The Oregon Placer Mineral Technical Task Force: 
Resources, Management, and Potential Impacts

by

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THE OREGON PLACER MINERAL TECHNICAL TASK FORCE: RESOURCES, MANAGEMENT, AND POTENTIAL IMPACTS

INTRODUCTION

In September 1988, the U.S. Secretary of the Interior and the Governor of Oregon announced the creation of the joint state-federal Placer Minerals Technical Task Force. The group was charged with performing an analysis of the potential economic and environmental aspects of placer mineral mining in the nearshore waters of the southern Oregon coast. The first objective of the task force was to prepare a preliminary feasibility study, which included a geological summary of the mineral resource, an economic evaluation and technology assessment, an environmental review, and recommendations for future studies. In March 1989, I was hired by Oregon State University to prepare a biological and environmental inventory of the living resources in the proposed mining area and to address the potential concerns related to placer-mineral mining. I completed the report, under the supervision of Dr. William Pearcy, Professor of Oceanography, Oregon State University, in December 1989.

Because the locations of a number of surface placer deposits were fairly well known, it was possible to begin to characterize the biological resources and environmental conditions associated with the deposits. The most extensive deposits are located off Cape Sebastian, south of the Rogue River, and in an area near Cape Blanco, just north of the Blanco Reef.

In these same areas, there are diverse marine habitats and resources. For example, the sea stacks, islands, and rocks within the nearshore zone are part of the Oregon Islands National Wildlife Refuge. These rocks and islands are important habitat for sea birds and marine mammals. Other nearby submerged habitats such as rocky reefs, kelp beds, and sandy and muddy bottom sediments are environments for a variety of fish and shellfish species, many of which are important commercially-harvested species.
Much of the existing literature suggests that the effects of an offshore mining project will be short-lived. The high advection in the nearshore zone will rapidly disperse turbidity plumes from mining, and high sediment transport rates will act to smooth out tracks or mounds left behind by the extraction process. However, most studies to date have dealt with the effects of short-term and transient dredging, and their results may not be applicable to a long-term continuous mining operation.

Impacts will also depend on other factors such as the size of the area to be mined and the oceanographic conditions at the proposed site. Information from similar dredging projects or from laboratory studies will only provide partial answers about the potential environmental and biological consequences of a commercial-scale mining operation on the southern Oregon coast. Prior to mining activities, site-specific research and modeling will be required to minimize the risks this type of operation may have on the biological communities and adjacent shoreline areas. Increased turbidity, sedimentation, noise, and general disturbance in the vicinity of sensitive habitats (spawning or nursery grounds, and nesting areas) or during critical periods (larval recruitment and seasonal migrations) are likely to pose the greatest threats.

The report is both a synthesis of existing data regarding the potential effects of offshore placer mining/dredging and a summary of the limited knowledge concerning the living resources off the southern Oregon coast. Within the context of task force responsibilities, the report fulfilled two preliminary objectives: 1) compiling of information about the effects of placer mining on the resources and uses of the nearshore ocean and 2) identifying data gaps. The report also served as a starting point for the planning phase of a biological sampling program carried out during the *Aloha* research cruise in September, 1990.

To provide the context for this report, a review of the offshore mineral resource is presented, followed by a brief description of the current management/policy regime for marine mining at both the federal and state levels. A more detailed explanation of the history and creation of state-federal
ocean minerals task forces in Oregon is also presented. The report itself, *A Preliminary Literature Review of Potential Environmental and Biological Concerns Related to Placer Mining on the Southern Oregon Coast*, is included here as Appendix A, as published in DOGAMI's Open File Report 0-89-12.
Growing interest in Oregon's marine mineral resources has caught the attention of both federal and state agencies within the last decade. Minerals such as chromite, ilmenite, zircon, garnet, magnetite, and gold, the "heavy minerals", are being evaluated for their economic potential. In addition, chromite is also valued for its importance as a strategic mineral. Currently, the United States is heavily dependent on foreign sources for this mineral (U.S. Bureau of Mines, 1986).

Knowledge of similar onshore deposits may provide clues as to the composition and quality of deposits located offshore. However, until more is known about the location, extent, and mineral characteristics of these deposits, the future of ocean mining off Oregon is conjectural.

Heavy minerals have been mined from the beaches and rivers of southwest Oregon in the past. Trace quantities of gold and platinum were mined as early as 1850, and chromite was mined from coastal terrace deposits between Cape Arago and Bandon during the Second World War (U.S. Department of the Interior, 1987). Today, interest has shifted from onshore deposits to offshore deposits. Recent studies identifying the location and concentrations of heavy mineral deposits on Oregon beaches show that there is considerable economic potential for these deposits (Peterson and Binney, 1988; Peterson and others, 1986, 1988).

The sources of these heavy minerals are the igneous and sedimentary rocks that form the drainage basins of southern Oregon and northern California (Kulm, 1988). Minerals are carried seaward by rivers and streams and deposited on the beach, where coastal processes then concentrate them into enriched placer deposits. The continental shelf adjacent to these coastal rivers is believed to contain similar placer deposits that were formed during periods of low sea level (Kulm and others, 1968).

Heavy-mineral deposits on the continental shelf presumably formed by the same processes seen occurring on beaches today. As heavy minerals are deposited on the beach face, they are subject
to wave swash, and sediment transport processes sort the heavier minerals from the lighter ones. Because these heavy minerals are fine-grained, high-density particles, they tend to concentrate on the beach face more readily than larger-grained, low-density particles such as quartz and feldspar, which tend to be transported offshore by wave action (Komar and Wang, 1984). Along with the sorting of minerals on the beach face, patterns of longshore-sediment transport are also responsible for the sorting of minerals. High-energy waves from the strong southwest winds of winter storms result in the deposition of sand and heavy minerals on the south sides of headlands. During the summer, smaller waves approaching from the northwest move sands back to the south, selectively transporting larger grained particles, thus leaving behind concentrations of heavy minerals (Peterson and others, 1988).

Several placer deposits have been located offshore as a result of magnetometer surveys and sediment core surveys. Surface and near-surface core samples of these deposits indicate that heavy minerals range from 10 to 56 percent by weight of the total sample. Chromite, ilmenite, and magnetite make up the bulk of the concentration. The most extensive deposits to date are located off the Rogue River, where heavy-mineral concentrations range from 20 to 30 percent, and in an area off Cape Blanco and the Sixes River, where heavy-mineral concentrations range up to 33 percent (Figure 1). The Rogue River deposit is approximately 37 km long and extends outward from the nearshore zone to depths of 90 m of water. The Cape Blanco deposit is about 13 km long and ranges in depth from 18 m to 55 m of water. It has been suggested that the magnetic anomalies found off the Rogue and Sixes Rivers are caused by mineral deposits having dimensions and mineral characteristics similar to those of deposits located onshore in adjacent beach and terrace deposits (Kulm and Peterson, 1990).

The mineral deposits themselves comprise unconsolidated sedimentary materials buried below varying depths of overburden. The most widely used technology applicable to offshore placer mining is dredging, which consists of excavating the unconsolidated material from the sea floor, raising the dredged material to the surface, and discharging it into a hopper or barge. In the case of
Figure 1. Heavy-mineral concentrations in the sand fraction of surface sediments. From Kulm, 1988.
dredge mining, waste materials, or tailings, are returned to the water after the desired minerals are removed. Similar dredging techniques are currently used by the U.S. Corps of Engineers in routine harbor and channel maintenance operations. To date, no minerals of any type have been dredged commercially offshore from depths greater than 100 m, and very little has occurred at depths greater than 50 m (Office of Technology Assessment, 1987).

A recent assessment of mining technologies applicable to the recovery of heavy minerals off the Oregon coast concluded that a trailing suction dredge would be the most appropriate method (Wetzel and Stebbins, 1990). This type of dredge is self-propelled and will have either a hold or hopper on board to store the dredged material or the dredged material will be loaded onto a tending barge. As the dredge moves along, a slurry of sediment and sea water is suctioned off the sea floor, pumped up through the drag arm, and emptied into the hopper or barge. A series of shallow swaths or trenches will be left behind on the sea floor. Once on board, the dredged material will undergo some degree of mineral concentration. This will be done through the use of mechanical separation devices, such as gravity jugs, spirals, or shaking tables. These methods take advantage of the difference in densities of the dredged materials. The heavier, valuable minerals will be separated from the lighter sand particles. The unwanted materials could be discarded by pumping them down to the sea floor.

Research efforts indicate that heavy mineral deposits do indeed exist on the continental shelf, but detailed information describing the exact location and mineral characteristics of Oregon's offshore placer deposits is lacking. Without such information, economic and mining technology assessments would not be possible, nor would a thorough environmental assessment.
THE MANAGEMENT REGIME FOR OCEAN MINING IN THE UNITED STATES: PRESENT STATUS AND EVOLUTION

THE FEDERAL REGIME

There are two key pieces of legislation that dictate leasing and regulatory authority over the mining of ocean minerals: the Outer Continental Shelf Lands Act (OCSLA) of 1953, and the Deep Seabed Hard Minerals Resource Act (DSHMRA) of 1980. The OCSLA, as amended in 1978, gives the responsibility of leasing areas of the seabed for minerals development to the Secretary of the Department of the Interior (DOI). The Secretary is directed to encourage exploration and development of marine mineral resources in order to achieve national economic and energy policy goals, assure national security, reduce dependence on foreign sources, and maintain a favorable balance of payments in world trade (Smith and MacGillvray, 1988) The DSHMRA grants authority to the National Oceanic and Atmospheric Administration to control the exploration and recovery of marine minerals by U.S. citizens in international waters. In contrast to the OCSLA, the DSHMRA seeks to regulate the activities of U.S. citizens rather than claim jurisdiction over the mineral resource (Office of Technology Assessment, 1987).

EVOLUTION OF THE CURRENT SYSTEM

Federal interest in marine minerals started as an outgrowth of the concern over mineral shortages during and after World War II. In 1945, President Harry Truman declared by Presidential Proclamation, that the U.S. asserted exclusive control and jurisdiction over the natural resources of the seabed and the subsoil of the continental shelf (Executive Proclamation No. 2667). The Executive Order placed the natural resources located on the continental shelf under the jurisdiction of the Secretary of the Interior, pending enactment of legislation. In 1953, Congress implemented the Truman Proclamation with the passage of the Outer Continental Shelf Lands Act. This act authorizes the Secretary of the Interior to lease minerals on the continental shelf beyond the state-controlled territorial sea. (The Submerged Lands Act of 1953 awarded each coastal state jurisdiction over the coastal resources within a 3-mile band seaward of the shoreline.)
Truman's Presidential Proclamation is credited in part with initiating the flurry of maritime claims that occurred in the 1950s. For instance, Chile, Ecuador, and Peru each claimed sovereignty and jurisdiction out to 200 miles and considered the 200-mile zone to be completely under their national control for all ocean uses except the innocent passage of vessels (Alexander, 1983). This action of the U.S. and other countries in extending jurisdiction over the continental shelf led to an international agreement in 1958, the United Nations Convention on the Continental Shelf (United Nations Conference on the Law of the Sea I). This treaty recognized the rights of all coastal nations to explore and exploit natural resources within the continental shelves adjacent to their coasts.

During the next three decades, many nations established Exclusive Economic Zones (EEZ). The EEZ is the area extending 200 miles seaward from coastal shorelines. Nations have sovereign rights over all resources, both living and nonliving, within their EEZs. Today more than 70 countries have established EEZs. The U.S. became the 59th nation to establish its own EEZ when President Ronald Reagan did so by Presidential Proclamation in March 1983 (Executive Proclamation No. 5030) (Figure 2). This action gave the United States jurisdiction over the area adjacent to the Commonwealths of Puerto Rico and the Northern Mariana Islands and all U.S. overseas trust territories and possessions in addition to the seabed adjacent to the 50 United States (Alexander, 1984).

Congress has yet to enact legislation to implement the provisions outlined in the Reagan Proclamation. As a number of other laws and acts refer to national ocean boundaries, the impact of new legislation created to implement the Reagan Proclamation must be carefully considered prior to enactment (Office of Technology Assessment, 1987).

The recovery of minerals from ocean areas beyond the U.S. Exclusive Economic Zone is under the regulation of National Oceanic and Atmospheric Administration (NOAA). The DSHMRA was established as an interim regulatory procedure for ocean mining activities that would eventually be superseded when a Law of the Sea treaty enters into effect for the U.S. (Hildreth and Johnson, 1983).
Figure 2. The Exclusive Economic Zones of U.S. Insular and Trust Territories. Adapted from Office of Technology Assessment, 1987.
The United States has not signed the treaty due in part to the provisions pertaining to the exploitation of mineral resources in areas beyond national jurisdiction (U.S. Congress, 1982).

Under the act, the Administrator of NOAA has authority to issue licenses for the exploration of hard mineral resources and for the commercial recovery of manganese nodules only. Because manganese nodules are primarily located at depths of 4000 to 6000 m (beyond most of the U.S. 200-mile EEZ), the DSHMRA seeks to regulate the mining activities of U.S. citizens outside its jurisdiction rather than claim authority over the mineral resources. The effects of such activities on the environment would be regulated through the completion of an environmental impact statement, which is required prior to the issuance of any license or permit. The OCSLA is far less specific in its treatment of the marine environment (Hildreth and Johnson, 1983).

**JURISDICTIONAL CONCERNS**

The various areas and zones that have been established to accommodate the development of the world's ocean resources have also created a world of confusion for their creators. The OCSLA provides a jurisdictional definition of Outer Continental Shelf as being "all submerged lands lying seaward and outside of the area of lands beneath navigable waters . . . , and of which the subsoil and seabed appertain to the United States . . ." But this concept of the Outer Continental Shelf is easily confused with the physical continental shelf, which is a geologic submarine landform. The establishment of the 200-mile EEZ adds another layer of uncertainty (Office of Technology Assessment, 1987). The EEZ overlays both the jurisdictional Outer Continental Shelf and the geologic continental shelf, although the three seldom coincide exactly (Figure 3). In some areas, the geologic continental shelf extends well beyond the 200-mile EEZ, while in other locations, including Oregon, the shelf falls far short of the 200-mile boundary (Figure 4).

