised by the experimenter, has shown that it is very difficult to achieve uniform coverage of even small areas with tracer particles. In a remotely controlled application, such a goal is even more elusive. Moreover, there is no absolute necessity of such a uniform dispersal in this experiment (see section 4 on sampling consideration and analysis of results). A simple "flour-sifter" mechanism, electrically controlled, or any other mechanism to ensure that sediment is released more-or-less continuously from the hopper as ALVIN moves over the area is preferred. Two considerations dictate the choice of a simple means of dispensing sediment. First, the simpler any device is, the more likely it will work--an especially important consideration at 4000 m. Second, and more important from the experimental aspect, is that the presence of ALVIN itself will in all likelihood prevent uniform resedimentation in the experimental areas (B. Walden, ALVIN Group Leader, Woods Hole Oceanographic Institution, personal communication). Because of the small particle size of the ambient sediments (of order 1 μm), sediment dispensation will have to be as close to the bottom as practical to prevent excessive dispersion by even slight currents. In this situation, turbulence from ALVIN's lift props will effectively prevent disposition of a uniform sediment layer.

With these considerations in mind, it is evident that effort will most profitably be focused on determining reliably how much sediment has actually been redeposited on any area sampled subsequently. Obviously, such data are essential to successful and unambiguous interpretation of experimental results. Some thought must be given to how to collect these data. Sediment traps will not furnish such information for several reasons. As already stressed, the unavoidable variation in sediment cover calls for sample-specific estimates of local coverage, which are not possible with a limited array of sediment traps. Any processes leading to removal of the resedimented material over time, which would affect analysis of ensuing benthic community changes, cannot be followed with sediment traps. Finally, and of most concern, sediment traps are often biased samplers, their collection efficiencies functions of particle characteristics and the local hydrodynamic environment (Hannan and Grant 1982). While not a panacea, incorporating tracers into the redeposited sediment will enable estimates of how much any given area has received. Because sediment will be released into the water where it will be subject to dispersion via ALVIN's prop wash and whatever bottom currents are present, it is essential that any tracer to monitor amount of sediment ultimately deposited has hydrodynamic characteristics similar to ambient sediments. In this experiment, settling velocities of the sediment components are the parameters of interest.

A relatively simple method to quantify resedimentation is to incorporate glass microbeads into the sediment dispensed by ALVIN. Glass microbeads are available in a range of sizes and specific gravities such that their transport characteristics can be selected to overlap natural sediments. They are also readily distinguishable from natural sediments by optical methods. In this method, a settling velocity histogram would first be determined for natural sediments using standard pipette analysis procedures. This analysis should be done on sediments from the depth interval likely to be resuspended during nodule collection. Samples should be homogenized but not otherwise treated (i.e., no H_2O_2 treatment or dispersants added) and settling velocities determined in seawater. A size range of glass microbeads whose range of settling velocities includes those of the natural sediment particles is then chosen and mixed with the natural sediment at some low level. Tracer at a 100-ppm level should be adequate for analytical and statistical purposes and can be determined during pretests. A new settling velocity histogram for the labelled sediment is constructed as in Figure E.1 (curve 1). The subsamples of the various settling velocity classes are analyzed for the numbers and sizes of glass microbead tracers they contain. These numbers are normalized to volume or weight of the subsample and plotted in the histogram to give the standard curve (curve 2). By analyzing cores from the experimental areas, determining the numbers of tracer particles in the various size categories, dividing by the correction factor from the standard curve, and summing results over all settling velocity classes, the amount of sediment redeposited is calculated. An example is given in Figure E.2. Note that this method gives both the amount and which classes of resuspended sediment are present in a sample. Such information is valuable since organisms may respond differently to coarser, faster-settling sediment components (those nearest the regions of active mining) and finer, slower-settling sediment (transported farther from the mining plume). Image analysis will be ideal for determining tracer levels in sediment samples.

Although, as already pointed out, precise control over how much sediment a given area receives will not be possible, by varying ALVIN's speed during dispersal three general treatments should be attempted: >1-cm thickness, to simulate the area closest to mining; ≈0.5 cm, to simulate intermediate areas; <0.1 cm, to simulate areas farthest from mining. Such gradations may be set up naturally by the inevitable dispersion occurring during sediment application; this can be evaluated during the pretest.

