Chapter 6
Environmental Considerations

CONTENTS

Boxes

Figures

Tables

Chapter 6
Environmental Considerations

INTRODUCTION

Mineral deposits are found in many different environments ranging from shallow water (sand, gravel, phosphorites, and placers) to deep water (cobalt crusts, polymetallic sulfides, and manganese nodules). These environments include both the most biologically productive areas of the coastal ocean as well as the almost desert-like conditions of the abyssal plains. (See figure 6-1.)

Given this broad spectrum, it is hard to generalize about the effects of offshore mining on the marine environment. However, a few generic principles can be stated. [1]As long as areas of importance for fish spawning and nursery grounds are avoided, ***surface*** and ***mid-water*** effects from either shallow or deep water offshore mining should be minimal and transient. Benthic effects (i. e., those at the seafloor) will be the most pronounced for any mining activity in either shallow or deep water. Animals within the path of the mining equipment will be destroyed; those nearby may be smothered by the "rain of sediment' returning to the seafloor. Mining equipment can be designed to minimize these effects. Barring very extensive mining sites that may eliminate entire populations of benthic organisms or cause extinctions of rare animals, negative impacts to the seafloor are reversible. Most scientists believe that shallow water communities would recover rapidly from disturbance but that recolonization of deep sea areas would be very slow.

Because little offshore mining is going on now, the degree of environmental disturbance that any particular commercial operation might create is difficult to characterize. Even areas that are dredged frequently do not have the same level of disturbance as a continuous mining operation. Nevertheless, U.S. dredging experience is a useful gauge of the potential for environmental impacts. In shallow nearshore waters, a few sand, gravel, and shell mining operations in the United States and Europe indicate possible impacts. In addition, results of research in the United States and abroad offer insights on the effects of offshore mining. These research efforts include:

- the International Council for Exploration of the Sea (ICES) Report of the Working Group on Effects on Fisheries of Marine Sand and Gravel Extraction—box 6-A,
- the U.S. Army Corps of Engineers Dredge Material Research Program (DMRP)—box 6-B,
- the New England Offshore Mining Environmental Study (NOMES)—box 6-C,
- Sea Grant Studies of Sand and Gravel in New York Harbor—box 6-D, and
- National Oceanic and Atmospheric Administration's (NOAA) Deep Ocean Mining Environmental Study (DOMES)—box 6-F.

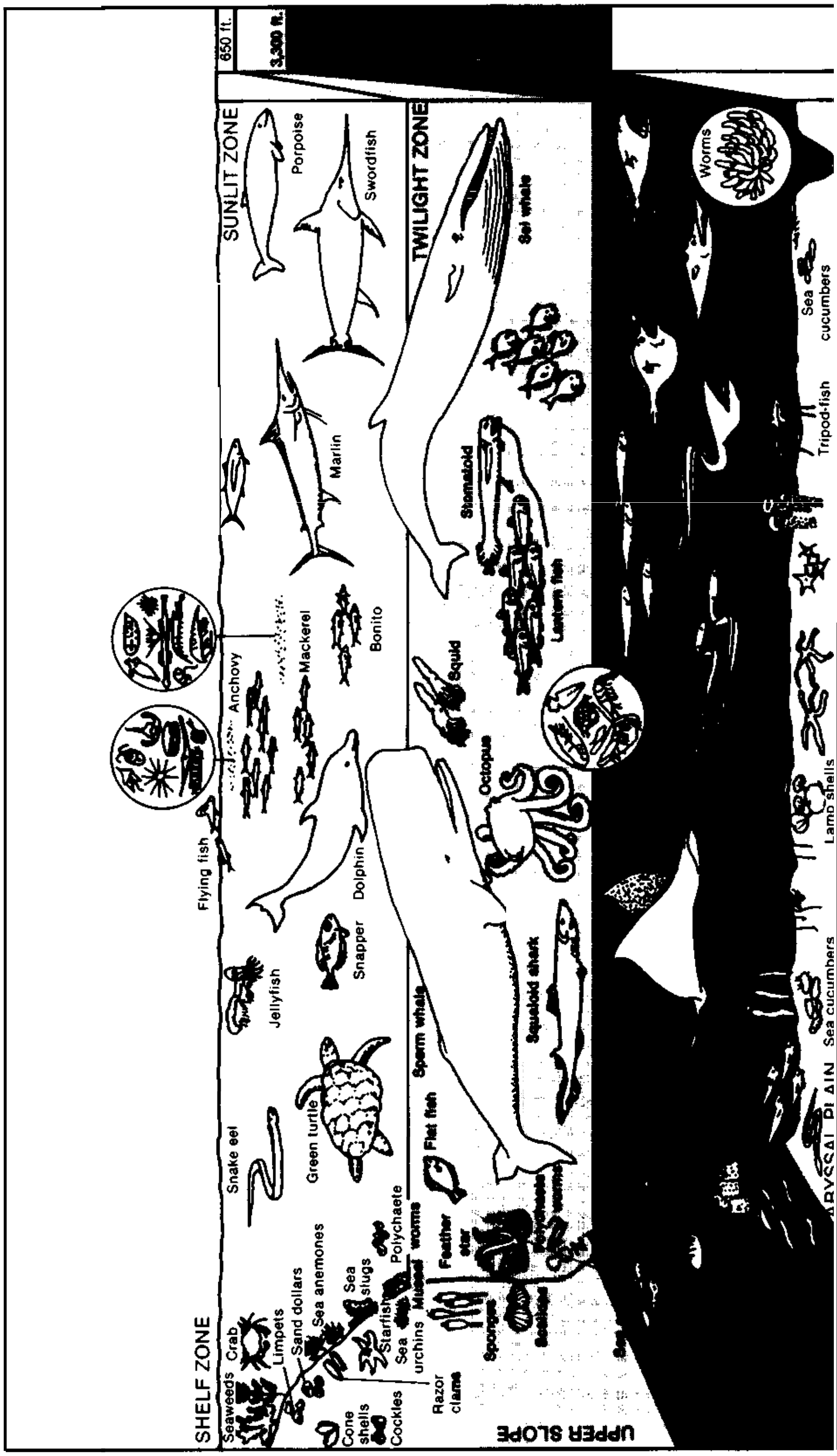
The Gorda Ridge Draft Environmental Impact Statement, and the Cobalt Crust Draft Environmental Impact Statement (see box 6-G) summarize related research as well.

Similarities among the mining systems used for deep water (2,500- 16,000 feet) and shallow water (less than 300 feet) suggest that the same general types of impacts will occur in both environments. Any mining operation will alter the shape of the seafloor during the excavation process, destroy organisms directly in the path of operations, and produce a sediment plume over the seafloor from the operation of the equipment.[2] When the mined material is sorted and separated at the ship, some percentage will be discarded—very little in the case of sand and gravel, a great deal for many other seabed minerals—resulting in a surface "plume' that will slowly settle to the bottom (see figure 6-2). The duration and severity of plume effects on the surface and water column depend on the grain-size of the rejected material. Sand (i. e., particle sizes 0.06 mm-1.0 mm.) settles quickly; silts (.001-.06

[1]These conclusions are for mining alone. If any at-sea processing occurs, with subsequent chemical dumping, guidelines may be totally different

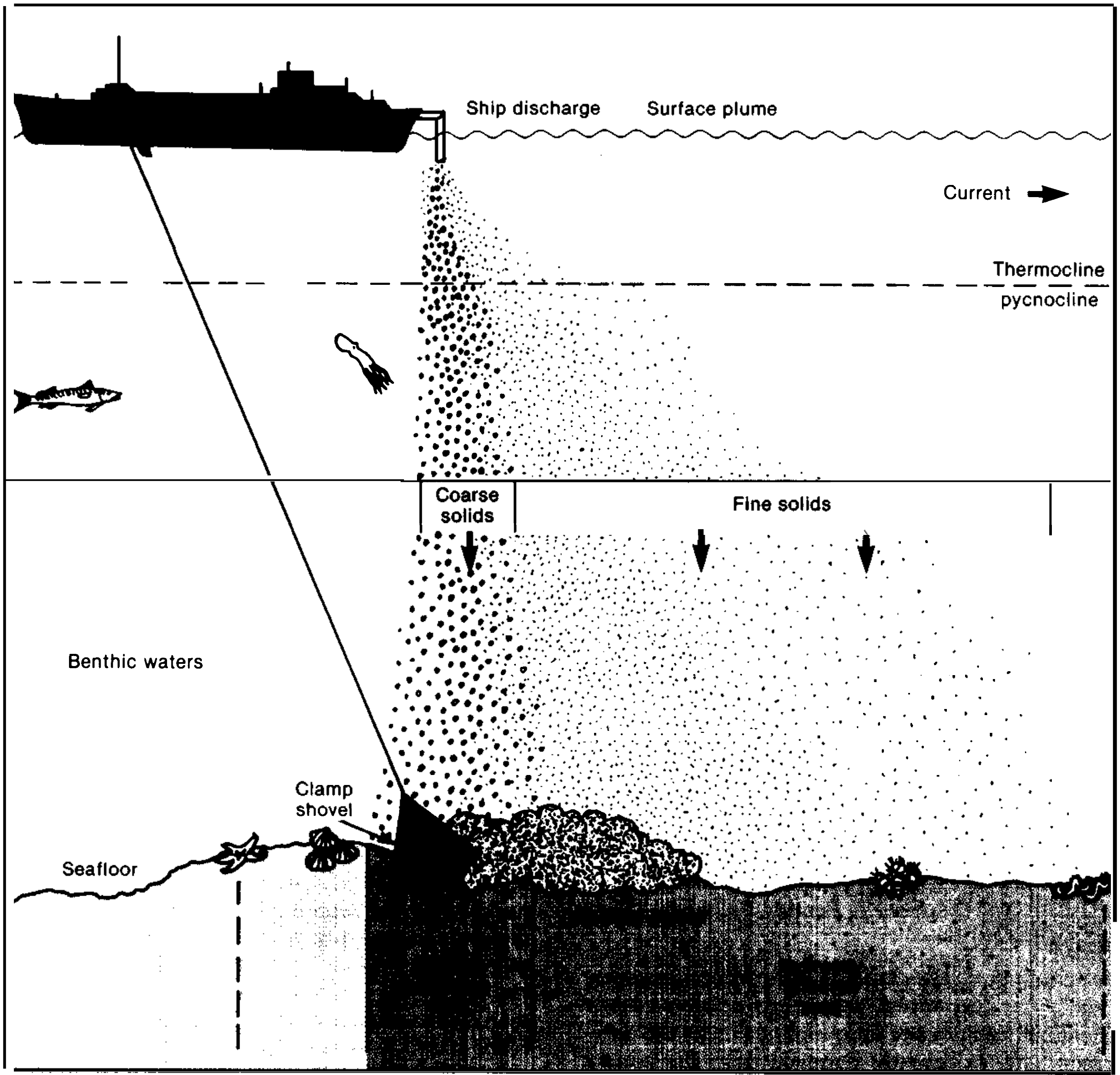
[2]These sediment plumes are the equivalent of the dust clouds produced by similar operations on land.

Figure 6-1.—The Vertical Distribution of Life in the Sea



SOURCE: Modified from The Rand McNally Atlas of the Oceans, New York, 1977.

Figure 6-2.—impacts of Offshore Mining on the Marine Environment



SOURCE: Office of Technology Assessment, 1987.

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mm.) and clays (finer than .06 mm.) remain in the water column for a much longer time.

It is not scientifically or economically possible to develop very detailed baseline information on the ecology of all offshore environments in the near future; the consequences of a variety of mining scenarios cannot be precisely predicted. However, presumably environmental impact statements (EIS) will be prepared to identify site-specific problems prior to the commencement of mining operations. Environmental impacts should also be monitored during an actual mining operation. Areas where offshore mining is most likely to pose an environmental risk can be identified now or in the near future using existing data. (e. g., see figure 6-4 showing areas of high biological productivity superimposed on a map, produced by the Strategic Assessment Branch of NOAA, depicting areas of high mining potential.) For shallow water environments, areas considered sensitive because of unique plant or animal species, spawning or nursery areas, migration pathways, fragile coastline, etc., should be prohibited from mining activities (see figure 6-3); this approach is being pursued in the United Kingdom and Canada and is one of the prime recommendations of the International Council for Exploration of the Seas (ICES) Working Group.

Analogues in natural environments that simulate disturbances on the scale of a mining effort should be investigated. For example, insight into the response of the deep-sea to a mining operation can be gained from studying deep-sea areas exposed to natural periodic perturbations such as the HEBBLE[3] (High Energy Benthic Boundary Layer Experiment) area.

In addition, when mining does proceed in either shallow or deep water, at least two reference areas should be maintained for sampling during the operation: one sufficiently removed from the impact area to serve as a control, and one adjacent to the mining area.

Shallow water effects are better understood than deep water effects because nearshore areas have been studied in detail for a longer time. A great deal is known about the environment and plant and animal communities in shallow water areas. But there has been no commercial mining and much less is known about ecology in deep-sea areas where manganese-cobalt crusts, manganese nodules, and polymetallic sulfides occur. However, there appears to be remarkable uniformity in the mechanisms that control deep-sea environments, so that information gleaned from one area in the deep-sea can be used to make predictions about others; shallow water environments on the other hand, differ significantly from site to site.

One area of shallow water research that requires attention is coastline alteration. Sand, gravel, and placer mining in nearshore areas may aggravate shore erosion by altering waves and tides. A site-specific study would have to be done for each shallow water mining operation to ensure wave climates are not changed. New theories about wave action suggest that, contrary to previous scientific opinion, water depth may be a poor indicator of subsequent erosion. The relative importance of different kinds of seafloor alterations on coastline evolution needs to be clarified. For example, what is the effect of a one-time, very large-scale sediment removal (e. g., at Grand Isle, Louisiana, for beach replenishment over a several mile area) versus cumulative scraping of a small amount over a very long period (such as decades).