The 1958 Convention on the Continental Shelf provides an internationally accepted, albeit open-ended, definition regarding the seaward extension of the continental shelf. It describes the shelf as extending from the shore to a depth of 200 meters or beyond that limit where the depth of the water
Figure 3. The EEZ extends 200 nautical miles from the coast. Within the EEZ, coastal states have jurisdiction over the resources in the 3-mile Territorial Sea. The continental shelf extends from the shore out to the continental slope. Adapted from Office of Technology Assessment, 1987.
Figure 4. The continental shelf off Oregon falls far short of the 200-mile EEZ outer boundary. Adapted from the Oregon Ocean Management Plan, 1991.
permits the exploitation of natural resources. As written, this definition bases the establishment of an outer jurisdictional boundary on the limits of available technology (Office of Technology Assessment, 1987).

In 1982, the United Nations Convention on the Law of the Sea (UNCLOS III) established another international definition for the continental shelf. Article 76 of the Law of the Sea Convention (LOSC) defines the continental shelf as the "seabed and subsoil of the submarine areas that extend beyond its territorial sea throughout the natural prolongation of its land territory to the outer edge of the continental margin . . ." In cases where the continental margin extends beyond the 200-mile EEZ, LOSC requires that the signatory nations devise a final outer boundary based on formulae for determining where the continental slope meets the abyssal plain. However, because the United States is not a signatory to the LOSC, the limitations imposed by Article 76 do not apply (Office of Technology Assessment, 1987). When considering the overlapping effects of the Outer Continental Shelf, the Convention on the Continental Shelf definition of continental shelf, and the 200-mile EEZ, there is the likelihood that a legal "no-man's land" exists offshore where no U.S. agency has authority (Hildreth and Johnson, 1983).

U.S. POLICY FOR MINERAL MINING
The primary focus of the OCSLA is on oil, gas, and sulphur, but Section 8(k) authorizes the Secretary of the Interior to lease other nonenergy minerals (phosphorite, sand and gravel, cobalt, manganese, etc.) on the outer continental shelf adjacent to the 50 United States. In such cases, the DOI is represented by the Mineral Management Service (MMS). When the law was enacted in 1953, little was known of the mineral resources located on the continental shelf. Scientists were aware of the existence of hard minerals, but the technology for their exploration and recovery was generally not available (Office of Technology Assessment, 1987). Consequently, the resulting statutory, regulatory, and institutional framework that has evolved is oriented towards offshore oil and gas rather than nonenergy minerals (The Oceanic Society, 1985).
In the past, several attempts have been made to develop a marine mineral leasing program. The Bureau of Mines initiated the development of a Marine Mineral Technology Center in 1963 and the U.S. Geological Survey (USGS) proposed a long-range program for mineral resource evaluation and lease management in 1974, but the project was not funded. In 1977, the Directors of the USGS and the Bureau of Land Management recommended that an interagency task force be established to develop policy recommendations for outer continental shelf mineral leasing. Preliminary work was completed, including the realization of the economic potential for seabed minerals; however, no regulations were ever prepared (Smith, Holt, and Paul, 1985).

During this same time, the DOI received a number of inquiries concerning the leasing of nonenergy minerals, but because approved regulations were not in place at the time, the requests went unanswered (Smith, Holt, and Paul, 1985). As the mineral resources on the outer continental shelf gained recognition as having the potential to provide alternate or supplemental sources of minerals essential to the U.S. economy, a program for the development of leasing offshore nonenergy minerals was approved by the Reagan Administration in 1982 (U.S. DOI, 1982).

The President further acted to eliminate barriers to marine minerals development by proclaiming the Exclusive Economic Zone during his 1984 State of the Union Address, and by stating that it would be the policy of the Administration to encourage exploration and development of the mineral resources in the EEZ. This latter action was significant because it provided the basis for the Mineral Management Service's leasing program and regulatory initiative for offshore minerals. The Office of Strategic and International Minerals (OSIM) was established shortly thereafter, and was charged with developing the policy and implementing programs for exploration and recovery of nonenergy minerals from the EEZ (Smith, Holt, and Paul, 1985). The overall goal of the OSIM program is to encourage exploration and development of marine mineral resources to reduce U.S. dependence on foreign sources of strategic and critical minerals, while ensuring environmental protection and encouraging full public and state participation (Smith and MacGillvray, 1988).
NEW POLICY PUT TO THE TEST

Shortly after the Reagan Proclamation, the Secretary of the Interior announced plans to lease a potentially rich polymetallic sulphide site off the coasts of Oregon and California, and cobalt-rich manganese crust sites off Hawaii. In keeping with the newly designed OSIM policy, joint state-federal task forces were created to allow for state input into the decision-making process for consideration of environmental and economic aspects of ocean mining (Smith, Holt, and Paul, 1985).

However, environmental groups, coastal states, and industry representatives questioned DOI's authority to offer these leases under the OCSLA. They claimed that the DOI was misinterpreting the 1958 Convention on the Continental Shelf definition of the continental shelf by using the "exploitability" term. This interpretation would extend DOI's authority out to 200 miles regardless of the location of the geologic continental shelf (The Oceanic Society, 1985). These groups asserted that no U.S. agency has the authority to lease hard minerals or grant licenses to recover such minerals beyond the geologic continental shelf except for NOAA, which has authority to license manganese nodule mining only.

There are a number of deficiencies in the OCSLA that limit the suitability of the DOI for managing hard minerals in either the OCS of the EEZ. The DOI is given little legislative guidance for planning environmental guidelines, coordinating between government agencies, or other administrative details for developing an offshore minerals leasing program under Section 8(k) of the OCSLA (Office of Technology Assessment, 1987). DOI may develop environmental requirements for mining activities, but it does so at its own discretion.

Another point of concern involves mineral leasing off of U.S. possessions and territories. While the Reagan Proclamation extended U.S. jurisdiction over resources out to 200 miles around these areas, it did not grant mineral leasing authority to any agency. The OCSLA does not apply in this case since it grants authority only to the continental shelf adjacent only to the 50 United States.
Therefore, the DOI may not have authority to lease minerals in those areas of the EEZ adjacent to U.S. territories and possessions (Office of Technology Assessment, 1987).

A MOVE FOR A NEW OCEAN MINING POLICY

In 1987, legislation regarding hard mineral exploration and recovery was introduced into Congress as the National Seabed Hard Minerals Act (the Lowry Bill). This bill was designed to deal solely with mineral resources on the outer continental shelf and within the Exclusive Economic Zone. Sponsors of the bill saw the need for a comprehensive research plan that would first map the EEZ and highlight areas that may be potential sites for future minerals development. They also intended that the bill clearly define the roles of the DOI and NOAA, by giving DOI authority over mining code provisions while NOAA would be responsible for ensuring environmental compliance (HR 1260). The Lowry Bill was not passed in 1987. It was redrafted in 1989 but again was not passed. Today, the DOI continues to promote seabed mining under current authority of Section 8(k) of the OCSLA.
OREGON OCEAN MINING LAWS AND POLICIES

In the last 25 years, the body of scientific knowledge regarding the Oregon's marine mineral resources has greatly increased. During this same time, the state has moved forward in developing policies necessary to safeguard Oregon's living ocean resources and in providing a regulatory framework that insures public control over all phases of mineral exploration and development.

Oregon law currently prohibits the exploration and development of hard mineral resources within the state's territorial sea. This action came in response to concerns that significant damage would be done to living ocean resources should marine mining take place (Bradbury, 1991).

AGENCY AUTHORITIES FOR MARINE MINING

DIVISION OF STATE LANDS. The Division of State Lands (DSL) is charged with managing the lands of the state with the objective of providing the greatest benefit to the people of Oregon while practicing sound techniques of land management for the conservation of its resource (Oregon Constitution, Article III, Section 5(2)). In 1987, Senate Bill 606 was passed. The law would allow DSL to enter into contracts with private mining interests for the exploration and development of minerals on submerged state lands. Senate Bill 606 made it clear that DSL could issue only exploration permits since a regulatory program for offshore mining had not yet been established. The law also required that all information collected by the mining companies be turned over to the state. This action was intended to increase the state's base of information regarding marine mineral deposits by encouraging limited industry exploration.

Placer mineral mining would require the removal and disposal of material from the nearshore seabed. Under Oregon's Removal-Fill Law, actions that involve the removal of more than 50 cubic yards of material from submerged lands require a removal permit from DSL. The Director of DSL may issue a permit if it is found that the action is consistent with the protection, conservation, and best use of the state's water resources. The disposal of mined material within Oregon's territorial
sea would require a fill permit, also from DSL. A permit may be issued if it is found that the proposed fill would not interfere with the preservation of use of the state's waters for navigation, fishing, and recreation.

DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES. Regulation of mining activities within the state falls under the authority of the Department of Geology and Mineral Industries (DOGAMI). This agency is responsible for coordinating basic research, data collection, and analysis to improve the understanding of geologic, mineral, and petroleum resources of the state, including those on submerged state lands. Before DSL may enter into a contract or issue a lease, it must first consult with and obtain approval from DOGAMI.

DEPARTMENT OF LAND CONSERVATION AND DEVELOPMENT. Recognizing the values and benefits of resources in the nearshore, the Department of Land Conservation and Development (DLCD) adopted Statewide Planning Goal 19 in 1976. This policy, which governs the use of ocean resources, requires that local, state, and federal activities give priority to the development of renewable ocean resources over non-renewable resources, unless it can be shown that non-renewable resource development can be carried out without damaging renewable ocean resources (DLCD, 1985). If a specific activity is proposed, Goal 19 requires that an inventory providing information on the long-term effects of the proposed activity on the resources and uses of the nearshore ocean be completed prior to any further decision making.

OREGON'S OCEAN MANAGEMENT PLAN

In 1987, the Oregon Ocean Resources Management Act (Senate Bill 630) was passed. This action created the Oregon Ocean Resources Management Program to plan for the "coordinated, comprehensive management of ocean uses and resources off the Oregon coast" (SB 630). The act also established the Oregon Ocean Resources Management Task Force, which was directed by the legislature to develop an ocean resources management plan for the state. Members to the Task Force included state agency personnel, interest group representatives, and members of the public. The plan
was adopted by LCDC and became part of Oregon's coastal zone management program in July 1990 (Oregon Ocean Management Plan, 1991).

The ocean management plan was intended to build on the policies outlined in Planning Goal 19 – to conserve the long-term values of ocean resources by giving priority to renewable resource over non-renewable resources. In the area of marine mining, the task force concluded that additional information about mineral resource and environmental conditions was needed before any decisions on mining are made. In addition, the task force recommended that a five year moratorium be placed on all commercial mineral exploration, that an effects assessment and inventory be completed, and that all mining activities be banned in and around important fishery areas and ecologically sensitive areas regardless of future mining policies (Oregon Ocean Management Plan, 1991).

OREGON'S BAN ON OCEAN MINING
Adoption of the Oregon Ocean Management Plan left the door open to the possibility of marine mining in Oregon's territorial sea, if it could be shown that such activities would not harm the ocean fishery or other renewable resources. Shortly after the Plan went into effect, a research cruise, conducted under the direction of the state-federal Placer Mineral Technical Task Force, found that the study sites in the nearshore zone comprised a "complex of productive and diverse habitats" (DOGAMI, 1991). Members of the scientific community, environmental and citizens groups, and a number of state legislators felt this information showed that clearly, there would be no way to mine the nearshore area and maintain its productivity. Senate Bill 499, which would ban all exploration and development of marine minerals in the territorial sea, was introduced during the 1991 legislative session and was signed into law in July 1991. The law prohibits DSL from entering into contracts for the exploration and development of marine minerals, except in the case of scientific research.
The state of Oregon has taken part in two state-federal interagency task forces dedicated to the assessment of ocean mineral resources. The Gorda Ridge Technical Task Force was created in 1984 in response to the Mineral Management Service's decision to lease polymetallic sulfide deposits off Oregon. The task force held sessions from 1984 through 1987. The Placer Mineral Technical Task Force was created in 1988 as an offshoot of talks about potential placer mining that developed during Gorda Ridge sessions. This task force completed its objective in 1991.

A BRIEF HISTORY

Soon after the establishment of the U.S. Exclusive Economic Zone, the Minerals Management Service sought to exercise lead-agency authority over minerals located there by announcing a proposed lease sale. The lease site focused on the Gorda Ridge and associated seafloor spreading centers within the EEZ, about 125 miles off the coasts of Oregon and California. An earlier lease proposal off the Washington coast was withdrawn after the Canadian government protested that the site lay beyond U.S. jurisdiction (Hildreth and Johnson, 1983).

The draft environmental impact statement (EIS) released by MMS for the proposed leasing area on the Gorda Ridge generated a primarily negative public response, not only from the environmental community, but from the states of Oregon and California and private industry as well. Criticisms were based on concerns related to the economic and strategic rationale for the proposed lease sale, the authority of MMS to lease hard minerals in the Exclusive Economic Zone under OCSLA, and the technical adequacy of the draft EIS (McMurray, 1986). In particular, critics of the draft EIS pointed to a lack of evidence in the actual existence of polymetallic sulfide deposits on the Gorda Ridge, a lack of sufficient baseline information on the proposed lease area, and a lack of appropriate mining technology from which to create a mining scenario and thus assess the potential environmental impacts (McMurray, 1986; Oswalt, 1987). In response to this public reaction, the joint state-federal Gorda Ridge Technical Task Force was formed in February 1984 by a cooperative
agreement between the Secretary of the Interior and the Governor of the State of Oregon. The State of California joined the task force in December 1984.

The task force was made up of members representing the federal government, the State of Oregon, and the State of California. The federal members represent Department of the Interior agencies, and the state members represented academia, private interests, and state agencies. Additional representatives from other federal agencies and academic institutions served as non-voting advisors to the task force.

The task force was directed to assess the mineral resource on the Gorda Ridge, conduct a review of existing data for the proposed lease area, and complete studies related to the need and economics of polymetallic sulfide mining. After reviewing the task force's findings, industry representatives believed it would be premature to move ahead with leasing because there was insufficient information available on the quality, composition, and extent of the deposits. They also emphasized that economic conditions in the industry would have to improve significantly before industry could begin to explore or fund the research required to develop technology needed to recover the mineral deposits. This lack of industry interest towards ocean mining of the Gorda Ridge prompted MMS to publish a notice in the Federal Register in March 1988 withdrawing the draft EIS, and thereby ending consideration of a Gorda Ridge lease sale in the immediate future (McMurray, 1990).