Several experimental areas should be established. While final dimensions should be based on pretest results on animal abundances, a temporary figure is 20 m by 20 m. This should be separated into two

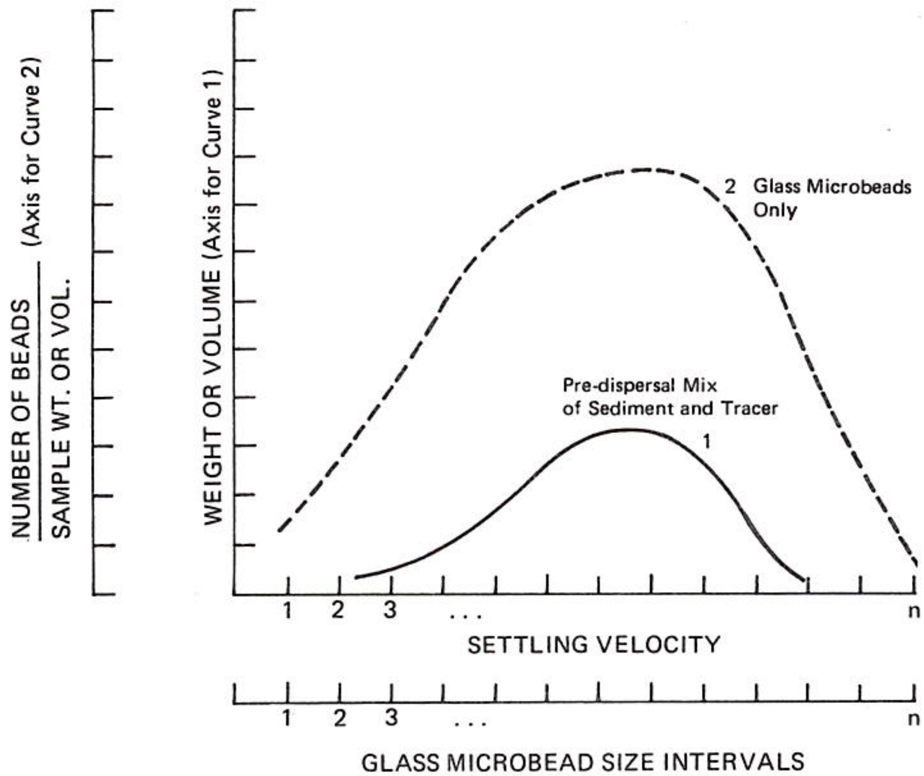

FIGURE E.1 Hypothetical histograms to illustrate method for labelling sediment. Smooth curves drawn instead of discrete intervals. Range of settling velocities of sediment must be a subset of tracer settling velocities. Curve 2 represents standard curve.

zones of equal areas, an inner 14.1-m square and a surrounding 5.9-m-wide strip, to allow distinguishing edge effects from possible longer-distance dispersal to disturbed areas. Simple random sampling in both of these areas will give a picture of the spatial pattern of recruitment.

The complete procedure to prepare the experimental areas can be summarized as follows: The settling velocity histogram of sediments from the experimental site is determined, and a suitable range of tracer particles is selected. A bottom dredge, adjusted to remove the top 5 to 10 cm of sediment, is used to collect the large amounts of sediment required for redeposition. Tracer particles, at a known concentration, are then mixed into this sediment. A portable cement mixer would be ideal for homogenizing the sediment-tracer mixture. Samples are taken to construct the standard curve (Figure E.1). The labeled sediment is then loaded into a container and lowered near the selected experimental area. ALVIN loads its sediment spreader from the storage container, cruises to the experimental area, and releases the sediment, repeating the procedure as necessary to cover an approximate 20-m square. Three replicates of each of three treatment levels-->1 cm, ≈0.5 cm, and 0.1 cm--should be established. When cores of the

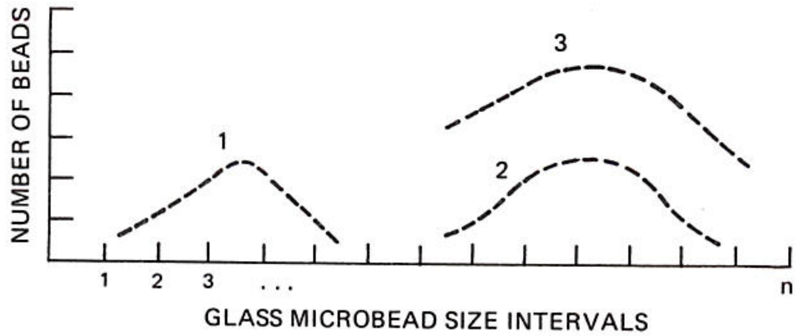

FIGURE E.2 Hypothetical results of tracer analyses for 3 cores taken after sediment dispersal. Core 1 would contain slower-settling, finer sediments farther from release point. Cores 2 and 3, containing larger, faster-settling tracers, from area near the point of sediment release. Core 3 received more sediment than core 2.

experimental areas are taken later, subsamples of each core should be analyzed for tracer particles to determine the actual amount of resedimented material applied (as in Figure E.2).

Before continuing, it should be noted that alternative strategies should be considered, with engineering expertise input.

3. Siting of the experiment. Site H of the Manganese Nodule Program (MANOP) combines several characteristics that make it a good choice for the experimental site. Site H has been the most thoroughly studied station in MANOP, so a wealth of physical and chemical background data exist (Bender 1983). At 3500+ m, this area is near ALVIN's depth limit. Surface productivity is high, and MANOP investigators have noted abundant macroepifauna at the site; infaunal abundances are also like to be greater than in depth regions. As emphasized by the July 1982 panel, this latter feature should improve statistical detection of any changes during the course of the experiment.