The information most needed to advance understanding of the deep-sea is even more basic. The research community needs more and better submersibles to adequately study the deepsea benthos. Currently, there is a 2-year time-lag between research grant approval and available time on one of the two U.S.-owned deepsea submersibles available to the scientific community. Deep-sea biota need to be identified and scientifically classified. Up to 80 percent of the animals obtained from the few samples recovered have never been seen before.[4] It will be impossible to monitor change in animal communities without systematic survey of these populations. Research funding is needed to develop

3D. Thistle 1981, "Natural Physical Disturbances and Communities of Marine Soft Bottoms, " Mar. Ecol. Prog. Ser. 6: 223-228, and B. Hecker, "Possible Benthic Fauna and Slope Instability Relationships, " *Marine Slides and Other Mass Movements, S.* Saxov and J. K. Nieuwenhuis (eds.), Plenum Publishing Corp., 1982.

4B. Hecker, Lament-Doherty Geological Observatory, OTA Workshop on Environmental Concerns, Washington, D. C., Oct. 29, 1986,

Photo credit: S. Jeffress Williams, U.S. Geological Survey

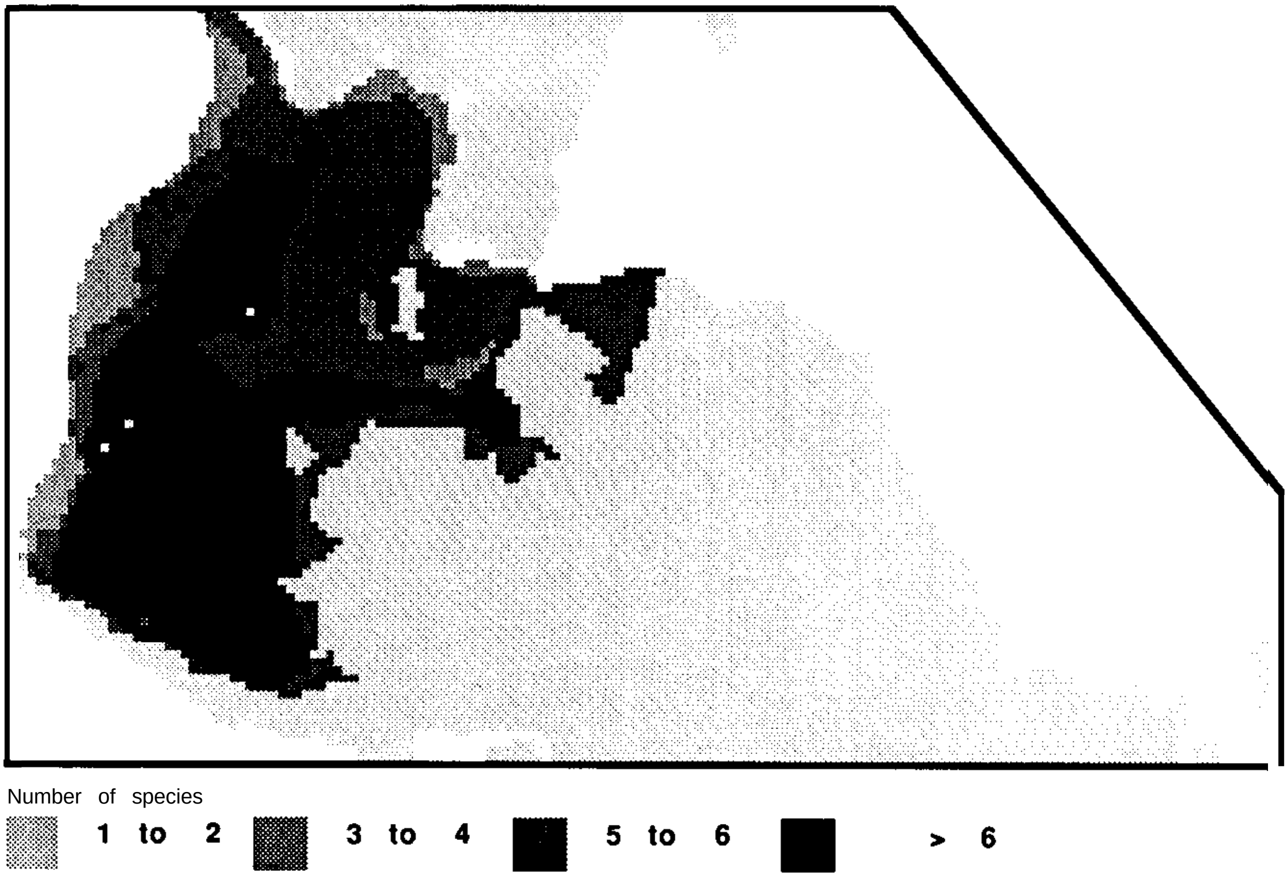
Hallsands once stood on a narrow ledge of rock protected by a cliff and high pebble ridge. The disappearance of this small fishing village was the result of dredging 650,000 tons of gravel offshore over a 4-year period. Removal of such vast quantities of offshore sediments from 1897 to 1901 altered wave patterns and caused beach erosion of 12 to 19 feet by 1904. By 1917, foundations of 29 homes were undermined by the waves and fell into the sea.

the taxonomy of deepsea creatures. Improvements in navigational capabilities are needed; in order to conduct ' 'before and after' studies, it is important to return to the exact area sampled.

A compendium of available studies and the data produced on both shallow and deep water environments is sorely needed. Unfortunately, a great deal of research on environmental impacts to offshore areas, performed for particular agencies and institutions, has never appeared in peer-reviewed literature. These studies may be quite useful in describing both the unaltered and altered offshore environment and may be directly applicable to proposed mining scenarios. An annotated bibliography summarizing all the information that went into the compilations of MMS Task Forces (see boxes 6-G and 6-H), DMRP, DOMES —see box 6-F, NOMES—see box 6-C, and Information from the Offshore Environmental Studies Program of the Department of Interior developed in conjunction with developing EISS for Oil and Gas Planning Areas would be invaluable. The combined research budgets represented by these efforts is hundreds of millions of dollars. Such data collection could not be duplicated by the private and academic sectors in this century. New research efforts—which tend to be quite modest in comparison—would benefit from easy access to this wealth of information.

An important effort to collect available biological and chemical data and screen them for quality control is underway in the Strategic Assessment Branch of NOAA. Since 1979, NOAA has been

Figure 6-3.—Spawning Areas (June-September) for Selected Benthic invertebrates and Demersal Fishes



This computer-generated map of the Bering, Chukchi, Beaufort Seas area of Alaska shows how information about various species can be combined to develop pictures of offshore areas (in this case, spawning areas) where mining activities may be detrimental.

SOURCE: Strategic Assessment Branch, NOAA,

List of Species Included in Computer-Generated Composite Map

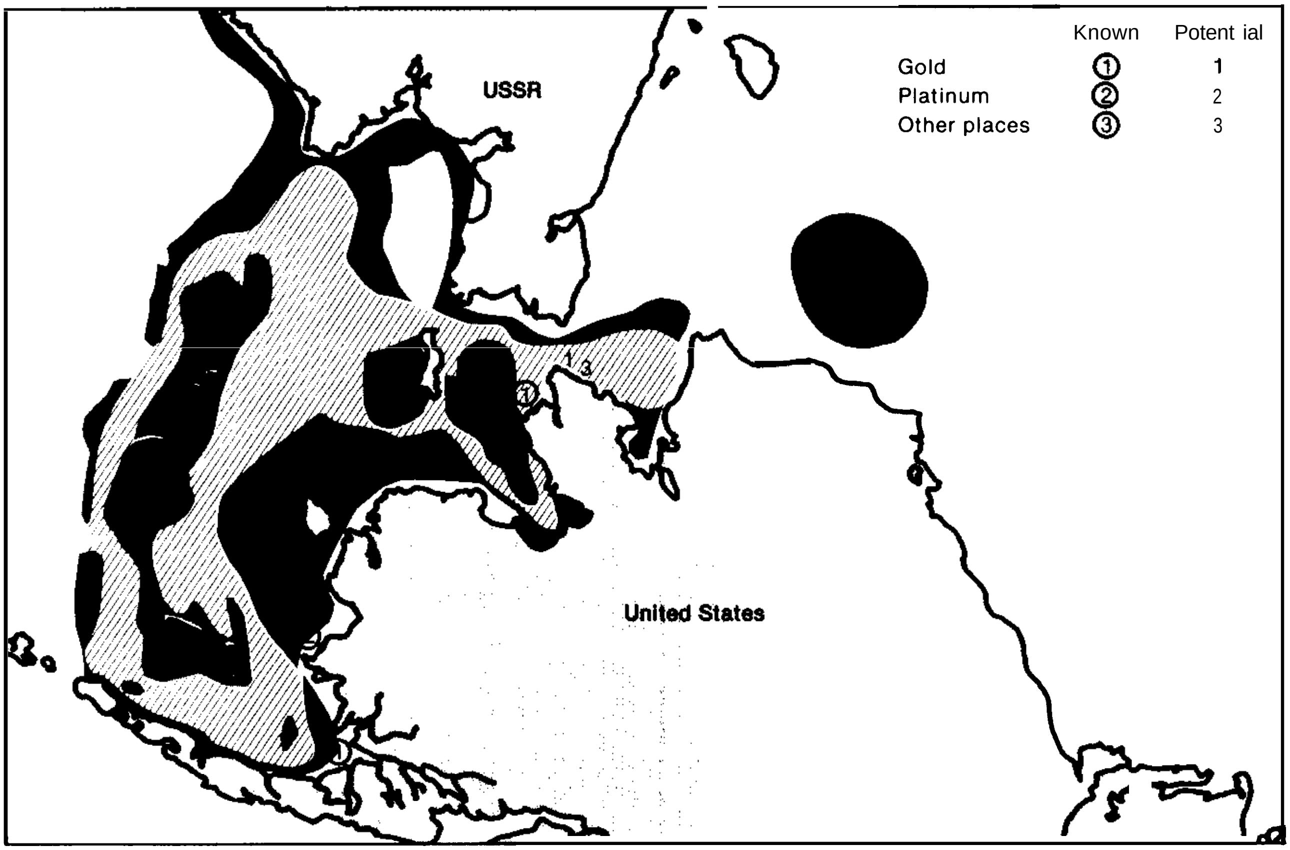
Invertebrates:

Small crangonid shrimps *(Crangon communis, C. dalli, C. septemspinosa)*
Northern Pink Shrimp *(Pandalus borealis)*
Sidestripe Shrimp *(Pandalopsis dispar)*
Humpy Shrimp *(Pandalus goniuris)*
Pandalid shrimp *(Pandalus tridens)*
Opossum shrimp *(Mysis relicta)*
Korean Hair Crab *(Erimacrus isenbeckii)*
Red King Crab *(Paralithodes camtschatica)*
Golden King Crab *(Lithodes aequispina)*
Blue King Crab *(Paralithodes platypus)*
Bairdi Tanner Crab *(Chionoecetes bairdi)*

Fishes:

Pacific Cod (Gadus *macrocephalus)*
Walleye Pollock *(Theragra chalcogramma)*
Yellowfin Sole *(Limanda aspera)*
Alaska Plaice *(Pleuronectes quadrituberculatus)*
Greenland Turbot *(Reinhardtius hippoglossoides)*
Rock Sole *(Lepidopsetta bilineata)*
Arrowtooth Flounder *(Atheresthes stomias)*
Flathead Sole *(Hippoglossoides elassodon)*
Pacific Halibut *(Hippoglossus stenolepis)*

Figure 6-4.–Composite of Areas of Abundance for Selected Invertebrates Superimposed With Known Areas of High Mineral Potential



Composite of Areas of Abundance for Selected Benthic Invertebrates
Number of Species
■ -1; ❑ - 2,3; ● -4,5; ■ -6,7,8

NOTES: Map constructed by combining areas of abundance (i.e., major adult areas and major adult concentrations) frOm maps of species indicated Boundaries have been smoothed Areas depict the number of Individual species with relatively high abundance; they do not necessarily reflect the distribution of total biomass

Species included: Small Crangonid Shrimp *(Crangon communis, C. dalli),* Large crangonid shrimp *(Argis dentata, Sclerocrangon boreas),* Northern Pink Shrimp, Korean Hair Crab, Red King Crab, Golden King Crab, Blue King Crab, Bairdi Tanner Crab, Opilio Tanner Crab, Chalky Macoma, Greenland Cockle, Iceland Cockle.

SOURCE: Strategic Assessment Branch, NOAA

compiling databases on coastal areas and the Exclusive Economic Zone (EEZ) (see Ch. 7 for more information on this program). These data are being used to develop a series of atlases and can be used to identify potential conflicts among the multiple uses of resources with given offshore areas (see figures 6-3 and 6-4).

SIMILAR EFFECTS IN SHALLOW AND DEEP WATER

Surface Effects

The surface plume created by the rejection or loss of some of the mined material or the disposal of unused material could cause a number of effects on the phytoplankton (minute plant life) community and on primary production.[5] In the short term, reduction of available light in and beneath the plume may decrease photosynthesis. Nutrients originally contained in the bottom sediments but introduced to the surface waters may stimulate phytoplankton productivity. Long-term plume effects from long-term continual mining operations might lead to changes in productivity or changes in species composition.

5A. T. Chan and G. C. Anderson, "Environmental Investigation of the Effects of Deep-Sea Mining on Marine Phytoplankton and Primary Productivity in the Tropical Eastern North Pacific Ocean, *Marine Mining,* vol 3. (1981), No. 1/2, pp. 121-150.