CREATION OF THE PLACER MINERAL TECHNICAL TASK FORCE
During Gorda Ridge Task Force sessions in 1986-87, interest was expressed by industry representatives over the potential development of aggregate and placer minerals in the shallow nearshore waters off Oregon. Heavy mineral deposits had long been known to exist offshore, but the extent and composition of the resource was largely unknown.

sales had been planned; rather, the task force was created in a cooperative effort to evaluate the potential for placer mineral mining.

This task force was also comprised of members and advisors representing state and federal government, academia, and the mining industry. The group was charged with completing an economic and environmental analysis of the possible development of placer mineral deposits offshore southern Oregon. The first objective of the task force was to prepare a preliminary feasibility study to assess the economic potential, technical feasibility, and environmental considerations of a possible mining project. In October 1989, a draft feasibility report was presented for public comment and review. The final report was completed in January 1990 and included a recommendation to the Governor of Oregon and the Secretary of the Interior that preliminary field studies be conducted to answer questions posed by the report.

In September-October 1990, the task force sponsored a research cruise using the MV Aloha. The cruise was designed to identify the distribution, composition, and quality of placer mineral deposits in target areas on the southern Oregon continental shelf, and to collect information on the biological and geologic resources that would contribute to the further understanding of placer deposits (DOGAMI, 1990).

**TASK FORCE RESULTS AND RECOMMENDATIONS**

The mineral assessment portion of the cruise met with limited success. Excellent geophysical coverage of the sites was achieved through the use of magnetometers, seismic profiling, and side-scanning sonar. However, the cruise was unsuccessful in obtaining sufficient core samples to determine the thickness and composition of the deposits due to rough seas and mechanical failure (DOGAMI, 1991). As a result, the full potential of the resource is still unknown. It appears that current sampling technology may not be adequate to answer the questions of how the deposits were formed and how extensive they are. Despite this setback, much useful data were collected in terms of mapping tectonic movement, offshore structures, and sedimentation patterns.
The environmental assessment portion of the cruise was entirely successful. The sampling program confirmed the presence of a highly productive, highly diverse complex of nearshore habitats. Species composition, abundance, and diversity of the sampled sites were found to be similar to other nearshore sites along the Oregon coast. However, the data collected from the cruise represents only one season. Investigators recommend that biological sampling should be performed over a number of years in all seasons to give a more accurate overall picture of the species composition and relative abundance in the study area (DOGAMI, 1991).

Based on the observations and results of the Aloha cruise, the task force concluded that there is no immediate need to continue work on developing Oregon's placer mineral resource and that no further action should be taken at this time (Oregon Placer Minerals Technical Task Force, 1991). Should interest or conditions change, the task force recommended that any future activities related to the exploration and development of placer minerals be managed by a similar interagency, multidisciplinary group in the public interest.
CONCLUSIONS

At present, it appears that there is little likelihood of a placer mining operation occurring offshore Oregon in the near future due to the recent passage of Senate Bill 499. However, if conditions improve in the mineral industry and adequate safeguards to the environment can be assured, another outcome may be possible. In the future, other marine mining activities beyond Oregon's territorial sea will depend in part on the location of the proposed activities. Section 307 of the recently reauthorized Coastal Zone Management Act provides for consistency between federal activities that directly affect the coastal zones of states with approved coastal zone management plans. Renewed federal interest in mineral deposits adjacent to Oregon's territorial sea would be subject to a consistency review by the state's coastal zone management agency, the Department of Land Conservation and Development. According to provisions in both Goal 19 and the Oregon Ocean Management Plan, marine mining in the federal EEZ would be allowed only if it could be shown that the proposed mining activities would not expose Oregon's living marine resources to significant harm.

From this, it is clear that the U.S. is in need of a comprehensive domestic ocean-mining policy. As it stands today, it remains unclear as to which federal agency does or should have the regulatory responsibility for mining of nonenergy minerals in the EEZ. Assuming that the DOI is correct in its assertion that the OCSLA does apply, then that statute is inadequate as it is now written.

Finally, the Placer Minerals Technical Task Force represents a new cooperative approach to developing offshore minerals in Oregon. The creation of such a group promoted coordination between federal agencies, state agencies, state officials, industry, academia, and the public by providing an opportunity to consider the complex issues surrounding ocean mining. The task force format provided the opportunity for open discussion and provided the state with an effective voice in the exploration and development of hard mineral resources. Efforts such as this may be an evolutionary step towards developing management strategies aimed at the regional management of
ocean resources. This interagency design could increase state involvement in establishing ocean-use priorities within the territorial sea as well as within federal waters. By focusing on multiple use rather than single-issue resources, a plan of coordinated regional management headed by an interagency task force could ensure a more balanced resolution of conflicts (Hildreth, 1989). In the future, the task force model may prove to be an effective means of prioritizing and analyzing technical information to be used in support of decisions by policy makers.


The Oceanic Society, 1985, Comments on advance notice of proposed rulemaking for considering the desirability of issuing new regulations for leasing of nonenergy minerals in the outer continental shelf, August 19, 1985, Washington, D.C.


APPENDIX
A PRELIMINARY LITERATURE REVIEW OF POTENTIAL ENVIRONMENTAL AND BIOLOGICAL CONCERNS RELATED TO PLACER MINING ON THE SOUTHERN OREGON COAST

A report prepared for the Oregon Department of Geology and Mineral Industries

by

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OCTOBER 1989
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This report reviews the possible environmental impacts of offshore mining of placer deposits of heavy minerals off the southern Oregon coast. After the introduction, which provides information on the location, geology, and mining scenario of the placer deposits, the report is divided into three major sections. The first discusses the generic impacts of mining based on the available literature. The second reviews the major components of the biological communities found off Oregon and where possible, focuses on living resources that are known to be important in the nearshore environment off southern Oregon, or those that may be affected by mining. The third section is a review of environmental studies of mining operations or dredging projects that may have application to placer mining off Oregon. This section includes a brief review of major findings, followed by detailed appendices of the studies.
ACKNOWLEDGMENTS

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INTRODUCTION

Hard mineral resources located on the continental shelf off southern Oregon are of particular interest for their concentrations of economic metals and minerals such as chromite, ilmenite, zircon, garnet, and gold (Kulm, 1988). Chromite is considered important for reasons of national security, since much of the current U.S. supply is imported from countries whose political climates are anything but stable.

Historically, heavy minerals have been mined from the beaches and rivers of southwest Oregon. Trace quantities of gold and platinum were mined as early as 1850, and chromite was mined from coastal terrace deposits between Cape Arago and Bandon during the Second World War (U.S. Department of the Interior, 1987). Today, interest has shifted from onshore deposits to offshore deposits. Recent studies identifying the location and concentrations of heavy mineral deposits on Oregon beaches show that there is considerable potential for these deposits (Peterson and Binney, 1988; Peterson and others, 1988; Peterson and others, 1986).

The sources of these heavy minerals are the igneous and sedimentary rocks that form the drainage basins of southern Oregon and northern California (Kulm, 1988). These minerals are carried by coastal rivers and streams to the beach, where coastal processes concentrate them into enriched placer deposits. The continental shelf adjacent to these coastal rivers is believed to contain similar placer deposits that were formed during periods of low sea levels (Kulm and others, 1968). Scientists can predict the characteristics of offshore deposits by studying onshore marine terrace and beach deposits.

Heavy-mineral deposits located on the continental shelf presumably formed by the same processes...
seen occurring on beaches today. As heavy minerals are deposited on the beach face, they are subject to wave swash and sediment transport processes that sort the heavier minerals from the lighter ones. Because these heavy minerals are fine-grained, high-density particles, they tend to concentrate on the beach face more readily than larger-grained, low-density particles such as quartz and feldspar, which tend to be transported offshore by wave action (Komar and Wang, 1984). Along with the sorting of minerals on the beach face, patterns of longshore-sediment transport are also responsible for the sorting of minerals. High-energy waves from strong southwest winds of winter storms result in the deposition of sand and heavy minerals on the south sides of headlands. During the summer, smaller wave approaching from the northwest move sands to the south, selectively transporting larger-grained particles, thus leaving behind concentrations of heavy minerals (Peterson and others, 1988).

Several placer deposits have been located offshore as a result of magnetometer surveys and sediment core surveys. Surface and near-surface core samples of these deposits indicate that heavy minerals range from 10 to 56 percent by weight of the total sample. Chromite, ilmenite, and magnetite make up the bulk of the concentration (Kulm, 1988). The most extensive deposits to date are located off the Rogue River, where heavy mineral concentrations range from 20 to 30 percent, and in an area off Cape Blanco and the Sixes River, where heavy mineral concentrations range up to 33 percent (Figure 1). The Rogue River deposit is approximately 37 km long and extends from the nearshore zone to depths of 90 m of water. The Cape Blanco deposit is about 13 km long and ranges in depth from 18 m to 55 m of water (Kulm and Peterson, 1990). It has been suggested that the magnetic anomalies found off the Rogue and Sixes Rivers are caused by mineral deposits having dimensions and mineral characteristics similar to those of deposits located onshore in adjacent beach and terrace deposits (Kulm, 1988; Peterson and others, 1988).

The offshore mineral deposits comprise unconsolidated sedimentary materials buried below varying depths of overburden. The most widely used technology applicable to offshore mining is dredging,
Figure 1. Heavy-mineral concentrations in the sand fraction of surface sediments. From Kulm, 1988.
which consists of excavating the unconsolidated material from the seafloor, raising the dredged material to the surface, and discharging it into a hopper or barge. Waste material or tailings are returned to the water after the desired minerals are removed. Similar dredging technologies are currently used by the U.S. Army Corps of Engineers in routine harbor and channel maintenance operations. Dredging methods were also used to mine the rivers draining the gold fields of southern New Zealand over a century ago. To date, no minerals of any type have been commercially dredged offshore from depths greater than 100 m, and very little has occurred at depths greater than 50 m (Office of Technology Assessment, 1987). Dredging and other ocean-mining technologies are described in detail by the Office of Technology Assessment (OTA) (1987) and Cruickshank and others (1987).

A recent assessment of mining technologies applicable to the recovery of heavy minerals off the Oregon coast concluded that the trailing suction dredge would be the most appropriate method used (Wetzel and Stebbins, 1990). This type of dredge is self-propelled and will have either a hold or a hopper to store the dredged material or the dredged material will be loaded onto a tending barge. As the dredge moves along, a slurry of material and sea water is suctioned off the seafloor, pumped up through the drag arm, and emptied into the hopper or barge. A series of shallow swaths or trenches will be left behind on the seafloor. Once on board, the dredged material will undergo some degree of mineral concentration. This will be done through the use of mechanical separation devices, such as gravity jigs, spirals, or shaking tables. These methods take advantage of the difference in densities of the dredged materials. The heavier valuable minerals such as ilmenite, chromite, and magnetite will be separated from the lighter sand particles. The unwanted materials, or tailings, could be discarded by pumping them back down to the seafloor where they will backfill trenches left by the initial collection process.

Recent research efforts indicate that heavy mineral deposits do indeed exist on the continental shelf, but detailed information describing the exact location and mineral characteristics of Oregon's offshore placer deposits is lacking. Such information is needed in order to assess the feasibility of
their development. A study including detailed seismic and magnetic surveys, along with deep core sediment samples, would be required in order to define the location, mineral content, and extent of placer deposits. Without such information, economic and mining technology assessments would not be possible, nor would a thorough environmental assessment.

Jurisdiction over resources located within 3 nautical miles (5.6 km) of the shoreline was awarded to the State of Oregon by Congress in the Submerged Lands Act of 1953. Further, the Exclusive Economic Zone (EEZ), established by Presidential Proclamation in 1983, is the area extending 200 nautical miles (371 km) seaward from coastal state shorelines. The EEZ guarantees the United States sovereign rights over all seabed resources, living and non-living. The majority of the placer deposits off of Oregon are located within 5.6 km of the shore and subsequently fall under the jurisdiction of state agencies. The agency authorities concerned with the mineral mining and exploration of Oregon's territorial sea have been described by Good and others (1987) and Good and Hildreth (1985). In 1987, the State of Oregon passed legislation to revise existing laws governing mineral leasing on submerged state lands. The Oregon Division of State Lands (DSL) has exclusive authority over both submerged lands and mineral exploration activities. Permits for the exploration of hard minerals on submerged lands are administered by the DSL. Administrative rules for offshore exploration and development of hard minerals are currently being developed by the DSL. Development leases will not be issued until the DSL adopts leasing rules for Oregon's territorial waters. To date, no state or federal exploration permits have been issued for areas off Oregon.
I. POTENTIAL GENERIC IMPACTS OF OFFSHORE PLACER MINING

Marine mining operations may affect various geological, physical, chemical, and biological processes and equilibria in the nearshore zone. Potential impacts of marine mining are presented in Table 1.

PHYSICAL IMPACTS

Coastal Erosion. The mining of offshore mineral deposits will require the removal of large quantities of material from the seafloor. An initial concern over this activity is the possibility of coastal erosion. The nearshore zone is in equilibrium between erosional and depositional processes and any disturbance in this balance could result in changes in sediment distribution (Komar, 1976). The removal of bulk quantities of material from the nearshore zone could result in materials from adjacent areas shifting into the excavated area, thereby causing erosion of the coastline (Rees, 1980). Increases in depth at the excavation site could alter wave patterns or the circulation pattern of tidal currents that affect the rate and direction of the longshore current, the principle agent of sediment transport in the nearshore zone. Any interference in the movement of sediment could result in siltation of harbors or navigation channels, formation of sandbars or spits, or erosion of shorelines, particularly beaches (Owen, 1977).