4. Sampling considerations and analysis of results. For reasons already emphasized by the July panel, sampling limitations have usually prevented definitive statements about changes in deep-sea benthic communities in previous monitoring studies (e.g., Jumars 1981 (see Appendix A.B in this report)). The nature and scope of the controlled impact experiment represent a unique opportunity to provide data needed for informed decisions on the SRA concept and to add to our basic knowledge of deep-sea ecology. A major commitment must be made to collect sufficient, high-quality samples. The following recommendations are made:

(a) The various sediment-thickness treatments should be sampled <u>at least</u> four times; 1 to 2 weeks, 6 months, 1 to 2 years, and 4 years after the experiment was begun.

(b) As noted earlier, treatment areas should be separated into inner and outer zones of equal areas to assess possible differences in recolonization processes that may occur. For the (initially) recommended 20 X 20 m area, this would result in an inner square 14.1 m on a side, surrounded by a 5.9-m-wide strip, both of 200-m^2 total area. Stratified random samples would be taken from both regions.

(c) The control samples, before the sediment release, can be standard 0.25-m^2 box cores taken from a surface ship. Sampling of the experimental areas should be by ALVIN, not a surface ship. Samples precisely located within the experimental areas are essential, given the intensive sampling planned over a several year period. Previously sampled areas must be avoided. While the position of a surface-deployed box core can be determined fairly accurately, once it is on the bottom, aiming for a specific spot is another matter. Repeated lowerings attempting to hit specific coordinates would excessively disturb the experimental areas. Box cores taken by ALVIN can be accurately positioned within the transponder net at the study site.

(d) For the preliminary control sampling and the 1- to 2-week postrelease sampling, separate samples should be taken for taxonomic purposes and for performing biochemical analyses to determine the physiological and nutritional status of organisms. It is possible that the redeposited sediment might act to bury the food sources of surface deposit feeders or might provide an elevated food supply (Jumars 1981); such biochemical analyses will enable these possibilities to be assessed. Samples for taxonomic purposes should be processed and preserved aboard ship as usual. Samples for biochemical analyses should be frozen after processing, not fixed in formaldehyde.

(e) Relative to collecting samples, sorting and identification of organisms requires the most effort. All the samples collected do not have to be sorted, if a trend is obvious after only a portion have been analyzed. On the other hand, more samples cannot be collected in those instances where additional samples could confirm statistically an emerging trend. Therefore, erring on the side of possibly taking too many samples is desirable. Since ALVIN box cores are 15 X 15 cm (0.0225 m^2), they sample a smaller area than surface-deployed box cores. Clustering nine such cores at a given sample coordinate would result in a total 0.2025-m^2 sample, 81 percent of a standard 0.25-m^2 box core. Given the required number of such samples to detect catastrophic changes in <u>total</u> organism abundance in typical deep-sea communities (Jumars 1981), balanced by the likelihood that animal abundances will be higher at MANOP Site H, 20 such nine-core clusters are the minimum number of samples that should be taken from each zone (inner and outer) of each treatment (three levels of sediment thickness) at each sampling period;

a total of 1020 of the small ALVIN box cores per sampling date. Thus ~2 percent of the total experimental area will be sampled destructively at each sampling date. This level of sampling should minimize disturbance to areas to be sampled at later dates. Ten additional samples should be taken from the control area during the preliminary cruise and from each of the treatments during the first postrelease cruise for use in biochemical analyses (see (d)).

While this number of samples may be modified in light of knowledge gained on organism types and abundances from the preliminary survey, it may be just as likely to increase as to decrease to achieve a given power for statistical tests. The most conservative attitude to adopt at this time is to plan on the indicated sampling effort. It must be stressed that insufficient sampling will nullify all efforts made in setting up these controlled impact experiments. If the indicated sampling effort cannot be made, sampling should preferentially be reduced or eliminated in the outer regions of the experimental areas, and efforts concentrated in the inner regions.

Correlation techniques will be useful in analysis of results. Because, as discussed earlier, discrete, well-separated treatment levels will likely not be possible, ANOVA techniques will not be applicable. Trend tests, with degree of sediment cover as the independent variable, and species or guild numbers, faunal composition, biomass, and so on, as dependent variables, will be more appropriate.

REFERENCES

Bender, M.L. 1983. The manganese nodule program. Eos, Trans. AGU 64:42-43.

Hannan, C.A., and W.D. Grant. 1982. Evaluating sediment trap biases in natural flows. Eos, Trans. AGU 63:46.

Jumars, P.A. 1981. Limits in predicting and detecting benthic community responses to manganese nodule mining. Marine Mining 3:213-229.