Water Column Effects

High particulate concentrations in the water column can adversely affect the physiology of both swimming and stationary animals,[6] altering their growth rate and reproductive success. Such stresses may lead to a decrease in the number of species,[7] a decrease in biomass (weight/unit area), and/or

6D. C. Rhoads, and D. K. Young, "The Influence on Sediment Stability and Community Trophic Structure, " *Journal of Marine Research, No. 28 (1970),* pp. 150-178.

7R. W. Grigg and R.S. Kiwala, "Some Ecological Effects of Discharged Wastes on Marine Life, *California Fish and Game, No. 56 (1970),* pp. *145-155.*

Photo credit: U.S. Geological Survey

A surface plume of turbidity is produced when a dredge discharges material overboard. The extent, duration, and negative impacts of such a plume depend on the size and composition of the rejected material. Larger particles will settle out quickly and the plume will rapidly disperse. Very fine sediments may remain suspended for several days.

changes in seasonal and spatial patterns of organisms.[8] Eggs and larvae in the mining area will be unable to escape. Most adult fish-the prime commercial species in the water column—are active swimmers and would be able to avoid the area of high particulate concentrations. Nonetheless, a large-scale, long-term mining operation will produce a ' 'curtain' of turbidity (cloudiness due to particulate) in the water column which might interfere with normal spawning habits, alter migration patterns, or cause fish to avoid the mining area altogether.

Heavy metals, e.g., copper, zinc, manganese, cadmium, and iron, may be released into the water column in biologically significant forms from some mining operations. The quantities of dissolved metals generally will be quite low, but current hypotheses suggest that small spatial and temporal differences in metal concentrations regulate the kinds of plankton found[9 10]. Metals could, therefore, cause changes in species composition; such changes have been verified for copper both in the laboratory[11] and at sea. [12] Trace metals may be as important as macronutrients (nitrogen, phosphorus, and silicon) in controlling species composition and productivity in the marine environment, If so, then any large-scale disruptions in the natural metal balance due to mining activities could alter marine food webs. However, our understanding of the role of metals in unpolluted marine environments is currently constrained by the difficulty of measuring such minute quantities.

Benthic Impacts

Little is known about the dynamics of animal communities on the seafloor. There are, however, several possible effects of concern. Animals within the mined area will be destroyed. Large-scale removal of bottom sediments will alter the topography and therefore could affect currents and substrate characteristics, which in turn affect species composition. [13] Benthic plumes from mining devices will cause sedimentation on the bottom-dwelling organisms and eggs in the vicinity. Surface plumes from rejection of some of the mined material will eventually settle over a much wider area and cover animals with a thin layer of sediment. Silt deposits can smother benthic organisms and inhibit growth and development of juvenile stages. [14-19] While the first new colonizing organisms in a mined area probably will be those with the highest dispersal, the direction of succession and final composition of the community is difficult to predict and is likely to be affected by grain size and suitability of the deposited sediment for colonization by benthic invertebrates.

The areas affected by mining will tend to be smaller than those affected by commercial fishing (especially bottom-trawling operations), which also removes large numbers of organisms and may disturb large sections of the seafloor. However, marine mining impacts may be more intense than those of fisheries.

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[8] A. Shar and H.F. Mulligan, "Simulated Seasonal Mining Impacts on Plankton, International Revue Gesamte Hydrobiologie, 62(4) 1977, pp. 505-510.

[9] S. A. Huntsman and W. G. Sunda, "The Role of Trace Metals in Regulating Phytoplankton Growth with Emphasis on Fe, Mn, and Cu, " *The Physiological Ecology of Phytoplankton, 1.* Morris (cd.) (Boston: Blackwell Scientific Publications, 1981), pp. 285-328.

[10] F. A. Cross and W.G.Sunda, "The Relationship Between Chemical Speciation and Bioavailability of Trace Metals to Marine Organisms—A Review, *Proceedings of the International Symposium on Utilization of Coastal Ecosystems: Planning, Pollution, and Productivity, Nov. 21-27, 1982* (Rio Grande, Brazil: 1985).

[11] W H, Thomas and D, L. R. Siebert, "Effect of Copper on the Dominance and the Diversity of Algae: Controlled Ecosystem Pollution Experiment, *Bulletin of Marine Science,* No. *27 (1977),* pp. 23-33.

[12] W. G, Sunda, R .T. Barber, and S. A. Huntsman, " Phytoplankton Growth in Nutrient-Rich Seawater: Importance of Copper-Manganese Cellular Interactions, "*Journal of Marine Research, No. 39 (1981),* pp. *567-586.*

[13] J.S. Gray, "Animal-Sediment Relationships, in *Oceanography and Marine Biology-An Annual Review,* H. Barnes (ed.), No. 12 (1974), pp. 223-262.

[14] W. B. Wilson, "The Effects of Sedimentation Due to Dredging Operations on Oysters in Copano Bay, Texas' (M.S. thesis, Texas A&M University, 1956).

[15] R. S. Scheltema, "Metamorphosis of the Veliger Larvae of Nassarius Obsoletus (Gastropod) in Response to Bottom Sediment, *Biological Bulletin, No. 120 (1961),* pp. 92-109.

[16] G. Thorson, "Some Factors Influencing the Recruitment and Establishment of Marine Benthic Communities, *Netherlands Journal of Sea Research, No. 3 (1966),* pp. 267-293.

[17] Grigg and Kiwala, ' 'Some Ecological Effects of Discharged Wastes on Marine Life.

[18] S. B, Saila, S. D. Pratt, and T.T. Polgar, *Dredge Spoil Disposal* in *Rhode Island Sound,* University of Rhode Island Marine Technical Report No. 2, 1972.

[19] P.S. Meadows and J. 1. Campbell, " Habitat Selection by Aquatic Invertebrates, *Advances in Marine Biology, No.* 10 (1972), pp. 271-382.

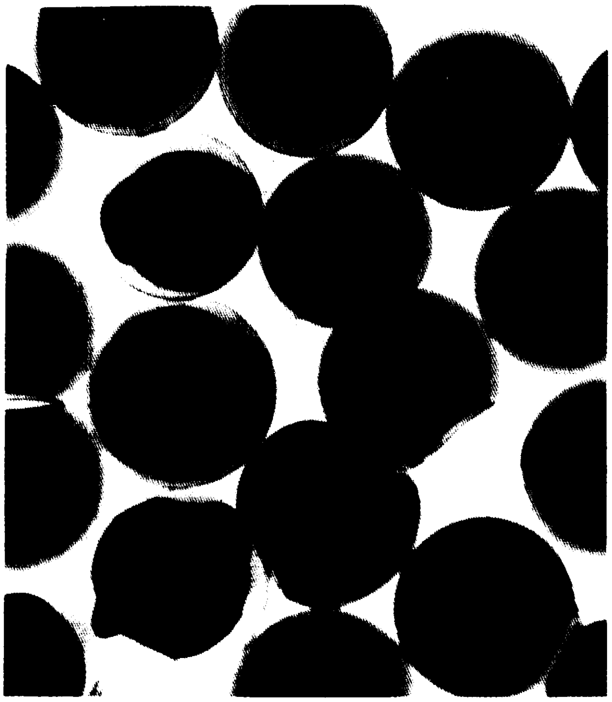

Photo credit" A Crosby Longwell, National Marine Fisheries Service

Atlantic mackerel eggs sorted out of plankton from surface waters of the New York Bight.

Alteration of Wave Patterns

Mining in shallow water may change the form and physiography of the seafloor. Wave patterns may be altered as a result of removing offshore bars or shoals or digging deep pits. When changes in wave patterns and wave forces affect the shoreline, coastal beaches can erode and structures can be damaged. The best example of these dangers occurred in the United Kingdom in the early 1900s when the town of Hallsands in Devon was severely damaged by wave action following large scale removal of offshore sandbars to build the Plymouth breakwater (see photograph). Coastal erosion is now the first consideration in the United Kingdom before mining takes place; dredging is limited to areas deeper than 60 feet. This criterion is based on studies that imply sediment transport is unlikely at depths greater than 45 feet; the additional 15 feet were added as an extra precaution.[20] Current work by the U.S. Army Corps of Engineers suggests that concern with water depth alone may not be sufficient to avoid beach erosion[21 22] and that detailed on-site modeling should be considered in pre-planning analysis. For example, the U.S. Army Corps of Engineers of the New Orleans District built a beach and dune on Grand Isle, Louisiana for erosion control in 1983. The project required 2.8 million cubic yards of sand obtained by digging two large borrow holes one-half mile offshore (about twice this amount was actually dredged to achieve the design section). Shortly after completion, cuspate sand bars began to form on the leeward side of the dredged holes and the beach began to erode adjacent to the newly formed bars. During the winter and spring of 1985, heavy storms exacerbated the areas of beach loss adjacent to the cuspate bars (e.g., see opposite page).[23] This unexpected response of beach formation and erosion as a result of altered wave patterns around the borrow areas illustrates the importance of site-specific assessment before mining large volumes of sediment from the seafloor.

Seasonal

During certain times of the year, e.g., when eggs and larvae are abundant, the effects of offshore mining may have a more negative impact on the ocean community than at other times. Juvenile stages of fish and shellfish are transported by water currents and therefore are less able to actively avoid adverse conditions. They are generally more susceptible to high concentrations of suspended sediments than swimming organisms that can avoid such conditions. For example, striped bass larvae in the Chesapeake Bay develop more slowly when particulate levels are high.[24] Therefore, restricting offshore mining

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[20] R. W. Drinnan and D.G. Bliss, *The U.K. Experience on the Effects of Offshore Sand and Gravel Extraction on Coastal Erosion and the Fishing Industry*, Nova Scotia Department of Mines and Energy, Open File Report 86-054.

[21] Jan Pope, U. S. Army Corps of Engineers, OTA Workshop on Environmental Concerns, Washington, D. C., Oct. 29, 1986.

[22] R. J. Hallermeier, *A Profile Zonation for Seasonal Sand Beaches from Wave Climate*, U.S. Army Corps of Engineers, Reprint 81-3 (Fort Belvoir, VA: Coastal Engineering Research Center, April 1981).

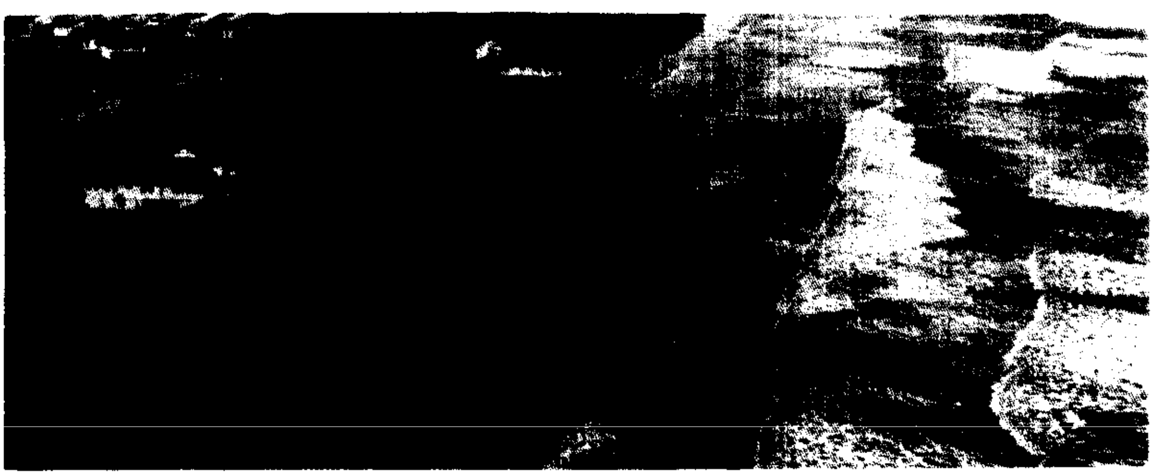
[23] A. J. Combe and C. W. Soileau, "Behavior of Man-made Beach and Dune, Grand Isle, Louisiana," *Coastal Sediment '87, 1987*, p. 1232.

[24] A. H. Auld and J. R. Schubel, "Effects of Suspended Sediment on Fish Eggs and Larvae: A Laboratory Assessment, *Estuarine and Coastal Marine Science, No. 6 (1978)*, pp. 153-164.

Photo credit' Jay Combe, US. Army Corps of Engineers

The U.S. Army Corps of Engineers of the New Orleans District built a beach and dune on Grand Isle, Louisiana for beach erosion control, recreation, and hurricane wave damage protection (Aug. 14, 1984).

The two offshore borrow areas from which the sand was obtained, were of sufficient width, depth, and proximity to the shore to modify wave climate. Over the next 3 years, cuspate sand bars formed in the lee of the borrow pits while erosion occurred adjacent to these bars (Aug. 9, 1985).



A series of hurricanes between 1984-85 severely eroded areas immediately adjacent to and between the cuspate bars destroying total beach and dune fill over one-seventh of the project length (Oct. 28, 1985). Plans to restore and modify the project to improve its resistance to damage in future hurricanes are essentially complete.

seasonally as environmental concerns warrant may protect biota during sensitive stages of development.

Permanently changing the topography of the seafloor may disrupt the spawning patterns of some marine species dependent on a particular substrate type (e. g., salmon and herring).[25]

[25] S.J. de Groot, "The Potential Environmental Impact of Marine Gravel Extraction in the North Sea, " *Ocean Management, No. 5* (1979), pp. 233-249.

DIFFERENT EFFECTS IN SHALLOW AND DEEP WATER

While the potential environmental impacts of mining operations in shallow water are similar to those in deep water, the effects may be more obvious in shallow areas and may have a more direct effect on human activities. Many of the organisms on the continental shelf and in coastal waters are linked to humans through the food chain; decreased animal productivity may have an adverse economic effect as well as an undesirable environmental effect in these nearshore areas (see figure 6-2).