In the United Kingdom, where sand and gravel extraction operations have been occurring for more than 50 years, there has been little actual evidence of coastal erosion resulting from dredging operations (Hess, 1971). However, several erosional problems of questionable origin have been noted at beaches and nearshore sandbars adjacent to long-term dredging operations. Some beaches have been completely denuded of sand, exposing lattice structures originally designed to retain sand on those stretches of shoreline. Dredging operations may have affected processes conducive to the natural replenishment of sand, while the natural erosional processes continued to transport sand away from the beaches (Hess, 1971).
Table 1. Outline of Potential Generic Impacts from Marine Mining

I. Physical Impacts
   A. Coastal erosion
   B. Navigational hazards (craters, swaths, mounds, etc.)

II. Biological Impacts on the Benthic Environment
   A. Destruction of benthic organisms
   B. Alteration of benthic habitat
   C. Benthic recolonization

III. Biological Impacts on the Pelagic Environment
   A. Increased turbidity, rain of fines
      1. Inhibit photosynthesis/primary production
      2. Interfere with feeding efficiency
      3. Disrupt animal behavior, migratory routes
   B. Reintroduction of substances from the sediment
      1. Anoxic sediments
      2. Nutrients
      3. Trace metals
      4. Toxic compounds (PCBs, pesticides, etc.)

IV. General Disturbance from Mining Operation
   A. Disruption of foraging, resting, breeding areas
   B. Interference with migration patterns, animal distribution

V. Exploration Techniques and Fuel Spills
Although little is known about the effects of ocean dredging on coastal erosion, research has shown that significant wave-induced sediment transport generally occurs at depths of less than 20 m (Crickmore and others, 1972; Swift and others, 1972). Beyond the zone of breaking waves, the water is sufficiently deep that any changes in bottom contours will not appreciably affect the wave energy expended at the shoreline. Gravel mining below this depth is not likely to cause coastal erosion (Baram and others, 1977). The United Kingdom now grants mining permits almost exclusively to regions beyond the 5.6 km limit where minimum depths range from 30 m to 50 m (Hess, 1971). However, detailed site-specific modeling should be performed prior to any dredging operation to fully evaluate the risks to shoreline areas.

Navigational Hazards. Other physical effects of dredging include the formation of depressions and mounds, and other changes in bottom contours due to the extraction process. A clamshell, bucketline, or any type of stationary dredge will cause large pits or craters to be formed in the seafloor. Stationary dredges currently used in sand extraction operations can leave holes in the seafloor up to 20 m deep and 70 m in diameter (Cruickshank and Hess, 1978). Craters of this size may persist for many years and will fill slowly with silt and clays if the water circulation in the area is poor. Under such conditions, these craters may become anaerobic and thus biologically unproductive (Good and others, 1987). A large dredge crater was the focus of a study by the Corps of Engineers in the Long Island Sound. The crater was formed when 334,000 m$^3$ of sand and gravel was removed from the seafloor. Three years later, bathymetric surveys indicated that only 18,350 m$^3$ of material had accumulated in the hole. Analysis of grab samples taken within the crater revealed that the refilled material was mainly silt and clays, although the surrounding material comprised sand and large-grained sediments (Vesper, 1961). A situation such as this is unlikely to occur in the high-energy environment on the inner continental shelf of southern Oregon.

Trailing dredges do not leave large craters; instead they leave behind a series of shallow linear tracks as a result of scraping or suctioning off the top layers of sediment (Cruickshank and Hess, 1978). This method of extraction tends to minimize the effects of altering bottom contours, although a
rough surface will be left behind that may reduce the efficiency of bottom trawls used by commercial fishermen (International Council for the Exploration of the Sea, 1975).

After the mined material is brought on board and processed, the unwanted materials will be disposed of at sea. Mounding or shoaling may occur if such disposal is allowed to take place at any one site over an extended period of time. Such mounds in shallow water could create potential navigational hazards if allowed to persist. Mounding is not likely to occur in the proposed south coast mining area due to the significant rates of sand transport in the high-energy nearshore environment.

The proposed mining dredge for the Oregon south coast will create a single trench approximately 30 m wide. The depth of the trench will depend on the amount of sediment over the deposit and the depth of the deposit itself. At present, it is estimated that the bulk of the recoverable minerals off Cape Blanco are located under 0 to 16 m of sediment overburden, while the average thickness of overburden for the Rogue River deposit is about 20 m (Kulm and Peterson, this volume). The depth of these deposits is currently unknown, therefore it is difficult to calculate the amount of material that will be removed from the seafloor for processing, or the approximate depth of the dredged trenches. Tailings from the on-board processing plant will be pumped down to the seafloor in such a way as to backfill previous trenches thus minimizing the potential for altering the configuration of the seafloor (Wetzel and Stebbins, this volume). The actual mining scenario for the Oregon coast will depend on the nature and location of the offshore deposits.
BIOLOGICAL IMPACTS

During any discussion of potential impacts on marine organisms, one must keep in mind that organisms interact via a complex system of ecological pathways; therefore, changes in one group or trophic level of organisms may affect other groups or trophic levels of organisms. In this way, the potential impacts associated with marine mining may come from secondary or indirect sources.

IMPACTS ON THE BENTHIC ENVIRONMENT

Potential impacts to the benthic community include entrainment, smothering or burial, loss of substrate, and redistribution of benthic populations due to changes in the sediment qualities (grain size, texture, etc.). Each of these impacts could potentially result in changes in the number of species present, species diversity, and density as well as the productivity of the affected area. A temporary reduction in the number of species as well as an overall decrease in the productivity in the affected area. These variations may not be significant ecologically, but if an area is slow to recover, it could have a long-term impact on the ecological pathways in the affected area. The severity of disturbance will depend on the size of the area to be mined, composition of the benthic community (presence of unique or commercially valuable species), seasonal timing of the operation, composition of the resulting substrate, and the rate at which the area will recover from the disturbance (Owen, 1977).

Destruction of Organisms. Any type of mining operation will invariably disturb benthic communities located in the path of the dredging device. Motile organisms may be able to avoid the dredging equipment, while less motile species will be collected along with mined material. In addition to the direct loss of benthos through entrainment, the resettlement of bottom sediments released during the mining process may effectively bury or smother organisms within the zone of deposition.
Elimination of Habitat. Resettlement of sediments could have long-term impacts on the benthos, especially if habitats that do not normally experience heavy sediment loads or are inhabited by long-lived species, are located within the zone of deposition. Such areas may be sensitive to disturbance and slow to recover (Bottom and others, in prep). Feeding and spawning grounds may also be particularly vulnerable to changes in sediment characteristics (texture, grain size, organics content, etc.). Sand and gravel mining in the North Sea has raised particular concern over loss of spawning habitat and benthic food sources for commercially important species (International Council for the Exploration of the Sea, 1975). Many species have specific requirements for spawning substrates, and changes in sediment type could result in the loss of preferred spawning grounds. Some organisms such as crabs may exhibit short-term avoidance of the disturbed area due to a loss of habitable substrate or food sources; however, they also may be attracted into the mined areas as new benthic food sources become available due to the disturbance of bottom sediments during mining. In areas where the repopulation of benthic communities is slow, organisms may move out of the area due to the displacement of a food source. Other commercial fisheries which target bottom dwelling species may also experience decreased catch rates as benthic feeding species move out of the area due to the displaced food source.

Creation of New Habitat. Conversely, changes in the bottom contours from the mining operation could create new types of habitats. Local mounding or shoaling of tailings and depressions created from mining may cause fish to congregate in these areas of relief, especially if a food source is also available (Rounsefell, 1975). Such effects may be short-lived, as the area will be smoothed out due to the natural migrations of sediment in the high-energy environment.

Benthic Recolonization. Benthic organisms residing in the nearshore zone tend to be well adapted to this high-energy environment and the natural erosional and depositional cycles associated with seasonal storms and sediment transport. Although an initial decline in species numbers and diversity will be observed immediately following dredging, recovery is rapid once operations have ceased (Jewett and others, 1989). In a study looking at the biological effects of sand mining off Panama
City Beach, Florida, Saloman and others (1982) found that although the physical environment had been altered and the benthic communities destroyed, recovery was almost immediate for some motile species, and almost complete within one year for dominant groups including annelids, mollusks, and crustaceans. At several sand and gravel mining sites in the North Sea, observations at post-dredged areas found that benthic recolonization began within months of cessation of dredging, and benthic communities similar to the pre-dredging communities were established after two to three years (de Groot, 1986). Macrofauna tend to recover quickly due to their short life cycles, high reproductive rates, and planktonic larval recruitment from unaffected areas. However, the composition of the new community may differ from the pre-mining community depending on the availability of larvae, suitable conditions for settlement, and mortality (Hurme and Pullen, 1988). The new faunal elements may be less-preferred food for other organisms and once established, may be difficult to be displaced by the original community species.

In areas that are periodically disturbed, a stable, diverse community may never be attained. Recolonization studies off Nome, Alaska, have shown that after an initial decline in the benthic population due to the removal of organisms, recolonization of sand substrate is apparent after one year, and a stable community is expected in three to four years; however the species composition of the reestablished community may differ from the composition of the community prior to dredging (Jewett and others, 1989).

Hurme and Pullen (1988) concluded that if the composition of the post-mining substrate is similar to the pre-mining substrate composition, the final long-term bottom profile has similar contours to the original profile, and the relative depths have not been changed greatly, then the removal or addition of layers of sediments will probably not have any long-term adverse effects on the marine benthos.
Turbidity Plumes
Turbidity plumes will be created as the material is collected off the bottom and as tailings are discarded from the ship. Although sediment plumes may be visibly observed for several kilometers, measurable effects from the resettling of suspended material will occur over much shorter distances from the source (Cruickshank and others, 1987). Physical factors influence how long particles remain suspended in the water column and therefore how far from the source they will be deposited. This in turn will determine the specific locations and habitats that may be at risk from the adverse effects associated with the resettling of suspended material (Bottom and others, in prep).

The degree of severity of the turbidity plumes will depend on the methods used in both the extraction process and during tailings disposal. The use of a suction-head type dredge will tend to minimize the amount of sediment released into the surrounding water at the site of collection, while piping tailings down to the seafloor will reduce the amount of material released into the water column adjacent to the dredging site (Demlow and others, 1989). It should be noted that conditions of high turbidity occur naturally in the nearshore environment where high rates of sediment transport are common (Komar, 1976).

Primary Productivity. Any increase in the suspended particle load will interfere with the passage of light into the water column (Lee, 1979). Increased turbidity due to sediment plumes created during mining may promote or inhibit photosynthesis depending on the light and nutrient requirements of each phytoplankton species. A reduction in photosynthetic activity due to a decrease in the available light may occur, or primary productivity may increase due to nutrient enrichment from nutrients released from the bottom sediments disturbed during mining. Either effect could alter the abundance, diversity, and composition of the plankton community. Because photosynthetic phytoplankton comprise the lowest trophic level, reduction of the standing stock of plankton could affect higher trophic levels. However, in all probability, the sediment plume will
have little immediate impact on phytoplankton due to the small area to be mined and the high dilution rate of the nearshore zone.

**Food Ingestion and Assimilation.** Intense turbidity may limit the availability of acceptable food sources, causing ingestion of non-nutritive particles or clogging of feeding mechanisms of filter-feeding organisms in the path of the turbidity plume (Cruickshank and others, 1987). A number of laboratory studies have assessed the lethal limits of suspended particles for a variety of organisms. Sensitivity to high turbidity varies between species and life stages, with larval and juvenile forms being more vulnerable than adult forms (Brinkhuis, 1980). Such studies often use artificial sediments such as Kaolin clay or glass shards to create conditions of high turbidity and do not allow for the behavioral response of avoidance (Lee, 1978). Although these studies have limited applicability to the conditions likely to occur in a real dredging scenario, their results may be useful in identifying those species that are more sensitive to prolonged exposure of suspended particles.

**Behavioral Responses.** Exposure of fishes to high suspended sediment loads will occur in the water column where the discharge plume exists and on the seafloor in the zone of deposition. The response of various fishes to the mining operation can be expected to vary, with some species being attracted to the area while others will avoid the area of increased turbidity. Some fishes may be attracted into the area if new sources of food are made available during the mining process. High turbidity could indirectly affect fish species by reducing the plankton and benthic populations that serve as a food source. It is expected that most fish will avoid the area if the suspended sediment load becomes stressful.

Many organisms respond to light intensity by moving vertically within the water column. Migrating species generally move toward the surface during dusk and away from the surface during dawn (Anikouchine and Sternberg, 1981). Changes in light penetration may disrupt the feeding behavior and success of these organisms by altering patterns of diel migration. A decrease in available light from turbidity could also interfere with the visual feeding of some organisms by inhibiting their
ability to locate food. This reduction in obtainable food sources may cause some organisms to leave
the area in search of food.

Most studies concluded that the impacts associated with increased turbidity would be minimal due
to rapid dilution in open waters, the relatively small area being mined, and the apparent tolerance
of many species to high suspended sediment loads that occur naturally in the nearshore environment
(Cruickshank and others, 1987; Office of Technology Assessment, 1987; Baram and others, 1977).
However, little is known about the long-term effects of a continuous sediment plume. Most research
has focused on the short-term effects of increased turbidity in a laboratory setting or from transient
dredged material disposal operations. During a commercial mining operation, the sediment plume
will be continuously renewed, thus creating a turbidity gradient down-current from the mining site.
Mobile species like fishes may avoid the areas of high turbidity or migrate around them.
Complications arise when species that avoid the area are an integral part of the food chain or are of
commercial value and no longer congregate in traditional fishing grounds (Owens, 1977). Because
of the difficulty of predicting the dispersion pattern of suspended particles, qualitative and
observational approaches will be needed to determine the long-term effects of such a sediment
plume (Baram and others, 1977).

**Reintroduced Substances**

The reintroduction of substances from the sediment can affect the water quality in the dredged area.
Exposure of anoxic sediments to the oxygenated environment of the overlying water column may
initiate a series of chemical reactions resulting in the reduction of dissolved oxygen levels and the
production of hydrogen sulphide in the surrounding water. The pH and redox potential of the
bottom sediments are particularly sensitive to the dissolved oxygen content and strongly influence
the chemical state and bioavailability of nutrients, trace metals, and toxic compounds that may be
present in the bottom sediments (Gambrell and others, 1976). However, due to the nature and
composition of the placer deposits, it is unlikely that such substances will be present.
Nutrients. The release of nutrients such as nitrogen and phosphorus into the water column may provide some beneficial effects to the mined area. An increase in the available nutrient supply may stimulate the growth of phytoplankton, which provide a source of food to other trophic levels. On the other hand, some species may be inhibited by these conditions, causing a change in species composition and production levels in the area. High production may also cause a reduction in oxygen levels in bottom waters as the additional cells die and begin to decompose (Lee, 1978).