Surface Effects

Surface plumes are of more concern in nearshore shallow water areas than they are in deeper areas. In the open ocean, plankton productivity is lower and populations extend over huge geographic scales. The effects of a localized mining operation on the surface biota, therefore, will be less in the offshore situation. Visual and aesthetic effects from mining operations and waste plumes also will be less apparent far offshore.

Water Column Effects

High metal concentrations can reduce the rate of primary production by phytoplankton and can alter species composition and succession of phytoplankton communities[26] Several factors act simultaneously to reduce the likelihood of adverse effects from metals released during mining operations in shallow water. Water over the continental shelf contains higher concentrations of particulate matter (and organic chelating agents) which convert the dissolved (ionic) metals into insoluble forms that are unavailable to plankton[27] While no studies have yet identified metal contamination of the water column to be a serious consequence of seabed mining, the potential for metal persistence is greater in the deep-sea.

[26] Thomas and Siebert, "Effect of Copper. "

[27] Huntsman and Sunda, "The Role of Trace Metals. "

Benthic Effects

Coastal waters are subject to continual wave action and seasonal changes, and the species found here are adapted to such conditions. The fine particulates stirred by mining operations may be similar to sediment resuspended by strong wave action in shallow water. In coastal areas, surface-living forms have been found to tolerate 2 inches of sediment deposition, sediment-dwelling animals (infauna) 10 to 12 inches, and deeper burrowing bivalves 4 to 20 inches. [28] On the other hand, animals accustomed to the relatively quiescent deep ocean environment may be less resilient to disruption of their habitat or blanketing by particulates. Since deep-sea animals live in an environment where natural sedimentation rates are on the order of millimeters per thousand years, they are assumed to have only very limited burrowing abilities. Thus, even a thin layer of sediment may kill these organisms. *g In general, if the resident fauna on an area of the shallow seafloor are buried, the communit_y will generally recover more quickly than in the deep-sea.

Populations of animals directly within the mining path will be destroyed. Dredged areas in shallow seafloor are buried, the community will recover more quickly than in the deep-sea.

[28] Consolidated Gold Fields Australia Ltd. and ARC Marine Ltd., *Marine Aggregate Project, Environmental Impact Statement,* vol. 1, February 1980.

[29] P. A. Jumars and E.D. Gallagher, "Deep-Sea Community Structure: Three Plays on the Benthic Proscenium, The Environment *of the Deep Sea, Rubey Volume II,* W.G. Ernst and J.G. Morin (eds.) (Englewood Cliffs, NJ: 1982); and P.A. Jumars, "Limits i_n Predicting and Detecting Benthic Community Responses to Manganese Nodule Mining, " *Marine Mining,* vol 3. (1981), No. 1/2, pp. 213-229.

Photo credit: Paul Rodhouse, British Antarctic Survey

Mussels, like many benthic marine organisms, filter their food. Sediments discharged from dredging vessels or stirred up by mining activities may clog feeding and respiratory surfaces of these animals or completely bury populations.

cies.[30 31] Animal populations in fine-grained sediments appear to recover more rapidly than those in coarse-grained sediments, which may require up to 3 years for recovery.[32] Recolonization rates in the deep sea are not known with any certainty, but they appear to be long—on the order of years—in areas not subject to periodic disturbance.[33-36] Deep-sea benthic communities are areas of high species diversity, few individuals, slow recolonization rates, and questionable resilience. Shallow water benthic communities may have either high or low diversity, usually with large numbers of individuals, fast recolonization, and resilience to physical disturbance.

[30] R .T Saucier et al., *Executive Overview and Derailed Summary*, Technical Report prepared for U.S. Army Corps of Engineers Office, Chief of Engineers, Washington, D. C., December 1978.

[31] D. Thistle, "Natural Physical Disturbances and Communities of Marine Soft Bottoms, *Marine Ecology Program Service*, No. 6 (1981), pp. 223-228.

[32] Saucier et al., p. 75.

[33] F. N. Spiess et al. , *Environmental Effects of Deep Sea Dredging*, Report to National Oceanic and Atmospheric Administration, November 1986.

[34] C. R. Smith, ' 'Food for the Deep Sea: Utilization, Dispersal, and Flux of Nekton Falls at the Santa Catalina Basin Floor, " *Deep-Sea Research*, vol. 32, No. 4.

[35] J. F, Grassle, ' 'Slow Recolonization of Deep-Sea Sediment, *Nature, No.* 265 (1977), pp. 618-619.

[36] J. F. Grassle, "Diversity and Population Dynamics of Benthic Organisms, *Oceanus*, No. 21 (1978), pp. 42-45.

SHALLOW WATER MINING EXPERIENCE

Since little mining has taken place offshore of the United States[37], any discussion of the environmental impacts must rely heavily on the European experience. This experience is summarized in the documents of the International Council for the Exploration of the Seas (ICES—see box 6-A). Additionally, the very extensive experience of U.S. Army Corps of Engineers in lifting, redepositing, and monitoring sediments from dredging operations provides insights into the effects of shallow water mining. In particular, the 5-year Dredged Material Research Program (DMRP) (see box 6-B) attempted to cover all types of environmental settings offshore, The information gathered is relevant to the activities involved in mining sand and gravel or placer deposits. Finally, there are two regional efforts—The New England Offshore Mining Environmental Study (NOMES) (see box 6-C), and Sea Grant studies in New York Harbor

[37] There is currently sand and gravel mining in the Ambrose Channel of New York Harbor and a gold mining operation off Nome, Alaska, (see Ch. 5).

Box 6-A.—ICES—International Council for Exploration of the Sea

The International Council for Exploration of the Sea was set up in the mid-1970s primarily because of concerns over the environmental effects of sand and gravel mining in the North Sea. Three reports were issued in 1975, 1976, and 1979. Each report described the current mining operations country by country, as well as the environmental impacts avoided/encountered. The countries participating are the United Kingdom, Netherlands, Denmark, Federal Republic of Germany, France, Sweden, Norway, Ireland, United States, Belgium, and Finland. Based on the accumulated experience, a series of recommendations were drawn up and set out in the second *Report of the ICES Working Group on Effects on Fisheries of Marine Sand and Gravel Extraction*:

Member countries should collect and submit maps for all areas of potential dredging activity showing:
a). the distribution of different types of sediment, bathymetry, etc.
b). relevant fishing grounds, spawning areas, nursery areas, etc.

Additionally, more research on biological, chemical and physical effects was encouraged and the need for an environmental impact statement before prospecting or licensing was highlighted.

The three ICES reports conclude that the method selected for sand and gravel mining determines the direct and indirect impacts to bottom fauna and the final condition of the seafloor. There are three alternative mining methods:

1. Extraction in a restricted area, deep into the seabed, with a stationary hopper dredger; the result will be a deep hole (as much as 230 feet) in the bottom. Such pits will not naturally be backfilled with sediment.
2. Extraction over a wide area with trailing hopper dredgers; this will result in only removal of the top 8 inches.
3. Extraction over a relatively large area with stationary seaworthy dredging equipment; the sea bottom is lowered over the area by about 33-50 feet.

For sand dredging off the Netherlands coast, where sand is found in thick layers, a shallow lowering of the sea bottom over a wide area is preferred[1]. Bottom composition and structure both before and after dredging remain similar. Although there would be destruction of the bottom fauna throughout the area mined, such effects are likely to be temporary. The recovery of the flora and the fauna should occur quickly because the colonizing substrate is unchanged.

If deep excavation is used in water depths greater than 50 feet, the pits will generally not backfill with sand because little transport takes place at these depths. An example of the impacts associated with deep excavation mining exists near the U.K. coast off Hastings, where gravel mining produced a pockmarked landscape in a previously good trawling area; here, bottom-trawling gear can no longer be used.[2]

From the many studies on the effects of marine aggregate dredging, it is evident that initial impacts can vary from minimal to severe and that disruptions range from short to long term. The sensitivity of the area involved determines the impact.

Belgium has adopted the ICES protocol and has designated all of its continental shelf as belonging to one of four zones that control the exploitation and extraction of sand offshore:

- *Zone 1*: Navigation areas. Extraction prohibited.
- *Zone 2*: Fishing Grounds. In view of their importance as spawning and nursery areas, this zone is prohibited for exploitation and extraction.
- *Zone 3*: Southern part of the Belgian continental shelf. Mining allowed when ecological monitoring is carried out.
- *Zone 4*: Northern part of the Belgian continental shelf. Extraction allowed after preliminary monitoring, with continuous ecological monitoring during extraction.

Canada is in the process of developing regulations for offshore mining[3] and is considering similar designations.

[1] International Council for the Exploration of the Sea, Marine Environmental Quality Committee, *Report of the ICES Working Group on Effects on Fisheries of Marine Sand and Gravel Extraction*, (Charlottenlund, Denmark: ICES, 1979).
[2] S.J. de Groot, "An Assessment of the Potential Environmental Impact of Large-Scale Sand-Dredging for the Building of Artificial Islands in the North Sea," *Ocean Management*, No. 5 (1979), pp. 211-232.
[3] David Pasho, Canada Oil and Gas Lands Administration, OTA Workshop on Environmental Concerns, Washington, D.C., Oct. 29, 1986.

Box 6-B.—U.S. Army Corps of Engineers

The U.S. Army Corps of Engineers (COE) maintains over 25,000 miles of navigable waterways that service over 155 commercial ports and more than 400 small boat harbors. About 465 million cubic yards of sediment are dredged each year in the United States; most of this dredging is the result of COE projects that have been approved by Congress. About 30 percent of the material is disposed of in marine environments. The major program addressing environmental effects of dredging and disposal conducted by the U.S. Army Corps of Engineers is the Dredged Material Research Program (DMRP). This work was initiated following congressional authorization for a comprehensive nationwide research program.[1]

The 5-year DMRP Program was completed in 1978 at a cost of approximately $33 million; about 300 reports were produced as a result of this research effort. The project was designed to be applicable nationally with all regions and environmental settings represented. The overall conclusion of the study was that physical effects (such as smothering benthic communities) caused by dumping dredged material were more important than chemical or biological effects. However, these effects were deemed avoidable under guidance for the Section 404[2] and Section 103[3] programs. In general, deep ocean areas were recommended as "more environmentally acceptable" for disposal than highly productive continental shelf areas. Except in unusally sensitive environments (such as coral reefs) or at critical stages in the life cycle of animals (spawning, larval development, and migration), turbidity plumes are "primarily a matter of aesthetic impact rather than biological impact." Benthic communities appear to recover if the grain-size of the sediment remains similar to the original condition after dredging or disposal occurs. Recolonization both of dredged areas and disposal mounds appears rapid for fine-grained sediments (silt) but requires up to 3 years for coarse-grained sediments (sand).

Short-term impacts from dredging and dredge disposal are brief and not of major environmental significance. Long-term monitoring studies still need to be done. In particular, chronic or sub-lethal effects of very long-term mining operations are not known.

[1]Public Law 91-611.
[2]Public Law 92-500, The Federal Water Pollution Control Act, 1972.
[3]Public Law 95-532, The Marine Protection, Research, and Sanctuaries Act of 1972.

(see box 6-D) that examined naturally occurring populations of organisms on the seafloor in the northeastern United States where shallow water mining operations are likely to take place. Guidelines have been established by EPA and the Corps of Engineers (see box 6-E) for testing the impacts of dumping dredged material which may, in turn, provide information about effects of concern from rejected mining material.

The U.S. Army Corps of Engineers reports suggest that concerns about water quality degradation from the resuspension of dredged material are, for the most part, unfounded. Generally, only minimal chemical and biological impacts from dredging and disposal have been observed over the short-term[38]. Most organisms studied were relatively insensitive to the effects of sediment suspensions or turbidity. Release of heavy metals and their uptake into organism tissues have been rare. The conclusion of the Dredged Material Research Program (DMRP) is that ***biological conditions of most shallow water areas—areas of high wave action—appear to be influenced to a much greater extent by natural variation in the physical and chemical environment than they are by dredging or drilling.***

The NOMES and Sea Grant studies corroborate the Corps of Engineer's finding, that in shallow water, there is much natural variation in both the distribution and abundance of species on the unaltered seafloor; these latter studies conclude that ***it is impossible to generalize about the effects of mining on all shallow water environments given the tremendous variability from site to site.*** This conclusion suggests that, if a mined area is compared with an unmined area, changes due to the dredging might not be statistically detectable because either:

- the mining really had a minimal impact, or
- the tremendous variability between sites masked the changes that occurred at the mining site.

[38]R. A. Geyer (cd.), *Marine Environmental Pollution, Dumping and Mining,* Elsevier Oceanography Series 27B (Amsterdam-Oxford, New York: Elsevier Science Publishing Co., 1981).

[Page Omitted]

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Box 6-D.—New York Sea Grant Studies

[illegible] the NOMES conclusion of benthic [illegible] been done on the biology of the benthos in this confined area. [illegible] stations were sampled for macrobiota [illegible] of 1 year (February 1966 to January 1967) [illegible] sampled 78 stations seasonally (1973 only) [illegible].[4] The New York District of the U.S. Army Corps of [illegible] Channel before and after sand borrow dredging operations.[5] [illegible] and Raritan Bay were sampled once to estimate standing stock and diversity.[6] A table [illegible] results of all five surveys, while not formally comparing numbers of [illegible], clearly shows the data sets have little in common. Kastens et al. conclude: [illegible] devices, sampling frequency, and sediment type; the paucity of [illegible] and spatial patchiness of benthos make such a comparison of little value.[3]

In the Raritan Bay, [illegible] to sandy bottoms had markedly different biological communities.[7] [illegible] While both sediment types were low in both density and diversity, [illegible] with only 10 species being reported. However, the Lower Bay has been [illegible] which may contribute to decreased biological activity.[8] [illegible] "far from depauperate."[10] This study identified a third unique community [illegible] area of the Raritan Bay. Differences in biota between dredged and undredged sites in the Lower New York Bay were less than differences from one geographic site to the next.[11]

[3] [illegible] York Harbor, Special Report 15, Reference 78-3, State University of New York, [illegible].

[4] [illegible] 99, 1975.

[5] [illegible] Long Island, New York," NOAA Technical Report [illegible], 1975.

[6] [illegible] of Raritan Bay," *Proceedings, Third Symposium on Hudson River Ecology*, [illegible] Environmental Society.

[7] [illegible] Research Program, Offshore Borrow Area, Results of Phase I-Predredging Studies, [illegible] Corps of Engineers, 1975.

[8] L.A. Walford, *Review of Aquatic* [illegible] *Lower, and Sandy Hook Bays*, report prepared for the [illegible] Laboratory), 1971.

[7] McGrath, "Benthic Macrofaunal Census."

[8] Kastens et al., *Environmental Effects of Sand Mining*.

[9] B.H. Brinkhuis, *Biological Effects of Sand and Gravel Mining in the Lower Bay of New York Harbor: An Assessment from the Literature*, State University of New York, Marine Sciences Research Center, (Stony Brook, NY: January 1980).

[10] Kastens et al., *Environmental Effects of Sand Mining*.

[11] Brinkhuis, *Biological Effects of Sand and Gravel Mining*.

column appears to cause only local and minor reductions in plankton productivity. The abundance and types of species found on the bottom also change.[41] When the substrate type is changed due to the dredging activities (e. g., removal of gravel or a sand layer on top of bed-rock) then adverse effects may be persistent.[42] The benthic communities that are established in the area after removing the top layers may differ significantly from the prior communities.[43]

Of great concern to the European community is the potential detrimental effects of mining on commercial fisheries. Removal of gravel in herring

[41] S.J. de Groot, *Bibliography of Literature Dealing with the Effects of Marine Sand and Gravel Extraction on Fisheries* (The Netherlands: International Council for the Exploration of the Sea, Marine Environmental Quality Committee, 1981); de Groot, "The Potential Environmental Impact of Marine Gravel Extraction in the North Sea."

[42] International Council for the Exploration of the Sea, *Second Report of the ICES Working Group on Effects on Fisheries of Marine Sand and Gravel Extraction*, Cooperative Research Report No. 64, (Charlottenlund, Denmark: ICES, April 1977); International Council for the Exploration of the Sea, Marine Environmental Quality Committee, *Report of the ZCES Working Group on Effects on Fisheries of Marine Sand and Gravel Extraction*, (Charlottenlund, Denmark: ICES, 1979).

[43] A. P. Cressard and C. P. Augris, "French Shelf Sand and Gravel Regulations," *Proceedings of the Offshore Technology Conference*, OTC 4292, 1982.

Box 6-E.—EPA/COE Criteria for Dredged and Fill Material

Section 103 of the Marine Protection, Research, and Sanctuaries Act of 1972, Public Law 92-532, specifies that any proposed operation involving the transportation and dumping of dredged material into ocean waters must be evaluated for potential environmental impact. The responsibility rests with the Secretary of the Army and the Administrator of the Environmental Protection Agency (EPA) acting cooperatively with the District Engineer and Regional Administrator. Environmental evaluations must follow criteria published by EPA in the *Federal Register*, vol. 42, No. 7, January 11, 1977. Techniques such as bioassays and bioassessments are emphasized as tools for estimating the potential for environmental impact.

It is possible that offshore sand and gravel extraction, placer mining, and phosphorite extraction will be excluded from detailed biological assessment under the exclusion of paragraph 227.13b.[1] Dredged material that does not meet these conditions must receive "a full technical evaluation for potential environmental impact." The procedures emphasize biological effects of possible contaminants. Dredged material is separated into three components for evaluation: a (1) liquid phase and a (2) suspended particulate phase are deemed to have the greatest potential for impact on the water column and are evaluated with this in mind. The (3) solid phase has the greatest potential for impact on benthic organisms, and evaluative emphasis is placed there. For each phase, three species must be used in assessing toxicity of the material.[2]

The *Register* required that a technical implementation manual for the criteria applicable to dredged material be developed jointly by EPA and the Corps of Engineers (COE). This manual contains summaries and discussions of the procedures for ecological evaluation of dredged material, tests to implement them, definitions, sample collection and preservation procedures, evaluative procedures, calculations, interpretative guidance, and supporting references required for the evaluation of permit applications.[3]

[1]Dredged material that meets the criteria set forth below is approved for dumping without further testing: a. It is composed predominantly of sand, gravel, rock, or other naturally occurring bottom material with particle sizes larger than silt, and the material is found in areas of high current or wave energy; [illegible]

[2]These include: one species of phytoplankton or zooplankton, one crustacean or mollusk, and one fish for the liquid bioassay; one species of zooplankton, one crustacean or mollusk, and a fish for the suspended particulate phase; and all benthic organisms—one filter-feeder, one deposit-feeder, and one burrowing species for the solid phase assays.

[3]EPA/COE Technical Committee on Criteria for Dredged and Fill Material, "Ecological Evaluation of Proposed Discharge of Dredged Material into Ocean Waters," Implementation Manual for Section 103 of Public Law 92-532, July 1977, Second Printing, April 1978. [U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS].

spawning areas or on sandbanks where sand eels hide at night adversely affects these fisheries[44]. While direct negative effects of dredging on adult fish stocks has not been clearly demonstrated, these concerns remain. To protect fishing interests, ICES proposed a "Code of Practice."[45] Elements of this code have been adopted by France and the United Kingdom. The code requires that the exact boundaries of the mining area and the amount and thickness of the sediment layer to be removed be specified. In addition, the expected condition of the seabed after completion of dredging operations must be described, including the amount of gravel remaining to enable herring to spawn.

[44]It is still not known why herring select a specific spawning ground or what the selection criteria are for sand eel (Ammodytes) in their choice of a specific bank in which to dig.

[45]International Council for the Exploration of the Sea.

From the U.S. and European work discussed above, it appears that there are three ways to minimize the environmental effect of mining operations in near-shore areas, namely:

1. identify and avoid environmentally sensitive areas with regard to biota, spawning areas, migration, currents, coastline erosion, etc.;
2. where mining does occur, use dredging equipment that minimizes destruction of the bottom as well as production of both surface and bottom particulate benthic plumes; and
3. effectively restore the site to its original premining condition—mine and "reclaim" the area by smoothing seafloor gouges and replacing removed sediment with a similar type and grain-size. (Note: While this option may be feasible in certain cases, it is expensive and energy-intensive. Because little information

Photo credit' Southern California Coastal Research Project Authority

Coastal regions are the most biologically productive areas of the ocean. Because offshore mining is most likely to occur here first, care must be taken to avoid areas important for fisheries.

exists on reclamation, this option will not be considered below.

Information from many existing environmental studies[46-51] can be combined to characterize the areas of prime ecological concern. Dredging and mining operations can then avoid prime fish and shellfish areas especially during times of reproduction and migration. The OTA Workshop on Environmental Concerns stressed that a compendium of such information should be developed; currently, there are many sources of data[52] housed in different agencies or institutions, but it is difficult to compare or combine them.

Historically, the dredging industry has emphasized increasing production rather than reducing sediment in the water column or minimizing damage to the environment. Information on particulate levels and other effects caused by different dredge designs exists (see table 6-l). U.S. Army Corps of Engineers field studies indicate that the butterhead dredge produces most of its turbidity near the bottom, as does the hopper dredge with-

[46]National Ocean Service, Office of Oceanography and Marine Assessment, Ocean Assessments Division, Strategic Assessments Branch, ***Coastal and Ocean Zones, Strategic** Assessment: Data Atlas.* The atlases consist of maps covering a range of topics on physical and biological environments (geology, surface temperatures, and aquatic vegetation); living marine resources (species of invertebrates, fishes, birds, and mammals); economic activities (population distribution and seafood product ion); environmental quality (oil and grease discharge); and jurisdictions (political boundaries and environmental quality management areas) The *Eastern United States Atlas (125* maps) was published by the Department of Commerce in 1980; it is now out-of-print. The *Gulf of Mexico Atlas* (163 four-color maps) was printed by the U.S Government Printing Office in 1985. The *Bering, Chukchi, and Beaufort* Seas *Atlas* (127 maps) will be printed early in 1987 The *West Coast and Gulf of Alaska Atlas* is scheduled for 1988 publication. A national atlas of 20 maps on the health and use of coastal waters of the U.S. is also being produced by NOAA. The first five arc. *Ocean Disposal Sites, Estuarine Systems, Oil Production. Dredging Activities,* and NOAA's *National Status and Trends Program* Future maps arc scheduled on hazardous waste sites, marine mammals, fisheries management areas, and other similar topics.

[47]U.S. Department of the Interior, Fish and Wildlife Service *Biological **Services** Program*: ''Gulf Coast Ecological Inventory, User's Guide and Information Base,'' August 1982; " Pacific Coast Ecological Inventory, User's Guide and Informat ion Base, October 1981; and ' 'Atlantic- Coast Ecological Inventory, User's Guide and Informat ion Base, September 1980.

[48]Marine Ecosystems Aria]}, sis Program (MESA), New York Bight Atlas Monograph Series, New York Bight Project, New York Sea Grant Institute, Albany, 1975, especially Monographs 13-15 (' 'Plankton Systematic and Distribution T. Malone, " Benthic Fauna by J.B. Pearce and D. Radosh, and "Fish Distribution" M.D. Grosslein and T.R. A. Zarovitz'').

[49]U.S. Department of the Interior, Minerals Management Service, " Proposed 5-Year Outer Continental Shelf Oil and Gas Leasing Program, Mid-1987 to Mid-1992, " *Final Environmental Impact Statement,* Volumes I and II, January 1987. There are 22 planning areas for oil and gas development within the U.S. For each area, information bas been collected on biological species, geologic and chem ical conditions, physical oceanography, and soc io-econom ic condit ions. About $400 million has gone into the Environmental Studies Program since 1973. Hundreds of paper-s and reports have been published as a result; these are listed and summarized in *En vironmental Studies Index, OCS* Report 86-0020, U.S. Department of the Interior, Minerals Management Service,1986.

[50]B L. Freeman and L.A. Walford, *Anglers ' Guide to the United States Atlantic Coast, Fish, Fishing Grounds and Fishing Facilities,* prepared for the U.S. Department of Commerce, Seattle, WA, July 1976.

[51] Scripps Institution of Oceanography, *California Cooperative Oceanic Fisheries In\'estimations (CalCOFI),* A-027. The distributions of species in the California Current Region are mapped in a 30-volume atlas series. This series is one of the few long-term monitoring studies of a large region; records are available from 1949 to the present clay.

[52]Besides th, large studies cited here, there arc many regional, state, and local studies.

Table 6-1.—Environmental Perturbations from Various Mining Systems

Mining method		Seabed					Water column	
Mining approaches	Mining systems	Fragmentation/ collection	Excavation	Turbidity plume	Resedimentation	Subsidence	Suspended particulate	Dissolved substances
Scraping	Drag line dredge	•		•	•		•	•
	Trailing cutter suction dredge	•		•*	•*		•*	•
	Rock cutter section dredge	•		•	•		•	•
	Crust-miner	•		•	*		•	•
	Continuous line bucket	•		•	•		•	•
	Clams shell bucket		•	•	•		•	•
	Bucket ladder dredge		•	•	•		•	•
	Bucket wheel dredge		•	•*	•*		•*	•
Excavating	Anchored suction dredge		•	•*	•*		•*	•
	Cutterhead suction dredge		•	•	•		•	•
	Drilling and blasting		•*					
Tunneling beneath seafloor	Shore entry					•		
	Artificial island entry					•		
Fluidizing (sub-seafloor)	Slurrying					•		
	Leaching							

“ Applicable or potentially applicable.
“ •Relative major perturbation.

SOURCE: *Environmental Effects Document* prepared by U.S. Department of the Interior Regulatory Task Force for Leasing of Minerals Other than Oil, Gas, and Sulphur In the Outer Continental Shelf, unpublished draft, October 1986.

out overflow. The bucket dredge and the hopper dredge with overflow, however, produce suspended sediments throughout the water column. The modified dustpan dredge appears to suspend more solids than a conventional butterhead dredge .[53]

A typical bucket dredge operation produces a plume of particulate extending about 1,000 feet downcurrent at the surface and about 1,600 feet near the bottom .[54] In the immediate vicinity of the operation, the maximum concentration of sediment suspended at the surface should be less than 500 mg/l and should rapidly decrease with distance. Water column concentrations generally should be less than 100 mg/l.[55] When mining stops, the turbidity plume will settle rapidly.

The dispersion of a turbidity plume can be effectively altered by the configuration of the pipeline at the point of discharge (see figure 6-5).[56] Pipeline angles that minimize water column turbidity (e.g., with a 90-degree angle) produce mud mounds that are thick but cover a minimum area. Conversely, those that generate the greatest turbidity in the water column disperse widely and produce relatively thin mud mounds of maximum areal extent .[57]

Many parameters, such as particle settling rates, discharge rate, water depth, current velocities, and the diffusion velocity, all interact to control the size and shape of the turbidity plume. As water current speed increases, the plume will grow longer. As the dredge size increases or particle settling rates decrease, the plume size will tend to increase[58]. Finally, with lower rates of dispersion or particle set-

[53] For more information on dredge designs, see Ch. 4.

[54] W. D, Barnard, *Prediction and Control of Dredged Material Dispersion Around Dredging and Open Water Pipeline Disposal Operations*, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, Technical Report DS-78-13, August 1978.