Trace Metals and Toxins. Trace metals occur in nearshore sediments naturally or as a result of runoff or discharges from industrial or agricultural processes (Baram and others, 1977). Disturbance of such sediments during dredging could cause the release of metals or toxic organic compounds into the water column. Most studies on the effects of reintroduced substances have been done in estuaries or harbors, where sediments tend to be contaminated and high in organics. Impacts on water quality due to the release of substances from the sediment are unlikely due to rapid dispersion rates and buffering abilities of open coastal waters (Baram and others, 1977).

Disturbance from Mining Activity

General Disturbance. General disturbance from the mining operation is likely to cause mobile animals to avoid the area. Noise and movement of dredges, support vessels, and air traffic may cause displacement of marine birds and mammals from established colonies located near the disturbance. Animal responses will depend on the species, reproductive state of the animal, distance from the disturbance, and the type, intensity, and duration of the disturbance (U.S. Department of the Interior, 1988). Low-flying aircraft operating near colonies of birds often frighten adults off their nests, leaving eggs and juveniles vulnerable to exposure, predation, or accidental displacement. Repeated disturbance could significantly reduce the hatching and fledging success of eggs and juveniles, which could cause a reduction in the local population (Roy Lowe, USFWS, personal communication). Noise from aircraft and vessel traffic also will panic hauled-out seals and sea lions near the source of the disturbance, possibly causing death, injury, or abandonment of pups. If such
disturbances occur frequently, preferred areas may be abandoned, resulting in a long-term change in animal distribution.

The possibility of entrainment exists not only for those organisms in the path of the dredge, but also for those organisms near water intakes located at the sides of the vessel. As water is drawn on board for benefication of the mined material, phytoplankton, zooplankton, and pelagic eggs and larvae of fishes and shellfishes may be entrained, although the effects will likely be undetectable on future recruitment.

In order to minimize disturbance to biological resources, buffer zones should be established around those areas frequented by various species. Consideration should also be given to those times of the year when species are breeding at or migrating through a particular area. The size of the buffer zone would be dependent on the sensitivity and behavioral patterns of the species involved or the time of year of life stage of the animal.

**Underwater Noise.** Sound may play an important role in the behavioral response of many marine fishes and mammal species, such as detection and localization of prey. Marine mammals use sound for communication and echolocation (US Department of the Interior, 1988). Many species may use natural background sounds as cues for locating preferred reproductive and feeding areas or traditional migratory routes. Sensitivities and responses of marine species to loud or prolonged underwater noise are poorly understood. The frequency and intensity of sound will also be factors in determining the degree of potential impact. Underwater noise from exploration or mining activities may alarm some species, including commercially valuable species, causing them to avoid the area or stop feeding (Pearson and others, 1987). Continuous noise or disturbance may interfere with long-range communication or echolocation signals, resulting in altered patterns of migration or species distribution (Ljungblad, 1985).
Exploration Techniques and Fuel Spills

Exploration techniques used in locating and defining offshore deposits, including magnetometers, gravimeters, and spectrometers, all of which are towed along behind the research vessel, would have minimal biological impacts (Office of Technology Assessment, 1987). However, such techniques as vibra-coring and seismic testing could have potentially greater impacts. Organisms located within the coring site will be collected along with the sediment sample, although the affected areas should be relatively small. Seismic exploration techniques will use high-resolution devices, air guns, and sparkers. Recent research by the Mediation Institute (CA) Eggs and Larvae Committee has shown no demonstrable effect of seismic impulses on Dungeness crab zoea. Pearson and others (1987) examined the effects of sounds from geophysical survey devices used in oil and gas exploration. This information may be useful for hard mineral exploration, although the seismic impulses used in high-resolution reflection requires much smaller quantities of energy than those required for deep reflection in oil and gas exploration. Timing of any seismic testing should be planned in relation to biological life stages and migrations.

A commercial dredging operation will require the dredge vessel to operate on a continuous basis. The proposed mining schedule for the Oregon coast calls for dredging to be carried out 24 hours and day, 7 days a week, 250 days per year, weather permitting. Fuel, food, and supplies for the dredge will be delivered on a weekly basis, and crews will be rotated every two weeks. Loaded barges will return to the on-shore processing plant approximately every two to three days (Wetzel and Stebbins this volume). At-sea refueling of vessels and the increase in vessel traffic in the area will introduce the possibility of fuel spills and accidents during the mining operation.
II. BIOLOGICAL RESOURCE ASSESSMENT

This section describes the major ecological groups of organisms found in the ocean off Oregon, studies specific to the southern Oregon coast, and comments of those species most likely to be affected by mining in this area. Information on the distribution and abundance of marine species, the composition of biological communities, and the identification of important habitats is available from published and unpublished reports, theses, agency reports, and selected databases. Although information specific to the biological resources of the south Oregon coast is limited, a thorough review of studies for the continental shelf from the intertidal region to depths of 900 m for the Oregon and Washington coasts is provided in a forthcoming publication by Bottom and others. Other sources of information pertaining to the biological resources off Oregon include a series of open-file reports identifying the state of scientific information relating to the biology and ecology of the Gorda Ridge study area (Harvey and Stein, 1986; Krasnow, 1986; Ellis and Garber, 1986).

**Plankton.** Organisms that drift passively with the ocean currents are called plankton. Although many planktonic organisms are capable of some degree of swimming, they spend most or all of their lives subject to the motion of the surrounding waters. Phytoplankton are the single-celled plants that comprise the lowest level of the food chain. Primary productivity is influenced by the quality, intensity, and duration of light as well as nutrient availability in the euphotic zone. Light and nutrients are essential for photosynthesis. Zooplankton are free-floating animals that occupy the first few trophic levels above the primary producers (Davis, 1978). They are an important link in the food chain as they convert plant tissue to animal tissue. Although the food habits of many marine animals are largely unknown, it is highly likely that most organisms feed on zooplankton at some stage of their lives (Parmenter and Bailey, 1985).

Patterns of wind stress affect the primary productivity of the nearshore areas. The northwest winds of the summer create periods of upwelling, when deeper, colder, nutrient-rich water rises to the surface to replace the surface layer which is being driven offshore by Ekman transport (Huyer,
This phenomenon can extend 10 to 30 km offshore but may affect a much greater area. Upwelling is not a constant occurrence but is episodic, with events lasting days to weeks. The intensity of an upwelling event depends on the strength and duration of the northwest winds (Huyer, 1983). Associated with upwelling events are coastal jets or squirts; fast, narrow surface currents that develop along the shoreline as the upwelled water is swept offshore.

These areas of upwelling are regions of high primary productivity when compared to the open ocean (Small and Menzies, 1981). Annual primary production on the Oregon continental shelf is estimated to be in the range of 200-300 g of carbon per square meter per year, while values for the area beyond the continental shelf are estimated to be between 100-150 g of carbon per square meter per year (Anderson, 1972). Landry and others (1989) found high chlorophyll concentrations over the inner continental shelf off Oregon and Washington during summer upwellings, although substantial stocks of phytoplankton were also present throughout the winter as well.

A considerable amount of research has been conducted on the distribution and species composition of zooplankton along the central Oregon coast (e.g., Peterson and Miller, 1975; Pearcy, 1976; Miller and others, 1985; Shenker, 1985). Because plankton drift along with the prevailing water currents, their distribution and composition are dependent on the seasonal cycle of water masses. During the summer months, when surface waters are advecting south and away from the coast and subsurface waters are upwelling along the coast, the zooplankton community off of Oregon is comprised predominantly of species associated with subarctic waters. During the winter months, when the prevailing winds are from the southwest, the surface waters are moving onshore, and downwelling occurs along the coast. The zooplankton community during these periods includes species from southern and offshore waters (Peterson and Miller, 1976; Menzies, and others, 1980).

Other important planktonic forms include larvae of fishes and shellfishes. These are meroplankton and occur in the plankton for a limited duration each year. The zoea and megalopae larval stages of the Dungeness crab are known to occur inshore from January to May, apparently being retained
in the area by inshore surface currents. The megalopae then metamorphose into juvenile crabs and settle out of the water column, moving into rearing areas of nearby estuaries. (Lough, 1976; Armstrong and others, 1986). Eggs and larvae of fish are also transient members of the inshore plankton community, and therefore timing of mining activities will be critical when larval and juvenile species are present in the water column. Information concerning the abundance and distribution of zooplankton off the central Oregon coast has been described by Richardson and Pearcy (1977), Richardson and others (1980), Brodeur and others (1984), Miller and others (1985), and Shenker (1985). To date, no similar studies have been conducted off southern Oregon.

Information specific to the plankton of the south coast is limited; however, Laurs (1967), studied a hydrographic line off Brookings which extended from 5 to 165 nautical miles offshore. This study provides a basis for understanding the general characteristics of the oceanographic conditions, particularly the relationships between upwelling and primary productivity. Laurs found that chlorophyll concentrations were highest inshore during upwelling activity and offshore during late winter and spring, while the number of primary carnivores and herbivores (zooplankton) was highest in the fall after upwelling had begun to subside. Euphausiids, copepods, salps, and crab zoea were the most numerically dominant herbivores. *Euphausia pacifica* was the most abundant euphausiid identified during the study, with the size and seasonal variation of catches being substantially greater inshore than offshore. Highest mean catches and greatest seasonal variation for copepods species were observed at intermediate distances offshore.

Fishes, chaetognaths, shrimps, and medusae were the most common primary carnivores sampled. Changes in the composition of fish species was evident in the offshore region during summer samplings. Species representative of the subarctic-transitional water mass were nearly absent offshore, while their numbers were intermediate inshore. Species present offshore were apparently of southern and/or western waters. The relative abundance of the shrimps was lowest in summer and late winter, intermediate in fall, and highest in spring. Mean catches of shrimps were two to five times higher inshore than offshore. *Sergestes similis* and *Pandulus jordani* were the most abundant
shrimp species sampled.

Satellite imagery off the Oregon coast has shown that coastal jets form tongue-shaped plumes that extend several hundred kilometers off of the southern portion of the state during the summer months (Abbott and Zion, 1987; Thomas and Strub, 1989). Coastal jets are associated with upwelling events, and their presence off the south coast indicates the oceanographic regime south of Cape Blanco varies significantly from that of the central and north Oregon coast. Because the pelagic environment is a dynamic system of physical, biological, and chemical processes, with its upwelling events and complex circulation patterns, our understanding of these processes and their interrelationships are not well understood. Long-term studies are needed to relate upwelling intensities and primary production in the area off southern Oregon. A review of physical oceanography and its effects on primary productivity for this region is presented in Landry and Hickey (1989).

**Invertebrates.** Benthic organisms are the bottom-dwelling animals of the ocean. They play an important role in secondary production in the nearshore environment by breaking down detrital matter and reworking bottom sediments as well as providing a food source to many demersal and benthic dwelling species. Benthic communities found in sandy, high-energy environments tend to be well adapted to natural disturbances such as high turbidity, burial, and scouring due to shifting sediments and bottom currents associated with storms or increased wave activity. (Sternberg and McManus, 1972; Rees and others, 1976; Oliver and others, 1980). Organisms such as clams and polychaete worms possess the ability to burrow freely through the sand, while other animals, such as crabs, are capable of migrating great distances along the sea floor.

Literature describing the benthic infaunal communities of the Oregon coast primarily focuses on areas off central Oregon (e.g., Carey 1965; Carey 1972; Bertrand 1970; Hogue 1982). These studies discuss the composition, distribution, and abundance of benthic assemblages, as well as the oceanographic conditions that affect these assemblages. Additional information concerning the
composition of benthic communities of the south coast is provided by the Corps of Engineers in their Ocean Dredged Material Disposal Site evaluations at the Rogue River disposal site (U.S. Corps of Engineers, Portland District, 1988). The results of the evaluations from the Rogue River (Gold Beach) disposal site indicate that the benthos of the offshore area was typical of a nearshore high-energy environment. The infaunal community was dominated by gammarid amphipods and polychaete worms; gastropods and cumaceans were also consistently found in all samples. Most species showed higher levels of abundance at the disposal site than at control sites. This result is different from that in Corps of Engineers studies at other Pacific Northwest ocean disposal sites. The higher densities could be due to enrichment at the disposal site or just a natural variation. Although the site has frequently received dredged material, the adjacent fauna show little evidence of negative impacts (U.S. Army Corps of Engineers, 1988).

Macroinvertebrate benthic species of commercial or recreational importance in the nearshore zone include Dungeness crab, sea urchins, razor clams, gaper clams, cockles, and Pittock clams. Dungeness crab (Cancer magister) is commercially important in the Pacific northwest. Extensive research has been conducted on this species, primarily on larval and juvenile crab biology (Lough, 1976; Stevens and others, 1984; Stevens and Armstrong, 1984). Information from the Oregon Department of Fish and Wildlife (ODFW) provides records of numbers caught and port of landing for the crab fishery. Only male crabs of a certain size may be harvested during certain times of the year; therefore landings records provide no information regarding female or juvenile crabs. Currently, commercial crab fishermen are not required to keep catch logbooks, so information regarding area of catch is unavailable. A voluntary logbook program for the Oregon coast has been proposed by ODFW to local fisherman in hopes of providing some insight as to the preferred locations of the harvestable Dungeness crab catch (Darryl Demory, ODFW, personal communication, 1989). Commercial landings for the south Oregon coast are available from ODFW (Table 2).