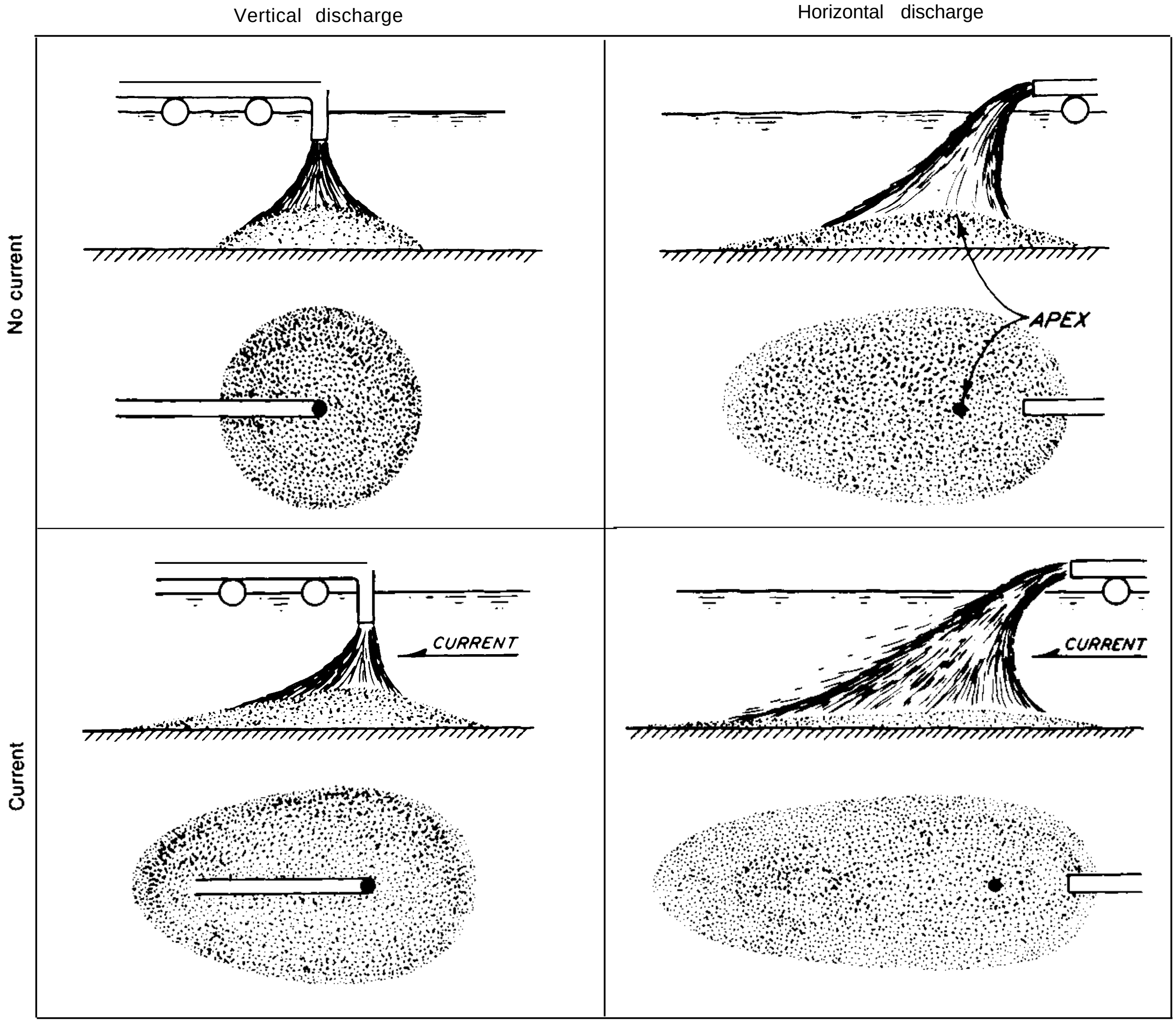
55 Sediment suspended b, a dredge is similar to the amount of disturbance produced by a small-scale storm.

[56] J. R. Schubel *et al.* , *Field Investigations of the Nature, Degree, and Extent of Turbidity Generated by Open Water Pipeline Disposal Operations* , U.S. Army Engineer Waterways Experiment Station, Technical Report, Vicksburg, MS, D-78-30, July 1978.

[57] A general rule of thumb is that, as the height of the redeposited mound *decreases* by a factor of two, the areal coverage *increases* by a factor of two. But as the mound height decreases, the amount of wave-induced resuspension of the surface material will also decrease.

[58] In addition, as the diffusion velocity increases for a given current velocity, the plume becomes longer and wider, while the solids concentrations in the plume decrease.

Figure 6-5.—The Effect of Discharge Angle and Water Current on the Shape and Depth of Redeposited Sediments



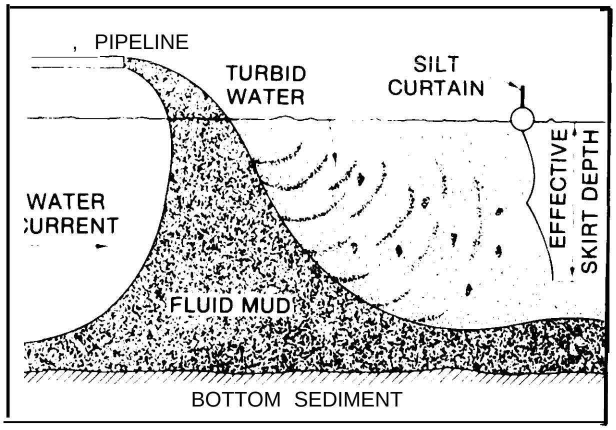
If mining ships discharge unwanted sediments through a vertical pipe (left portion of diagram) seafloor deposits will cover a smaller area but to a greater depth than if a horizontal discharge pipe is used (right side of diagram) which results in a large but thin "footprint" of sediments. The movement of water current (bottom of diagram) will similarly expand the area of the seafloor blanketed by sediment but decrease the depth of the deposit overall.

SOURCE: Modified from W. Barnard, "Prediction and Control of Dredged Material Dispersion Around Dredging and Open Water Pipeline Disposal Operations," U.S. Army Corps Engineer Waterways Experiment Station, Vicksburg, MS, Technical Report DS 7S-13, August 1979.

tling or an increase in water depth, the length of time required for the plume to dissipate after the disposal operation has ceased will increase.

One method for physically controlling the dispersion of turbid water is a "silt curtain. " (see figure 6-6). A silt curtain is a turbidity barrier that extends vertically from the water surface to a specified depth around the area of discharge. At present, silt curtains have limited usefulness; they are not recommended for "operations in the open ocean, in currents exceeding one knot, in areas frequently exposed to high winds and large breaking waves, or around hopper or butterhead dredges where fre-

Figure 6-6.—Silt Curtain



SOURCE: Modified from US. Army Corps of Engineers, "Executive Overview and Detailed Summary," Synthesis of Research Results, DMRP Program, U.S. Army Corps Engineer Waterways Experiment Station, Vicksburg, MS, Technical Report DS 78-22, December 1978.

quent curtain movement would be necessary.[59] Once environmental effects are better defined, engineering techniques can be developed to address them. For example, Japanese industry has developed a system that may reduce turbidity in the surface layers of the water column when sediment is discarded. Air bubbles entrained in the water during dredge filling and overflow exacerbate the surface turbidity plume associated with hydraulic hopper dredging. A system, called the "Anti-Turbidity Overflow System" employed by the Ishikawajima-Harima Heavy Industries Company, Ltd., (IHI) reportedly separates air from the water prior to overflow. According to IHI data, the result is a clear water column and, presumably, a smaller area of fine sediment at the dredge site caused by particles that settle rapidly.

[59] Barnard, *Prediction and Control of Dredged Material Dispersion*, p. 87.

DEEP WATER MINING STUDIES

In the deep-sea, the abundance of animal life decreases with increasing depth and distance from land. Deep-sea animals are predominantly restricted to the surface of the seafloor and the upper few inches of the bottom. Species, especially smaller-sized organisms, are incompletely catalogued at present, and little information is available on their life cycles. The density of animals is low but diversity may be high. In these regions, the low total number of animals is thought to reflect the restricted food supply, which comes from either residues raining into the deep sea from above or from ***in situ*** production.[60]

All estimates of the environmental impacts of deepsea mining draw heavily on information from the Deep Ocean Mining Environmental Study (DOMES), the only systematic long-term research program conducted in very deep water. Justification for extrapolating from these deep-sea sites to others rests on the hypothesis that, in general, the abyssal ocean is a much more homogeneous environment than shallow water environments.

DOMES: Deep Ocean Mining Environmental Study

DOMES was a comprehensive 5-year (1975-80) research program funded by NOAA. The goal was to develop an environmental database to satisfy the National Environmental Policy Act requirements to assess the potential environmental impacts of manganese nodule recovery operations.[61] During the first phase of DOMES, the environmental conditions in the designated manganese nodule area of the Pacific Ocean (i. e., the DOMES area) were characterized to provide a background against which mining-produced perturbations could be later compared. These baseline studies were carried out at three sites that covered the range of environmental parameters expected to be encountered during mining (see box 6-F).

The mining scenario presumed removal of nodules from the deep seabed by means of a collector (up to 65 feet wide) pulled or driven along the seabed at about 2 miles per hour. Animals on the

[60] Deep-sea biomass often correlates with primary productivity above; areas beneath low productivity subtropical waters may be an order of magnitude lower in biomass per unit area than at high latitudes.

[61] U.S. Department of Commerce, NOAA Office of Ocean Minerals and Energy, *Deep Seabed Mining, Final Programmatic Environmental Impact Statement, vol.* 1, (Washington, D. C.: Department of Commerce, September 1981).

Box 6-F.—Deep Ocean Mining Environmental Study (DOMES)

The objectives of the first phase of the DOMES program were:

1. to establish environmental baselines at three sites chosen as representative of the range of selected environmental parameters likely to be encountered during nodule mining,
2. to begin to develop the capability to predict potential environmental effects of nodule mining, and
3. to contribute to the information base available to industry and government for development of appropriate environmental guidelines.

Field work associated with the studies included upper water layer measurements of currents, light penetration, and plant pigments and the primary productivity, abundance, and species composition of zooplankton and nekton. Temperature, salinity, suspended particulate matter, nutrients, and dissolved oxygen were measured throughout the water column. Current measurements were also made in the benthic boundary layer. Abundance and distribution of benthic populations and characteristics of the sediments and pore water were determined. In addition, the seasonal and spatial variability of chemical and biological parameters at four oceanographic depth zones were studied:

1. the surface mixed layer,
2. the pycnocline,
3. the bottom of the pycnocline to 1,300 feet, and
4. 1,300 to 3,300 feet—were characterized for future comparison with measurements made during actual mining activities.

The second phase of the DOMES project focused on refining predictive capabilities through analysis of data acquired during pilot-scale tests of mining systems. Two successful pilot-scale mining tests were monitored in 1978, one using both hydraulic and air-lift mining systems, and one using air-lift only. Each test saw hundreds of tons of manganese nodules brought from water depths of 13,000 to 16,400 feet to the surface. These tests established the engineering feasibility of deepsea mining, provided the first opportunity to observe actual effects of operations such as those envisioned for the next decade, and allowed comparisons of those effects with earlier estimates of mining perturbations. During these tests, discharge volumes, particulate concentrations, and temperature were measured from each mining vessel; limited studies were made of the surface and benthic plumes; and biological impact assessments were made. The second phase of DOMES consisted of monitoring actual pilot-scale mining simulation tests. Its objectives were:

- to observe actual environmental effects relevant to forecasting impacts, and
- to refine the database for guideline development.

SOURCE: U.S. Department of Commerce, NOAA, Office of Ocean Minerals and Energy Deep Seabed Mining, Final Programmatic Environmental Impact Statement, vol. 1, September 19s1.

seafloor directly in the mining path or nearby would be disturbed by the collector and the subsequent sediment plume. In addition, when the nodules reached the mining ships, the remaining residue (consisting of bottom water, sediments, and nodule fragments) would be discharged over the side of the ship, resulting in a surface discharge plume that might also cause adverse impact.

The Final Programmatic Environmental Impact Statement concluded that of 20 to 30 possible negative impacts (see table 6-2) from deepsea mining, only 3 were of sufficient concern to be investigated as part of the 5-year research plan required by the 1980 Deep Seabed Hard Mineral Resources Act .[62]

[62]Public Law 96-283.