ODFW has identified an emerging commercial sea urchin fishery at the Port Orford and Rogue
Table 2. Combined Dungeness Crab Landings and Effort (number of landings) for Port Orford, Gold Beach, and Brookings

<table>
<thead>
<tr>
<th>Season</th>
<th>*Pounds</th>
<th>No. of vessels</th>
<th>Effort</th>
<th>lb/landing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980-81</td>
<td>2,857,200</td>
<td>158</td>
<td>3576</td>
<td>799</td>
</tr>
<tr>
<td>1981-82</td>
<td>2,192,403</td>
<td>140</td>
<td>3224</td>
<td>680</td>
</tr>
<tr>
<td>1982-83</td>
<td>1,038,517</td>
<td>163</td>
<td>2777</td>
<td>374</td>
</tr>
<tr>
<td>1983-84</td>
<td>959,976</td>
<td>100</td>
<td>2658</td>
<td>361</td>
</tr>
<tr>
<td>1984-85</td>
<td>1,164,224</td>
<td>95</td>
<td>2802</td>
<td>415</td>
</tr>
<tr>
<td>1985-86</td>
<td>1,088,375</td>
<td>96</td>
<td>1977</td>
<td>550</td>
</tr>
<tr>
<td>1986-87</td>
<td>1,032,163</td>
<td>86</td>
<td>1889</td>
<td>546</td>
</tr>
</tbody>
</table>

* Based on landings made during months when the ocean season was open.

From ODFW, Marine Region
Reefs (Jean McCrae, ODFW, personal communication, 1989). The urchin harvest for the 1989 season is expected to exceed 2,000,000 pounds. This fishery could be affected if sediments suspended during mining operations resettle in these areas.

Information concerning the distribution, abundance, and population dynamics of pink shrimp off the Oregon coast is available from Lukas (1979), PFMC (1980), Rothlisberg and Miller(1983), and ODFW reports. Catch data and fishery logbooks provide more extensive information concerning the distribution and abundance of adult shrimp (Starr and Zirges, 1985). Logbook data are being analyzed by ODFW as part of their computerized information system to describe the distribution and catch per effort rates off Oregon (Starr and Saelens, 1987).

Recent research has provided some information on the distribution and abundance of squid collected during surveys off Oregon and Washington (Jefferts and others, 1985; Starr, 1985; Brodeur and Pearcy 1986). Schools of market squid (Loligo opalescens) are found all along the Oregon coast, but no specific studies have been conducted to identify spawning areas along the south Oregon coast. Market squid have been fished commercially off the central Oregon coast (Starr, 1985).

**Fishes.** The nearshore zone supports a variety of fish species. These include two major groups, mid-water (pelagic) and groundfish (benthic) species. Pelagic species include salmonids, mainly coho and chinook salmon and steelhead trout, and schooling species, such as Pacific herring, northern anchovy, and Pacific sand lance. Coho and chinook salmon are important species to both commercial and recreational fisheries off Oregon. The commercial salmon troll fishery takes place over the entire Oregon coast, although most fishing activity takes place in depths of less than 150 m (Parmenter and Bailey, 1985). Little is currently known about the ocean phase of these species, although studies describing their abundance, distribution, and food habits of juveniles have been conducted (Brodeur and others 1987; Fisher and Pearcy, 1988). Recovery of tagged fish at sea provides insight to the ocean migration patterns of coho and chinook salmon (Pearcy and Fisher,1988; Fisher and Pearcy, in prep). Ocean survival of coho salmon off Oregon and California
has been correlated with the intensity of coastal upwelling in these areas (Nickelson, 1983; Nickelson, 1986; Fisher and Pearcy, 1988).

The commercial salmon troll fishery is a highly regulated fishery, with limits set on size, area, time, and number of fish allowed to be harvested each year. Fluctuations in annual harvests (Table 3) are difficult to assess due to the number of limitations placed on the fishery (i.e., size limits, catch quotas, gear restrictions, etc.). Commercial landings for the combined Port Orford-Gold Beach-Brookings area in 1988 totaled over 580,000 pounds of chinook and over 105,000 pounds of coho salmon (ODFW, 1989a). To rebuild the Klamath River (California) salmon stocks, ODFW and California Fish and Game have required catch quotas and temporary fishing closures for the area south of Cape Blanco to Point St. George (California) to prevent over-harvesting of these stocks.

Small schooling species are food sources for adult salmon and other commercially important species. Although the distribution, abundance, and seasonal variations of the northern anchovy and Pacific herring off Oregon and Washington have been described (Richardson, 1973; Laroche and Richardson, 1980; Richardson, 1981; Brodeur and Pearcy, 1986), little is known about the life history, food habits, and production dynamics of these forage fish species. During the mid 1970's, anchovy were occasionally commercially harvested as a bait fishery (David Fox, ODFW, personal communication, 1989) but now are utilized primarily by recreational fishermen. Pacific herring spawn in selected estuaries along the coast and are fished commercially at Yaquina Bay (Jerry Butler, ODFW, personal communication, 1989).

Groundfish species include rockfishes, flatfishes, sablefish, and cod. The most commercially valuable species for Oregon include sablefish, Dover sole, petrale sole, widow rockfish, and yellowtail rockfish (David Fox, ODFW, personal communication, 1989). These species are generally caught in the deepwater trawl fishery along the outer continental shelf and continental slope. Information on flatfish species off Oregon is generally more complete than for other groundfish species. Literature describing the distribution, abundance, and composition of demersal
Table 3. Commercial Ocean Salmon Landings and Effort (number of landings)

<table>
<thead>
<tr>
<th>Port</th>
<th>CHINOOK</th>
<th>COHO</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pounds</td>
<td>Number</td>
<td>Pounds</td>
<td>Number</td>
<td>Effort</td>
</tr>
<tr>
<td>1980</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Port Orford</td>
<td>252,342</td>
<td>25,671</td>
<td>95,359</td>
<td>15,975</td>
<td>2191</td>
</tr>
<tr>
<td>Gold Beach</td>
<td>101,255</td>
<td>10,126</td>
<td>21,000</td>
<td>3,010</td>
<td>714</td>
</tr>
<tr>
<td>Brookings</td>
<td>282,008</td>
<td>28,017</td>
<td>64,152</td>
<td>10,125</td>
<td>3728</td>
</tr>
<tr>
<td>1981</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Port Orford</td>
<td>108,825</td>
<td>10,664</td>
<td>142,649</td>
<td>23,206</td>
<td>1820</td>
</tr>
<tr>
<td>Gold Beach</td>
<td>47,595</td>
<td>4,961</td>
<td>28,372</td>
<td>4,414</td>
<td>470</td>
</tr>
<tr>
<td>Brookings</td>
<td>603,813</td>
<td>66,510</td>
<td>160,247</td>
<td>23,446</td>
<td>5029</td>
</tr>
<tr>
<td>1982</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Port Orford</td>
<td>251,752</td>
<td>26,499</td>
<td>74,882</td>
<td>12,96e</td>
<td>2247</td>
</tr>
<tr>
<td>Gold Beach</td>
<td>98,209</td>
<td>9,524</td>
<td>8,847</td>
<td>1,509</td>
<td>967</td>
</tr>
<tr>
<td>Brookings</td>
<td>365,445</td>
<td>36,241</td>
<td>50,154</td>
<td>8,758</td>
<td>4613</td>
</tr>
<tr>
<td>1983</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Port Orford</td>
<td>46,220</td>
<td>4,970</td>
<td>26,594</td>
<td>7,776</td>
<td>809</td>
</tr>
<tr>
<td>Gold Beach</td>
<td>23,603</td>
<td>2,989</td>
<td>7,962</td>
<td>2,109</td>
<td>386</td>
</tr>
<tr>
<td>Brookings</td>
<td>113,591</td>
<td>14,856</td>
<td>52,226</td>
<td>13,91e</td>
<td>2176</td>
</tr>
<tr>
<td>1984</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Port Orford</td>
<td>86,683</td>
<td>8,926</td>
<td>------</td>
<td>------</td>
<td>926</td>
</tr>
<tr>
<td>Gold Beach</td>
<td>25,926</td>
<td>3,231</td>
<td>104</td>
<td>22</td>
<td>191</td>
</tr>
<tr>
<td>Brookings</td>
<td>91,467</td>
<td>11,297</td>
<td>------</td>
<td>------</td>
<td>1004</td>
</tr>
<tr>
<td>1985</td>
<td></td>
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Table 3 (cont). Commercial Ocean Salmon Landings and Effort (number of landings)

<table>
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<th>Effort</th>
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From ODFW, Marine Region
assemblages as well as seasonal variations and food habits of juveniles is available (Pearcy and others, 1977; Laroche and Richardson, 1978; Hogue and Carey, 1982). Limited information concerning the spawning behavior and preferred areas of some flatfishes is also available (Hosie and Horton, 1977; Pearcy, 1978). Juvenile Dover sole tend to live in shallower water than adults, and females are also found in shallower water in the summer, while males remain in deeper water year round (Demory, 1975). Dover sole are the most important commercial flatfish species caught off Oregon. Despite fluctuations in catch rates over the years, they have consistently remained the dominant flatfish species caught.

Habitat disturbance caused by the mining operation could potentially result in the loss of suitable spawning habitat for fishes that spawn in depths of less than 100 m. During the 1982 commercial groundfish season, a number of trawls were targeted at depths of less than 100 m in the area off the south Oregon coast (Cape Blanco south to Crook Point). Flatfish species made up the vast majority of the catch, with petrale sole (47,766 lbs.), English sole (41,815 lbs.), and Dover sole (25,111 lbs.) being the most abundant species caught. Fair amounts of ling cod (10,424 lbs.), Rex sole (9,409 lbs.), and rockfish species (5,618 lbs.) were also harvested in the area. Incidental species caught included sanddabs, sablefish, and butter sole (ODFW, 1989b). Most of these fish produce pelagic eggs, and some, such as petrale sole, have localized spawning grounds. Other species, like lingcod, lay demersal eggs that could be smothered or buried by sedimentation. The long-term effects from the permanent loss of spawning habitat is unknown. Most fish species are widely distributed along the Oregon coast; therefore, there may be a negligible effect on the population as a whole, although local populations may experience a decline in numbers.

Recreational fisheries are an important economic industry for Oregon. The principal sport species include coho and chinook salmon and bottom fish species (Table 4), black rockfish, canary rockfish, ling cod, and cabezon (Jerry Butler, ODFW, personal communication, 1989). Recreational fishing for most of the Oregon coast is limited by the range of charter and pleasure boats, and the type of boat facilities at the various ports. Most sport fishing on the south coast originates from the Gold
Beach (Rogue River) and Brookings area, as Port Orford lacks adequate port facilities. Fishing occurs year round, but tends to be seasonal due to the weather. Recreational catch data from ODFW include information on the number of species caught and on the amount of fishing effort.

The Rogue River (Gold Beach) also supports an active in-river recreational fishery for chinook salmon and steelhead. The 1987 recreational fishery harvested over 6,000 fall chinook, 12,000 spring chinook, 5,000 summer steelhead, and 700 winter steelhead from the river (ODFW, 1989c). Timing of mining operations so as not to interfere with the migrations of either juvenile salmonids entering the ocean or adult salmonids returning to natal streams may be crucial to minimize straying of adults and to maintain the productivity of runs. It is unknown what effect a turbidity gradient would have on the migratory behavior of anadromous species.

Catch records from ODFW provide valuable information concerning both the commercial and recreational fisheries off Oregon, but this information is limited. These data do not reveal information about species that are not landed or individuals that are too small to be caught or kept legally. Some species are fished more intensely than others, which may be reflected in the data as a disproportionate amount of the target species being caught in a particular area. Catch data and landings reports reveal information about where the species are caught but are not necessarily unbiased data about their distribution. Fluctuations in catches could be due to a number of factors other than changes in the species abundance or distribution – current markets, more efficient fishing gear, shifts in target species being harvested, government regulation, etc., all affect the number of individuals caught.

ODFW is currently involved in developing a long-term ocean management program designed to identify areas of biological significance and to provide insight as to how these resources respond to environmental change. This system will prove to be very useful in defining the locations of catch of certain species and in describing the relationships between habitats and species. At present,
Table 4. Ocean Salmon Sport Catch and Effort (number of landings)

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From ODFW, Marine Region
fishery data (pink shrimp and groundfish) for only three years have been entered into the system, but once more data are entered, ODFW expects to be able to identify areas of high species diversity or areas that contain a high percentage of gravid females or juvenile fish. A brief summary of the Ocean Habitat and Mapping (OHAM) program and sample maps are included in Appendix A.

**Marine Birds**

Numerous species of marine birds occur along the Oregon coast. Information concerning the distribution and abundance of bird species is presented by Scott (1973), Varoujean (1979), Varoujean and Pitman (1979), Bertrand and Scott (1979), and Pitman and others (in press). A catalog of seabird colonies in Oregon is currently in preparation by personnel at U.S. Fish and Wildlife Service.

Rocky outcroppings are a major feature of the Oregon coast, especially between Coos Bay and the Rogue River. Many of these rocky islands and sea stacks, which make up the Oregon Islands National Wildlife Refuge system, provide nesting sites for marine birds. Recent estimates indicate that the marine bird population for the south Oregon coast exceeds 122,000 (Roy Lowe, USFWS, personal communication, 1989). Oregon's seabird population is dominated by the common murre and Leach's storm petrel; all other species combined account for less than 10 percent of the total population (Pitman and others, in press). Murre colonies are often extremely large, with tens of thousands of birds occupying rocky areas of the south coast during the breeding season. Leach's storm petrels are present off Oregon only during the summer months, but the south coast supports one of the largest breeding colonies of these birds on the entire West Coast (Parmenter and Bailey, 1985). Other species common to the south Oregon coast include pelagic cormorants, pigeon guillemots, black oyster catchers, and western gulls, Brandts cormorants, double-crested cormorants, and tufted puffins (Table 5).

Several species of birds that are of special concern include the brown pelican, peregrine falcon, and
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<tr>
<th>Location</th>
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<th>Bl Oyster</th>
<th>Pigeon Cormorant</th>
<th>Catcher</th>
<th>Guillemot</th>
<th>Western Gull</th>
<th>Common Murre</th>
<th>Dbl Crd Brandt's Cormorant</th>
<th>Puffin</th>
<th>St Petrel</th>
<th>St Petrel Auklet</th>
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</table>
Table 5 (cont). 1988 Summer Seabird Colony Counts from Black Point Rocks south to Hunters Island.

<table>
<thead>
<tr>
<th>Location</th>
<th>Pelagic Cormorant</th>
<th>Bl Oyster Cormorant</th>
<th>Pigeon Guillemot</th>
<th>Western Gull</th>
<th>Common Murre</th>
<th>Dbl Crst Brandt's Cormorant</th>
<th>Tufted Puffin</th>
<th>Tufted St Petrel</th>
<th>Leach's St Petrel</th>
<th>Cassin's Auklet</th>
<th>Jaeger's Auklet</th>
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</table>
Table 5 (cont). 1988 Summer Seabird Colony Counts from Black Point Rocks south to Hunters Island.

<table>
<thead>
<tr>
<th>Location</th>
<th>Pelagic Cormorant</th>
<th>Bl Oyster Catcher</th>
<th>Pigeon Guillemot</th>
<th>Western Gull</th>
<th>Common Murre</th>
<th>Dbl Crstd Brandt's Cormorant</th>
<th>Tufted Puffin</th>
<th>Leach's Storm Petrel</th>
<th>Cassin's Auklet</th>
<th>Rhino Auklet</th>
<th>Total</th>
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<td>Needle Rock</td>
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<td>46</td>
<td>519</td>
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<td>Pyramid Rock</td>
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<tr>
<td>Cape Sebastian North</td>
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<td>18</td>
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<tr>
<td>Cape Sebastian South</td>
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<tr>
<td>Hunters Island</td>
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<td>104</td>
<td>880</td>
<td>100</td>
<td>X</td>
<td>19,740</td>
<td>40</td>
<td>160</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>3,784</strong></td>
<td><strong>78</strong></td>
<td><strong>711</strong></td>
<td><strong>3,118</strong></td>
<td><strong>91,933</strong></td>
<td><strong>804</strong></td>
<td><strong>3,158</strong></td>
<td><strong>433</strong></td>
<td><strong>&gt;19,740</strong></td>
<td><strong>&gt;40</strong></td>
<td><strong>&gt;160</strong></td>
</tr>
</tbody>
</table>

P = Birds probably present
X = Birds present

From U.S. Fish and Wildlife Service, Newport, Oreg.
the Aleutian Canada goose. The brown pelican, which is listed as a Federally endangered species, is a summer resident of the Oregon coast. The peregrine falcon is listed as an endangered species and is often associated with headlands, sand spits, and offshore rocks that are used as foraging areas. Aleutian Canada geese use some south coast rocks and islands for feeding and roosting during spring migration. Brown pelicans are found locally all along the Oregon coast during the summer months (Roy Lowe, USFWS, personal communication, 1989). Numerous other shorebirds and waterfowl also utilize the shoreline areas for nesting, feeding, and resting.

Noise and the general activity of a continuous mining operation located near one of these colonies could cause the area to be abandoned and therefore cause a reduction in the local population. Disturbance from vessel or air traffic may frighten birds off their nests, leaving their young vulnerable to exposure or predation. If mining occurs in areas heavily used by marine birds for foraging, prey species may be obscured due to turbidity. Food sources may also be reduced as a result of negative impacts to prey species.

**Marine Mammals**

Information on marine mammals off Oregon other than seals and sea lions is limited. Gray whales traverse the Oregon coast during fall and spring migrations, and a small population of gray whales reside year round off the Oregon coast. Little is known about the movements and specific feeding habits of gray whales off the Oregon coast, although gray whales are known to feed extensively on benthic organisms. Studies in the Bering Sea have shown that gray whales feed on gammarid amphipods, molluscs, mysids, hydroids, and polychaetes (Rice and Wolman, 1971). Minke, humpback, and blue whales have also been sighted off the Oregon coast. Other cetaceans that are seen occasionally are the harbor porpoise, Pacific whitesided dolphin, and killer whales (Maser and others, 1981).

The results of the first year of a three-year study to assess the pinniped population of Oregon are presented by Brown (1988). Monthly aerial photographic surveys were taken along the coast to
document the seasonal distributions and abundances of the Steller (northern) sea lion, California sea lion, and harbor seal. Of particular importance on the southern Oregon coast are the Rogue and Orford Reefs. These areas are used by seal and sea lions as haul outs and are also used by Steller sea lions as a rookery on a year-round basis. This area supports the largest reproductive stock of Steller sea lions in United States waters south of Alaska. The current Oregon population is estimated to be about 1,500 individuals (Brown, 1988). After the breeding season (mid-July), most males migrate northward to locations in Alaska and British Columbia, while the female and pups remain in Oregon throughout the year (Parmenter and Bailey, 1985).

Although California sea lions are not year round residents of Oregon, adult and subadult males move through the nearshore area on their fall migrations to the north and spring migrations to the south. Females and their young generally remain in California year round. In 1984, a peak count of 1,938 individuals was taken at haul-out sites on the Oregon coast. Other studies have estimated the number of California sea lions passing through Oregon waters at about 5,500 animals (Bigg, 1985). Harbor seals are a non-migratory species which are present all along the Oregon coast. Current populations estimates for the south coast range from 300 to 500 individuals (Brown, 1988).

Survey counts of Stellar sea lions indicate that the Oregon population has remained fairly stable since 1977. The number of animals at the Rogue and Orford Reefs also seem to have not changed significantly. The population of California sea lions off British Columbia and Washington have shown a dramatic increase since the early 1970's. No comparable surveys for wintering California sea lions in Oregon have been completed yet, but greater numbers of individuals would be expected. Statewide counts for harbor seals indicate that the number of animals has been increasing since the mid-1970's. The passing of the Marine Mammals Protection Act in 1972 is credited in part to the observed increases in pinniped populations (Brown, 1988).

Noise and general activity from the mining operation may cause seals and sea lions to flee their haul-out sites. Repeated or continuous disturbance may result in a long-term change in animal
distribution. Such disturbance could also have impacts on the reproductive success of these species. The mining operation may also indirectly affect marine mammals by reducing zooplankton, benthos, or fish populations that serve as food sources.
III. REVIEW OF RELEVANT CASE STUDIES

Since little offshore mining is currently being done in United States waters, it is difficult to assess the specific impacts from such an operation on the southern Oregon coast. Therefore, any discussion of potential environmental impacts must rely on the mining experiences of other countries and on information gathered from dredge and disposal operations. This section briefly discusses major conclusions from other studies, some of which are described in detail in the appendices.

Project NOMES
An ambitious study was initiated in 1972 to identify the environmental and biological impacts associated with a large-scale sand and gravel mining operation on the east coast of the United States (Padan, 1977). The New England Offshore Mining Environmental Study (Project NOMES) was a three-phase program consisting of one year of pre-mining baseline evaluations at the proposed area in Massachusetts Bay, a minimum of one year of sand and gravel extraction with a coinciding environmental and biological monitoring program, and a two-year study of post-mining monitoring to document changes in the mined area. The project was terminated in 1973, when a suitable disposal site could not be identified for the approximately 1 million cubic yards of material to be mined during the test period. The monitoring program would have included sediment dispersion modeling, water-and sediment-quality analyses, and an extensive course of biological monitoring focusing on the response of organisms to the presence of sediments.

Although Project NOMES was not completed, a wrap-up phase was conducted, and the following recommendations were offered for similar projects in the future (Padan, 1977):

1. Laboratory studies of the effects of turbidity on marine organisms should be conducted, including nonphysiological responses, such as organisms' avoidance of a turbidity plume. Results may be extremely relevant to local commercial fishermen.
2. Once a site has been agreed upon, a two-year period should be devoted to pre-mining studies. The first year should be devoted to the development of sampling and test procedures for coordinated use the second year. The main focus of the baseline studies should be the long-term effects of a change in substrate characteristics caused by the blanket of fine materials.

3. The mining test should be at a commercial scale and should continue for at least one year. A brief period of mining should not be extrapolated for long-term mining.

4. Although the period of mining must be well-monitored, the post-mining environment can be examined less frequently but should continue for at least two years.

The European Experience
During the mid 1970's, the International Council for the Exploration of the Sea (ICES) was established to identify environmental concerns in the North Sea, where sand and gravel mining operations have been occurring for over 50 years. Of particular concern to the European community is the potential loss of commercial fisheries to due to mining activities, although no direct negative effects of dredging on adult fish stocks were clearly demonstrated. Each participating country described its current mining scenarios as well as any environmental issues it had encountered or avoided. Based on the combined experiences of the group, ICES proposed a "Code of Practice" with recommendations to minimize the environmental effects of mining operations in the nearshore area. The Code requires that the exact area to be mined, as well as the amount and thickness of the overburden to be removed, be specified prior to mining. Important fishing grounds and spawning and nursery areas are excluded as potential mining areas. Also, the expected substrate composition for the area after mining must be described, including the amount of substrate suitable for spawning of commercially valuable species. Additionally, more research as to the biological, chemical, and physical effects from dredging operations is encouraged, and environmental impact statements are needed prior to licensing and excavation.
The Corps of Engineers Dredging Disposal Operations

The U.S. Army Corps of Engineers is responsible for maintaining over 40,000 km of navigable waterways, which requires the routine dredging of nearly 356,000,000 m$^3$ of material each year. About 30 percent of the material is disposed of at designated at-sea disposal sites (Office of Technology Assessment, 1987). The River and Harbor Act of 1970 (Public Law 91-611) authorized the Corps of Engineers to conduct a program that addresses the environmental effects of dredging and disposal of dredged material. The objective of the Dredged Material Disposal Program (DMRP) was “to provide – through research – definitive information on the environmental impact of dredging and dredged material disposal operations and to develop technically satisfactory, environmentally compatible, and economically feasible dredging and disposal alternatives, including consideration of dredged material as a manageable resource” (U.S. Army Waterways Experiment Station, 1973). The information gathered during this research effort provides insight into the environmental effects of shallow-water mining, because similar activities are required in the lifting and redepositing of sediments in both types of operations (OTA, 1987).

Regarding the effects of open-water disposal, the studies concluded that unless the dredged material was highly contaminated, the physical impacts caused by sediment disposal, such as burial of benthic communities, are likely to be of greater potential consequence than chemical or biological impacts. Biological effects are also unlikely to be of great consequence, due to the resiliency of most organisms (excluding larval stages) and the ability of many organisms to rapidly repopulate the affected areas. Except during times of fish migrations and spawning activities, turbidity is more likely to be an aesthetic than a biological problem. In general, areas of high wave activity appear to be influenced to a greater extent by naturally-occurring variations in the physical and chemical environment than by any disturbance created by dredging or disposal operations (U.S. Army Waterways Experiment Station, 1978). These results suggest that the natural variations characteristic of a high-energy environment will make it difficult, if not impossible, to generalize about the effects of mining without obtaining site-specific information concerning the proposed mining area (OTA, 1987).
Although these conclusions are related to a short-term disposal operation, they may be relevant to the proposed mining scenario for the Oregon south coast. Similar dredging techniques will be used for the placer mining project, and unwanted materials will be disposed of at sea. A commercial-scale mining project would be a long-term operation requiring continuous disposal of tailings, unlike the Corps of Engineers dredging project. The area offshore is a high-energy environment heavily influenced by wave activity, and organisms indigenous to the area are well adapted to such conditions. It is unknown what effect a long-term, continuous mining operation will have on the biological communities within the affected area and whether or not results from transient dumping operations can be extrapolated to the proposed scenario on the south Oregon coast. Two DMRP investigation reports that assessed the impact of dredged material disposal on benthic communities and demersal finfish and decapod shellfish species are reviewed in Appendix B.

In addition to the Dredged Material Research Program, the Corps of Engineers also has site-specific information for Ocean Dredged Material Disposal Sites (ODMDS) located off the estuaries of most navigable coastal rivers in Oregon. For each site, physical, chemical, and biological studies were performed to determine the suitability of existing disposal sites for continued use. The biological sampling consists of collecting benthic invertebrate samples from stations located within the disposal site and from stations at adjacent control sites to determine if any negative effects of ocean dumping are apparent on the benthic community located at the disposal site. The results of the evaluations from the Rogue River (Gold Beach) and Chetco River (Brookings) disposal sites indicate that the benthos of the offshore areas were typical of a nearshore, high-energy environment (U.S. Army Corps of Engineers, 1988a, 1988b).

**WestGold Mining in Alaska**

Western Gold Exploration and Mining Company, Limited Partnership (or WestGold), has been mining a gold placer deposit offshore of Nome, Alaska, since 1985, and ENSR Consulting and Engineering (Anchorage, AK) has been performing the biological and environmental monitoring for the project (Rusanowski and others, 1989). Their findings are thus far inconclusive but do
provide valuable insight into the environmental impacts created by such a mining operation. Damage to renewable resources, particularly the king crab fishery, and potential mercury contamination or bioaccumulation, are two primary concerns. Information on benthic recovery is available for sites that were mined one and two years previously (Jewett and others, 1989). Particular attention has also been paid to the potential impact on king crab through loss of habitat or food source. Trace-metal monitoring and bioaccumulation studies are performed regularly to collect information on the possibility of contamination of the environment. No significant difference was observed for catch-per-unit effort rates for crab pots fished in mined and non-mined areas for the 1987 or 1988 surveys. Post-mining sampling indicates decreases in the number of taxa, density, and biomass values one year after mining. Crustaceans were numerical dominants, particularly cumaceans. Two years after mining, increases in both density and biomass were evident, as well as a shift in species dominance from crustaceans to polychaetes. One year after mining, polychaetes accounted for 20 percent of the invertebrate abundance, while samples from two years after mining showed polychaetes accounted for nearly 75 percent of invertebrate abundance (Jewett and others, 1989).

Although the oceanographic conditions are very dissimilar between Norton Sound and coastal Oregon, the WestGold mining operation may provide valuable insight about the potential environmental and biological impacts associated with a placer mining operation on the Oregon continental shelf. The research approach used by WestGold should be reviewed to evaluate appropriate monitoring approaches for the Oregon coast. A review of the WestGold mining operations is included in Appendix C.

Research Needs
Much of the existing literature suggests that the effects of an offshore mining project will be short lived. The high dilution factor of the nearshore zone will rapidly disperse the turbidity plume, and high sediment transport rates will act to smooth out tracks or mounds left behind by the extraction process. However, most studies to date have dealt with the effects of short-term and transient
dredging, and their results may not be applicable to a long-term continuous mining operation.