The first of the three important impacts occurs at the seabed. First, the collection equipment will probably destroy benthic biota, an impact which—as in the case of shallow water mining—appears to be both adverse and unavoidable, The degree of disturbance depends upon the kinds of equipment used and the intensity of mining. The affected biota include animals such as sea stars, brittle stars, sea urchins, sea cucumbers, polychaete worms, and sea anemones. NOAA did not identify any benthic endangered species in the area that may be affected by bottom disturbance, Most ***benthic animals*** in the DOMES area appear to be tiny detritus feeders that live in the upper centimeter of sediment and are fed by organic material that falls from upper waters. A worst-case estimate is that the ben-

Table 6-2.—Summary of Environmental Concerns and Potential Significant impacts of Deep-Sea Mining

Disturbance Initial conditions	Physico-chemical effects	Potential biological impacts *(remaining concerns in italics)*	Potential significance of biological impact: Probability of occurrence	Recovery rate	Consequence	Overall significance
collector	• Scour and compact sediments	*Destroy benthic fauna in amount near collector track*	Certain	Unknown [c]	Adverse	Unavoidable* (uncertain significance)
	• Light and sound	Attraction to new food supply	Unlikely	Unknown (probably rapid)	Uncertain	None
Benthic plume	• Increased sedimentation rate and increased suspended matter (“rain of fines”)	• *Effect on Benthos*				
		—Covering of food supply	Likely	Unknown [c] (probably slow)	Adverse	Unknown”
		—Clogging of respiratory surfaces of filter feeders	Likely	Unknown [c] (probably slow)	Adverse	Unknown
		—Blanketing	Certain	Unknown [c] (probably slow)	Adverse	Unknown*
		• Increased food supply for benthos	Unlikely	Rapid [d]	Possibly beneficial	None
	• Nutrient/trace metal increase	Trace metals uptake by • zooplankton	Unlikely	Rapid	No detectable	None
	• Oxygen demand	• Lower dissolved oxygen for organisms to utilize; mortality from anaerobic conditions	Unlikely	Rapid	No detectable effect	None
Surface discharge Particulate	• Increased suspended particulate matter	• Effect on zooplankton				
		—Mortality	Unlikely	Rapid [d]	No detectable effect [b]	None
		—Change in abundance and/or species composition	Unlikely	Rapid [d]	No detectable effect [b]	None
		—Trace metal uptake	Unlikely	Rapid [d]	Locally adverse	Low*
		—Increased food supply due to introduction of benthic biotic debris and elevated microbial activity due to increased substrate	Unlikely	Rapid [d]	Possibly beneficial	None
		• Effect on adult fish	Unlikely	Rapid [d]	No detectable effect [b]	None
		• *Effect on fish larvae*	Uncertain (low)	Uncertain (probably rapid)	Uncertain	Low*
	• Oxygen demand	• Low dissolved oxygen for organisms to use	Unlikely	Rapid	No detectable effect	None
	• Pynocline accumulation	• Effect on primary productivity	Unlikely	Uncertain (probably rapid)	Unknown (probably undetectable)	Low
	• Decreased light due to increased turbidity	• Decrease in primary productivity	Certain	Rapid [d]	Locally adverse	Low
Surface discharge Dissolved substances	• Increased nutrients	• Increase in primary productivity	Very low	Rapid [d]	No detectable effect [b]	None
		• Change in phytoplankton species composition	Very low		No detectable effect [b]	None
	• Increase in dissolved trace metals	• Inhibition of primary productivity	Very low	Rapid [d]	No detectable effect [b]	None
	• Supersaturation in dissolved gas content	• Embolism	Very low	Rapid	No detectable effect [b]	None

[a] Includes characteristics of the discharge and the mining system.
[b] Based on experiments/measurements conducted under DOMES.
[c] Years to tens Of years or longer.
‘Days to weeks.
Uncertain = Some knowledge exists; however the validity of extrapolations is tenuous.
Unknown = Very little or no knowledge exists on the subjects; predictions mostly based on conjecture.
● Areas of future research.
SPM = Suspended Particulate Matter.

SOURCE: Adapted from U.S. Department of Commerce, Office of Ocean Minerals and Energy, *Deep Seabed Mining, Final Programmatic Environmental Impact Statement,* vol. 1 (Washington, DC: September 1963), p. 126.

thic biota in about 1 percent of the DOMES area, or 38,000 square nautical miles, may be killed due to impacts from first generation mining activities. Although recolonization is likely to occur after mining, the time period required is not known. No effect on the water-column food chain is expected.

The second important type of impact identified is due to a benthic plume or "rain of fines' away from the collector which may affect seabed animals outside the actual mining tract through smothering and interference with feeding. Suspended sediment concentrations decrease rapidly, but the plume can extend tens of kilometers from the collector and last several weeks after mining stops. No effect on the food chain in the water column is expected due to the rapid dilution of the plume. However, mining may interfere with the food supply for the bottom-feeding animals and clog the respiratory surfaces of filter feeders (such as clams and mussels). Such effects will involve biota in an estimated 0.5 percent or 19,000 square nautical miles of the DOMES area.

The third impact identified as significant is due to the surface plume. Under the scenario, a 5,500 -ton-per-day mining ship will discharge about 2,200 tons of solids (mainly seafloor sediment) and 3 million cubic feet of water per day. The resulting surface discharge plume may extend about 40 to 60 miles with a width of 12-20 miles and will continue to be detectable for three to four days following discharge. As the mining operation is supposedly continuous (300 days per year), the plume will be visible virtually all the time. Surface plumes may adversely affect the larvae of fish, such as tuna, which spawn in the open ocean. The turbidity in the water column will decrease light available for photosynthesis but will not severely affect the phytoplankton populations. The effect will be well within the realm of normal light level fluctuations and will resemble the light reduction on a cloudy day.

Follow-Up to DOMES:

Research by the National Marine Fisheries Service, under NOAA's five-year plan, concluded that the surface plume was not really a problem due to rapid dilution and dissipation. This study identified another potential adverse effect that previously had not been considered—that of thermal shock to plankton and fish larvae from discharge at the surface of cold deep water.[63] However, except for mortality of some tuna and billfish larvae (the two commercially important fish) in the immediate vicinity of the cold water (4-100 C) discharge, adverse effects appear to be minimal.

Continued study of surface plumes suggests that discharged particulate will not accumulate on the pycnocline.[64] Because new measurements show much of the material discharged settled more slowly than previously thought, the plumes will cover more area.

In June 1983, Expedition ECHO I collected 15 quantitative samples of the benthic fauna in the vicinity of DOMES site C (150 N, 1250 W). These samples were collected for a study of potential impacts on the benthic community of a pilot-scale test mining by Ocean Mining Associates, carried out 5 years earlier. Fauna from the immediate test mining area were compared with fauna from an area

[63] W.M. Matsumoto, Potential *Impact of Deep Seabed Mining on the Larvae of Tuna and Billfishes*, SWFC Honolulu Laboratory, National Marine Fisheries Service/NOAA, prepared for NOAA Division of Ocean Minerals and Energy, NOAA-TM-NMFS-SWFC-44, Washington, D. C., 1984.

[64] J.W. Lavelle and E. Ozturgut, "Dispersion of Deep-Sea Mining Particulate and Their Effect on Light in Ocean Surface Layers, *Marine Mining,* vol *3. (1982), No. 1/2,* pp. 185-212.

Photo credit: National Oceanic and Atmospheric Administration

The box core sampler is a standard tool for studying ocean bottoms. This particular sample, containing manganese nodules, is from the DOMES area. Box cores provide a relatively intact picture of the sediment and animals in the top layers of the seafloor.

far enough away to have been undisturbed. Disturbance to the seafloor was either not extensive enough to produce a statistically detectable difference in community structure from unaltered areas, or recovery had taken place within 5 years.[65] Conclusions were that the test mining was not indicative of an actual mining operation. Future research will include some short-term (30-day) sedimentation studies to try to characterize the response time of benthic animals to plume effects.[66]

Recommendations for future research include:

- studying a much larger mining effort or other similar impact on the benthos,
- sampling at the same sites previously sampled to develop trends over time, and
- evaluating data to detect differences at a community level, not at individual or species levels.

Environmental Effects From Mining Cobalt Crusts

The environmental baseline data that DOMES collected and the conclusions it drew about potential impacts of nodule mining are somewhat applicable to mining cobalt crusts. The environmental setting described from the DOMES area has much in common with proposed crust sites. DOMES stations span the central and north Pacific basins and are in areas meteorologically similar to the Hawaiian and Johnston Island EEZs. The environment studied was typical of the tropical and subtropical Pacific in terms of water masses, major currents, and vertical thermal structure. Species recorded in the water column of the DOMES area are all characterized as having broad oceanic distributions. The settings differ primarily with respect to topography and bottom type. The crusts occur on the slopes of seamounts with little loose sediment, while the nodule mine sites occur on plains carpeted with thick sediments. The two areas consequently differ in their potential for resuspension of sediments.

Baseline benthic biological data collected in the DOMES study area are less analogous to the crust sites than are the water column pelagic data. The chief depth range of interest for crust mining is 2,500 to 8,000 feet. Bottom stations sampled in the DOMES area varied in depth from 14,000 to 17,000 feet. Communities would be different because of the substrate as well as the depth. The DOMES sites consist of soft sediments interspersed with hard manganese nodules; the crusts are hard rock surfaces with little sediment cover. The communities actually living on the manganese nodule hard surfaces may resemble the fauna on the crust pavement because the substrate composition is very similar.

Plume Effects

As part of the Manganese Crust EIS Project, mathematical models were constructed to simulate the behavior of surface and benthic discharges.[67] This effort was based upon extensive modeling of dredged material discharge dispersion conducted for the Army Corps of Engineers' Dredged Material Research Program.[68 69]

Surface Plume.—The DOMES data indicate that a mining plume will increase suspended particulate matter in the water by a factor often. This would effectively halt photosynthesis about 65 feet closer to the surface of the water than normal.

The results of field measurements made during the DOMES program were extrapolated to commercial-scale discharges and it was estimated that the surface plume could reduce daily primary production by 50 percent in an area 11 miles by 1 mile and by 10 percent over an area as large as 34 miles by 3 miles. The shading effect will only persist until the bulk of the mining particulate settle, usually within a period of less than a day. Since it takes phytoplankton 2 to 3 days to adapt to a new light regime, the short-term shading effect of particulates is not likely to affect the light-adaptation char-

[65] Spiess et al., *Environmental Effects of Deep Sea Dredging.*

[66] Ed Myers, NOAA, pers. comm.. OTA Workshop on Evironmental Concerns, October 1986.

[67] E.K. Noda & Associates and R.C.Y. Koh, "Fates and Transport Modeling of Discharges from Ocean Manganese Crust Mining, ' prepared for the Manganese Crust EIS Project, Research Corporation the University of Hawaii, Honolulu, HI, 1985.

[68] B. H, Johnson, 1974, ''Investigation of Mathematical Models for the Physical Fate Prediction of Dredged Material, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, Hydraulics Laboratory, Technical Report D-74- 1, March 1974.

[69] M. G. Brandsma and D.J. Divoky, 1976, "Development of Models for Prediction of Short-term Fate of Dredged Material Discharged in the Estuarine Environment, " Tetra Tech, Inc., Pasadena, CA, Contract Report D-76-5, May 1976.

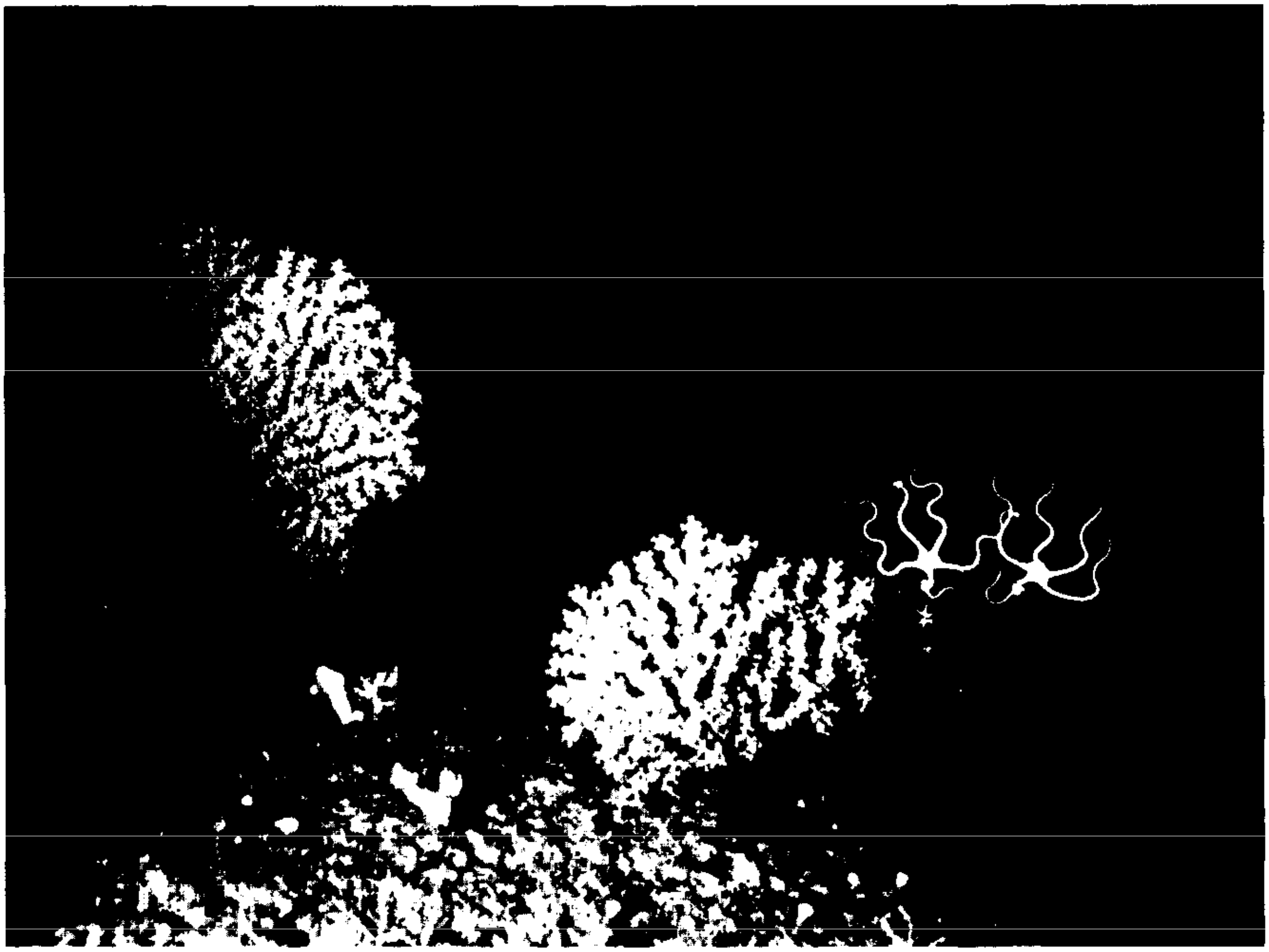


Photo credit: Barbara Hecker, Lament-Doherty Geological Observatory

Brittle stars and corals, shown here at 2,000-foot water depth, are two common kinds of animals living on hard substrates in the deep sea.

acteristics of the phytoplankton. No other potential effects (including increased production due to nutrient enrichment or heavy metal toxicity) could be demonstrated.[70]

Application of the DOMES conclusions to the crust mining scenario requires some modifications. The crust mining surface plume will contain more solids in less water than the nodule mining surface plume, but the crust particles are larger and settle out faster. Thus, the area of reduced primary productivity probably would be approximately 50 percent smaller than that predicted for the nodule scenario, a very short-term localized impact.[71]

Bottom Plume.—A bottom plume would be generated from the movement of the mining equip-

[70] U.S. Department of Commerce, *Deep Seabed Mining, Final Programmatic Environmental Impact Statement.* Minerals Management Service, *Draft Environmental Statement: Proposed Marine Mineral Lease Sale in the Hawaiian Archipelago and Johnston Island Exclusive Economic Zone,* Honolulu, HI, (1987), p. 208.

[71] U.S. Department of the Interior, p. 208.

ment on the bottom and, in an emergency, from release of materials in the lift pipe. Ten hours after suspension, most material will be redeposited within 65 feet of the miner track, but only 1 percent of the smallest particles will be redeposited after 100 hours. From the test mining data, the researchers calculated that about 90 percent of the resuspended material would be redeposited within 230 feet of the miner track, and the maximum redeposition thickness would be a little more than half an inch thick near the centerline of the track. 7.

The crust scenario envisions recovery of about two-thirds of the ore volume of the nodule scenario but assumes a much thinner range of overburden. Peak base-case crust miner redeposition thicknesses were about one-thousandth of an inch. 73 There is a highly significant difference between the two mining scenarios. The "worst case' scenario for crust mining,[74] would result in less than 1 percent of the maximum deposition in the nodule mining scenario.

From the DOMES baseline data (average of 16 macrofaunal individuals/ft^2) and an assumed nodule mining scenario, Jumars[75] calculated that a nodule miner would directly destroy 100 billion individuals. In comparison, data from a case study done at Cross Seamount (see box 6-G) indicate that passage of the crust miner over 11 mi^2 per year would directly destroy from 100,000 to 10,000 macrofaunal organisms at 2,600 and 7,800 feet respectively. The DOMES and Cross Seamount databases differ in that infaunal organisms (those actually living within the sediments) were not sampled in the Cross Seamount reconnaissance. However, the crusts provide little sediment for organisms to inhabit. Nevertheless, it appears that the number of macrofaunal organisms destroyed in the crust mining scenario is orders of magnitude less (one-millionth to one ten-millionth) than in the nodule scenario.[76]

[72] J.W. Lavelle et al. "Dispersal and Resedimentation of the Benthic Plume from Deep-Sea Mining Operations: A Model with Calibrations, *Marine Mining,* vol. *3 (1982), No. 1/2,* pp. 185-212.

[73] U.S. Department of the Interior, Minerals Management Service, p. 197.

[74] Mining at the shallowest depth and superimposition of surface and bottom plume footprints.

[75] Jumars, "Limits in Predicting and Detecting Benthic Community Responses.

[76] U.S. Department of the Interior, Minerals Management Service, p. 240.

The severity of the impacts on populations in areas adjacent to the miner track would be determined by the intensity of the disturbance, i.e., proximity to the track, and the type of feeding behavior characteristic of the population. As in the case with shallow water mining, highly motile organisms such as fish, amphipods, and shrimp would be most able to avoid localized areas of high redeposition and turbidity. Once conditions become tolerable, these organisms could venture into the mined area to feed on the dead and damaged organisms.

The area mined may be invaded by opportunistic species with dispersal capabilities greater than those of the original resident species. Reestablishment of the original community has been postulated to take a very long time, perhaps decades or longer.

Temperature

Comparing the ambient surface water temperature in the lease areas with a temperature of 4 to 10 degrees C for the bottom water released at the surface, there is reason to believe that eggs and larvae coming into direct contact with the cold discharge water could be affected adversely; such effects should be limited to the area immediately beneath the ship's outfall.[77]

To estimate the annual loss of tuna larvae and the impact of this loss on adult fish biomass, it was assumed that all tuna eggs and larvae coming into direct contact with the cold water discharge could die. At least 46,000 skipjack tuna and 15,000 yellowfin tuna could be lost annually due to thermal mortality. These values would be about four times larger if the mining ship acts as a fish aggregating device by concentrating tuna schools in the immediate vicinity.

The loss of adult fish biomass due to death of larvae would be a very small fraction (less than 1 percent) of the total annual harvest of these species in the central and eastern North Pacific. The crust mining scenario assumes a surface plume volume about 60 percent that of the nodule mining scenario, and the effects of thermal mortality of larval fish would be reduced proportionately.

[77] Matsumoto, "Potential Impact of Deep Seabed Mining. " Contact of larvae with cold water could cause the development of deformed larvae.

Box 6-G.—Cobalt Crust Case Study

As part of the present program to assess the environmental impacts of crust mining in the EEZs of Hawaii and Johnston Island, a representative area, Cross Seamount, located about 100 miles south of Oahu, Hawaii (at 18° 40 'N, 158° 17 'W), was selected for a comprehensive, biogeological reconnaissance. The study was conducted by the Hawaii Undersea Research Laboratory.

At depths where manganese-cobalt (Mn-Co) crusts were thickest (1,000 to 2,000 m), the biota is unusually sparse, suggesting that larvae may be selectively avoiding crust substrates. More research will be required to substantiate this hypothesis. The depauperate nature of the benthic fauna of Cross Seamount, if representative of other Hawaiian seamounts, suggests that environmental impacts of possible future mining of Mn-Co crusts in such environments would be negligible, at least in terms of benthic species populations.[1]

In general, the fauna of Cross Seamount is patchy, low in diversity and only a few species of commercial importance were seen. At depths of 1,300 feet to about 3,300 feet the fauna were about an order of magnitude more abundant than the fauna from 3,300 to 13,500 feet. The density of organisms in the upper depth interval (less than 1,000 feet) was about 8 organisms/ft^2, approximately 3 times that in the second interval (1,300 to 1,650 feet). From 1,650 to 2,000 feet density declined markedly to about 1 organism/ft^2. Again, from 2,000 to 2,300 feet density decreased to about one organism per 312 ft^2.

Most of the organisms encrusting manganese crusts are relatively small (less than two-thousandths of an inch long) and cannot be identified in bottom photographs. The observed fauna is overwhelmingly composed of various types of sessile, suspension feeders. Estimates of infaunal organisms are not included, and highly mobile organisms may be under-represented in the data due to avoidance of the camera.

Detrimental Effects of Mining

1. Direct destruction of precious coral and deep-sea shrimp populations, squid eggs, or their respective habitats by the miner or subsequent sedimentation of discharged materials.
2. A reduction in bottom habitat of 11 mi^2/year at mining sites.
3. Destruction of between 10,000 (at 7,900 feet) and 100,000 (at 2,600 feet) epibenthic macro-organisms at mine sites.
4. Effects on groundfish or pelagic fish adults or larvae from turbidity plumes generated above the bottom by mining or at the surface from shipboard dewatering operations.
5. A reduction in phytoplankton productivity due to shading by solid particulate matter in the surface discharge plume.
6. Death of plankton and/or pelagic fish larvae due to thermal shock.
7. An elevation in substrate available for bacterial growth in the water column due to particulates in the discharge plume.
8. Possible aggregation of pelagic fishes by the surface mining ship.
9. Minor behavioral disruptions to the endangered humpback whale, the green sea turtle, and resident marine mammals.

[1]U.S. Department of the Interior, Minerals Management Service, *Draft Environmental Impact Statement: Proposed Mineral Lease Sale in the Hawaiian Archipelago and Johnston Island Exclusive Economic Zones*, Honolulu, HI, 1987.

Threatened and Endangered Species

The Endangered Species Act of 1973 (ESA)[78] prohibits "attempts' to harass, pursue, hunt, etc., listed species. The ESA also prohibits significant environmental modification or degradation to the habitat used by threatened and endangered species, as well as any act that significantly disrupts natural behavior patterns.

[78]16 U.S.C. 1531

Living within the general proposed lease area of the cobalt crusts are the endangered Hawaiian monk seal ***(Monachus schauinslandi),*** the endangered humpback whale ***Megaptera novaea gliae),*** the threatened green sea turtle ***(Chelonia mydas), an*** occasional endangered hawksbill ***(Eretmochelys imbricata),*** the threatened loggerhead ***(Caretta caretta), the*** endangered leatherback (Dermochelys ***coriacea)*** and the threatened Pacific ridley ***(Lepidochelys olivacea)*** sea turtles. However, in

Photo credit: U. S. Geological Survey

Deep-sea Hydrothermal vent communities consist of exotic life forms such as these giant tube worms and crabs from the East Pacific Rise.

recognition of these species' presence, the more densely populated areas have been excluded from leasing.

Gorda Ridge Task Force Efforts

In 1983, a draft Environmental Impact Statement was circulated by the Minerals Management Service in preparation for a polymetallic sulfide minerals lease offering in the Gorda Ridge area. Much of the discussions of potential environmental impacts drew from the DOMES work because there was little site-specific information to summarize. In response to concerns that there was too little information to adequately characterize the effects of any prospecting or mining operation, the Gorda Ridge Task Force was set up to augment the draft EIS.

The major research efforts focused on characterization of the mineral resources and led to the discovery of large deposits in the southern Gorda Ridge. However, a series of reports was also prepared by the State of Oregon under the Task Force's oversight summarizing the state of scientific information relating to the biology and ecology of the Gorda Ridge Study Area. The reports included information on the benthos,[79] nekton,[80]

[79] M.A. Boudrias and G. L. Taghon, *The State of Scientific Information Relating to Biological and Ecological Processes in the Region of the Gorda Ridge, Northeast Pacific Ocean: Benthos*, State of Oregon, Department of Geology and Mineral Industries, Portland, OR, Open File Report O-86-6, February 1986.

[80] J.T. Harvey and D. L. Stein, *The State of Scientific Information Relating to the Biology and Ecology of the Gorda Ridge Study Area, Northeast Pacific Ocean: Nekton*, State of Oregon, Department of Geology and Mineral Industries, Portland, OR, Open File Report O-86-7, February 1986.

Box 6-H.-Gorda Ridge Study Results

Plankton

Most work on the study area is now 10-20 years old. No information exists on feeding ecology, secondary production, and reproduction. The phytoplankton community is dominated by diatoms. Many estimates of phytoplankton abundance were made in the 1960's;[1] they indicate productivity in this region is low (e.g., chlorophylla concentration ranges from 0.1-0.8 mg/m^3 throughout the year).

Nekton

Only one species-albacore ***(Thunnus alalunga)*** is commercially fished in the Gorda Ridge Lease area. Larvae and juvenile form of other commercially important species (the Dover and Rex sole) occur within the area. These larvae are far west of the shelf and slope areas where the adult populations live, and their survival and input to the commercial fishery population is unknown. While occurrences of species of fish, shrimps, swimming mollusks (cephalopods), and mammals with the Gorda Ridge area are fairly well-known, their abundances, reproduction, growth rates, food habits, and vertical and horizontal migratory patterns are not.

Benthos

Little is known about the benthos of the Gorda Ridge area. Until recently, these rocky environments were avoided by benthic ecologists because of the difficulty in sampling them. Photographic surveys from the submersibles Alvin (1984) and Sea Cliff (1986) as well as from a towed-camera vehicle behind the S..P. *Lee* (1985) provide most of the benthic information for this area. The Gorda Ridge rift valley animals appear to be primarily filter feeders and detritus feeders. Soft sediment and rocky epifaunal communities appear to differ in species composition; however, quantitative data from controlled photographic transects across the Ridge and taken close to the substrate (3-6 ft. off the bottom) are needed to permit identification of smaller organisms. Non-vent areas may represent several types of environment with some areas of high particulate organic material concentrated by topographic features juxtaposed with off-axis rocky surfaces.

[1]S.G. Ellis, and J.H. Garber, *The State of Scientific Information Relating to the Biology and Ecology of the Gorda Ridge Study Area, Northeast Pacific Ocean: Plankton,* Open-File Report 0-S6-S, State of Oregon, Department of Geology and Mineral Industries (Portland, OR: February 19S6).

plankton,[81] seabirds,[82] and epifaunal and infaunal community structure.[83] The information contained in these reports was collected h-em a variety of sources such as peer-reviewed journals, government investigators, and active researchers, as well as less traditional sources such as fishing records, etc. The reports are useful compendia identifying what baseline information exists for biota at and near the proposed lease area and what missing information needs to be developed before the effects of a mining operation can be fully characterized (see box 6-H).

While active vent sites such as the Gorda Ridge area often contain lush communities of unique species, the MMS has decided it will not lease such areas for mining should they be encountered .8A Thus, their discussion is not included here.

[81]S.G, Ellis and J. H. Garber, *The State of Scientific Information Relating to the* Biology *and Ecology of the Gorda Ridge Study Area, Northeast Pacific Ocean: Plankton,* State of Oregon, Department of Geology and Mineral Industries, Portland, OR, Open-File Report O-86-8, February 1986.

[82]L.D. Krasnow, The *State of Scientific Information Relating to the* Biology *and Ecology of the Gorda Ridge Study Area, Northeast Pacific Ocean: Seabirds,* State of Oregon, Department of Geology and Mineral Industries, Portland, OR, Open File Report O-86-9, February 1986.

[83]A C, Carey, Jr., D.L. Stein, and G. L. Taghon, *Analysis of Benthic Epifaunal and Infaunal Community Structure at the Gorda Ridge,* State of Oregon, Department of Geology and Mineral Industries, Portland, OR, Open File Report 0-86-11, July 1986.

[84]Thus far, none have been found on the Gorda Ridge sites.