Impacts will depend on a number of factors including the size the area to be mined and the oceanographic conditions of the proposed site. Information from similar dredging projects or from laboratory studies will not provide the complete answers on the potential environmental and biological consequences of a commercial-scale mining operation on the southern Oregon coast. Research and site-specific modeling will be required prior to mining activities in order to minimize the risks this type of operation may have on the biological communities and adjacent shoreline areas. Increased turbidity, sedimentation, noise, and general disturbance in the vicinity of sensitive habitats (spawning or nursery grounds, and nesting areas) or during critical periods (larval recruitment, and seasonal migrations) are likely to pose the greatest risks. Research to assess and monitor the effects of a placer mining operation on the Oregon continental shelf are described in Bottom and others (in press).
ODFW Ocean Habitat Analysis and Mapping Program

The Oregon Department of Fish and Wildlife is currently involved in developing a long-term ocean management program designed to identify areas of biological significance and to provide insight as to how these resources respond to environmental change. This Ocean Habitat Analysis and Mapping (OHAM) program is being created in response to the need for more detailed fishery resource information required in order to improve fisheries management and to help resolve resource user conflicts. The system is set up to store and analyze different types of biological and environmental data as well as economic data of the resources as reported in official landings records and in data provided in the Fisheries Economic Assessment Model by Jensen and Radtke (1987).

A pilot project was initiated to demonstrate how existing information can be used by the system. Data from logbooks and catch landings records for the commercial pink shrimp and groundfish fisheries were entered into the system to test the program. Using this information, computer-generated maps showing the average catch and the amount of fishing effort per 5-minute block (approximately 8 km by 8 km) were produced for the area off the Oregon coast (Figure A-1). This type of information can be used to highlight areas of high productivity (catch per unit effort) and to estimate the importance of a particular area for a given fishery. Bottom-sediment data are also being used to identify ocean habitats based on sediment types. By overlaying bottom substrate maps with catch data maps, species distributions and sediment types may be correlated.

The OHAM system will prove to be very useful in defining the locations of catch of certain species and in describing the relationships between habitats and species. This information, in conjunction with population dynamics models, will enable evaluation of the potential biological impacts of a particular management strategy. By including economic information, the economic trade-offs of different management strategies will also be identified. At present, only three years of fishery data (pink shrimp and groundfish) have been entered into the system, but once more data are entered, ODFW expects to be able to identify areas of high catch rates or areas that contain a high percentage
of gravid females or juvenile fish.
Figure A-1. ODFW Ocean Habitat Analysis and Mapping Project sample map. Courtesy of ODFW, Marine Region.
Aquatic Disposal Field Investigations, Columbia River Disposal Site, Oregon

This section reviews two research efforts undertaken as part of the Corps of Engineers' Dredged Material Research Program (DMRP). The general objective of the DMRP was to determine the degree and extent of impacts resulting from the disposal of dredged material on the biological communities in the area of the disposal site. The mouth of the Columbia River was chosen as one of five regional study sites. Phase I of the project was initiated in October of 1974 and consisted of the collection of baseline and pre-disposal information in the area offshore of the mouth of the Columbia River. Baseline studies continued through the second phase of the project, July-August 1975, during which time, 460,000 m³ of dredged material was disposed of at the experimental site. The final phase of the study, conducted from September 1975 through April 1976, was a continuation of sampling within the study area to assess the effects of the disposal on the biological communities located there.

Part A: The Effects of Dredged Material Disposal on Benthic Assemblages

The initial purpose of this study was to collect baseline information on the benthic community structure of the nearshore zone (0 - 90 m) in the vicinity of the mouth of the Columbia River (Figure B-1) and to examine the spatial and temporal changes in this community. The second phase of the study was to identify and determine the relative significance of physical, chemical, and biological factors that dictate the rate of benthic colonization. Five sampling cruises were performed prior to the test disposal to establish baseline and pre-disposal conditions, and five sampling cruises were performed after the test disposal to evaluate post-disposal effects of disposed dredged material on the benthic community in the test site (Richardson and others, 1977).

Smith-McIntyre grabs, with a sampling surface area of 0.1 m², were used to collect macrofauna and sediment samples. Macrofauna samples were then washed through a 1.00-mm screen for collection
Figure B-1. Location of benthic sampling stations. From Richardson and others, 1977.
and identification. Sediment samples were collected by removing the top 1 cm of surface of the sediment grab contents. Meiobenthic samples (retained by 0.50- to 1.00-mm screens) were obtained during the first two cruises but were later discontinued due to the long sorting time required per sample and the difficulties in identification of species. One grab per station for the remaining cruises was washed through a 0.50-mm screen in order to sample resident juvenile macrofauna. Five replicate macrofauna samples and one sediment sample were collected from each station. Megafauna samples were collected with a 3-m beam trawl with a 1½-inch stretch mesh and a ½-inch stretch mesh liner. Each trawl was towed on bottom for 30 minutes, and the distance covered was measured with odometer wheels attached to the trawl frame. Two trawls were obtained at each station.

After analyzing the data collected during the baseline studies, it was determined that with the exception of one assemblage, there was little similarity between the benthic assemblages found in the Columbia River study area and benthic assemblages as documented from other parts of the Oregon-Washington continental shelf (e.g., Lie, 1969; Lie and Kelley, 1970; Lie and Kisker, 1970; Carey, 1972). The range of values for species composition, biomass, and density of benthic assemblages in the study area was greater than the range of values reported from the entire Oregon-Washington continental shelf. The influence of the Columbia River – sediment deposition and high primary productivity – probably accounted for these differences (Richardson and others, 1977).

The distribution, composition, and seasonal constancy of benthic communities in the study area were interpreted in part to be the result of increases in the percent silt, clay, and organics in the sediments offshore and an increase in sediment stability due to reduced sediment stirring during winter storms with depth (Richardson and others, 1977). Species diversity was related to the relative stability of the surrounding sediments. In general, diversity values were greater at sampling stations further offshore than stations located in shallower, nearshore areas. The sediment stability at the offshore stations also increased due to a reduction in sediment stirring by winter storms. A higher abundance of tube-dwelling polychaetes at the deeper stations also contributed to the increase in sediment
stability at these stations. The lowest values of diversity were observed at stations that experienced considerable seasonal changes in sediment texture or grain size as a result of the deposition of fine-grained sediments at high flow from the Columbia River.

Biomass of the macrofaunal assemblages was related to the organic content of the sediment. As the amount of organic matter in the sediments increased, generally offshore, so did the biomass values for these communities (Richardson and others, 1977). The highest biomass values were found in areas of high silt deposition. Organic content was related to the percent silt and clay content of the sediments.

Assemblages exposed to the deposition of sediment from the Columbia River discharge had the lowest constancy between seasons of any stations in the study area. The seasonal constancy of abundance of dominant species was correlated to the seasonal stability of the surrounding sediment (Table B-1, Stations 16, 17). Komar and others (1972) concluded that short-period summer waves are capable of stirring the bottom to depths of 90 m, and long-period winter waves can stir the bottom to depths of 125 m and possibly 200 m. Benthic species that exist on these unstable sediments are probably well adapted to burial and scouring of sediments.

During the test disposal, two hopper dredges deposited 200 loads of dredged material (from the Columbia River) totaling 460,000 m$^3$. The disposal site was then sampled one, two, five, eight, and ten months after the test disposal. Samples obtained from the disposal site were divided into three groups, depending on their location relative to the disposal mound. Bathymetric surveys conducted after the disposal operation found a relatively circular deposit with a radius of about 750 m in the deposition area. Sampling stations located in the center of the mound (to a radius of about 230 m) were buried to a maximum depth of about 1.5 m stations located on the slope of the deposit were buried by 0.3 m to 0.6 m of material, and stations outside the disposal area probably were not directly affected by the disposal operation. Sediment texture samples were collected at each station along sand, but had high factor loadings on the 2.00-o and 2.50-o grain size fractions. During
Table 8-1. Sediment characteristics and community structure parameters for selected seasonal baseline stations. From Richardson and others, 1977.

<table>
<thead>
<tr>
<th>Station</th>
<th>Sediment Characteristics</th>
<th>Community Structure Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% Sand</td>
<td>% Silt</td>
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<tr>
<td>Station 1</td>
<td></td>
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</tr>
<tr>
<td>Dec 74/Jan 75</td>
<td>97.97</td>
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<tr>
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<td>96.29</td>
<td>1.39</td>
</tr>
<tr>
<td>Station 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dec 74/Jan 75</td>
<td>96.87</td>
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</tr>
<tr>
<td>April 1975</td>
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<tr>
<td>Station 12</td>
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</tr>
<tr>
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<td>98.26</td>
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</tr>
<tr>
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</tr>
<tr>
<td>Jan 1976</td>
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<td>21.30</td>
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Parameters include diversity (H'; H' = Σ pᵢ log₂ pᵢ), evenness (J'; J' = H'/log₂ S), species richness (SR; SR = (S-1)/ln N), density (N/m² - individuals/m²), and biomass (B/m²; grams ash-free dry weight/m²).
disposal operations, the sediments at the area directly affected by the disposal were therefore changed from a well-sorted sand to a coarser, less well-sorted sand. The phi diameter (ø) is defined as the negative logarithm, base 2, of the diameter in millimeters (Inman, 1952).

Post-disposal sediment texture analysis for the 10-month period revealed a gradual increase in factor loadings on the 2.50-ø and 2.75-ø sediment size classes at the area exposed to direct disposal of the dredged material, indicating a return to the sediment texture characteristics of the area prior to disposal. Five months after the disposal operation, the sediment characteristics of the stations exposed to direct burial of the dredged material were nearly identical to that of the intermediate stations located on the slope of the mound. From this point on, subsequent analysis of community structure parameters were based on only two sets of stations, those affected (direct burial or intermediate) and those unaffected (outside the zone of deposition).

The stations exposed to direct burial of dredged material had significantly higher diversity and evenness values and significantly lower density of macrofauna when compared to unaffected stations. The significant difference in diversity and evenness persisted for at least eight months after disposal. During this period, both diversity and evenness increased at affected stations until April and at the unaffected stations until June. A significant difference in density persisted throughout the ten-month post-disposal sampling period (Figures B-2, B-3, B-4). Density values also decreased significantly at the unaffected stations during the sampling period. This depression in the number of individuals at these sites was attributed to a series of intense winter storms occurring in December 1975 and January 1976, illustrating the strong seasonal fluctuations that may occur in shallow-water benthos.

The effects of sediment disposal on the abundance of the numerically dominant macrofaunal species was estimated by using the Friedman's two-way rank test. There was a significant reduction in the abundance of 11 of the dominant species at the stations exposed to direct burial as compared to the unaffected stations. Thirteen species showed no significant difference in abundance between
Figure B-2. The indicated diversity of benthic assemblages within the test site after disposal (Sept. 1975 – June 1976).

Sediment characteristics of the affected and intermediate stations were nearly identical in January 1976 and were treated as one set for subsequent samplings.
Sediment characteristics of the affected and intermediate stations were nearly identical in January 1976 and were treated as one set for subsequent samplings.
Figure B-4. Density (N/m²) for benthic assemblages within the test site after disposal (Sept. 1975 – Jun 1976).

Sediment characteristics of the affected and intermediate stations were nearly identical in January 1976 and were treated as one set for subsequent samplings.
affected and unaffected stations.

The species apparently most affected by the burial was the polychaete, Spiophanes bombyx. The disproportionate reduction in the abundance of this species compared to the abundance of other species at the station caused an increase in the evenness of species abundances and an increase in diversity values. Species density and species richness values were lower (except for September) at those stations exposed to direct burial, thus indicating the elimination of some species from the area.

There was very little evidence of introduced species at the test site after the disposal operation. Most of the dominant species present in the dredged material (from the navigation channel) were also present in low numbers at the test site prior to disposal. With a few possible exceptions, those species that were dominant at the dredge site were either missing entirely from the affected stations or were found in greater numbers at the unaffected stations compared to the affected stations.

Sediment samples from the dredged area contained 0.95-1.26 percent silts and clays, while sediments at the test site after disposal contained less than 2 percent fines. Turbidity levels during and after disposal were the same as those prior to disposal (Sternberg and others, 1977); therefore, it was concluded that turbidity and introduced substances in the water column had no significant effect on the benthic community in the area of deposition. Sediment samples were also analyzed for total organic carbon and nitrogen and a series of possible contaminants (sulphides, ammonia, oil and grease, Cd, Cu, Fe, Pb, Mg, Hg, Ni, Zn). Values for total carbon and nitrogen were low in the dredged sediment and in the sediments at the test site after disposal and were not significantly different for those values reported for the \textit{in situ} sediment at the test site prior to disposal. Values for possible contaminants were the same as would be expected for uncontaminated sediments (R. Holton, OSU, personal communication, 1977, as cited in Richardson and others, 1977).

The most apparent effect of the disposal on benthic assemblages was the significantly lower abundance of 11 of the 33 most abundant species present. In general, most of the species not
significantly affected by the disposal of dredged material were more motile species capable of burrowing or migrating considerable distances over sediments – shelled gastropods and molluscs, non-tube dwelling polychaetes, and cumaceans. Those species with a limited or no ability to burrow (tube dwelling polychaetes and amphipods) were probably eliminated from the site initially due to the effects of burial and smothering. The mechanism of the repopulation of benthos in the affected area is unknown but was probably accomplished by benthos burrowing up or migrating into the area, not as a result of the introduction of new species or larval recruitment into the area (Richardson and others, 1977).

The principle short-term effects of dredged material disposal on benthic communities include the following: the direct burial or smothering of benthos by the dredged material; the increased turbidity from the disposal operation or from the resuspension of dredged materials through current or wave action; the introduction of pollutants, trace metals, or organic material from the dredged material or from resuspension of sediments; and textural changes in sediment or substrate type (Saila and others, 1977). The investigators concluded that the primary short-term factor affecting benthic community at the test site was probably the direct burial or smothering from deposition of the dredged material. A second possible short-term factor could have been the change in sediment grain size at the disposal site.
Part B: The Effects of Dredged Material Disposal on Demersal Fish and Decapod Shellfish Studies

The purpose of this particular study was to describe the composition, abundance, and distribution of demersal finfishes and decapod shellfishes; to describe feeding habits of dominant finfish species; and to assess the impact of dredged material disposal on finfish and decapod shellfish species in the disposal area (Durkin and Lipovsky, 1977).

Baseline data were collected at four pre-selected sites to provide information on the temporal and spatial distribution of species of finfishes and decapod shellfishes. Two of the sites selected have been used as disposal sites by the Corps of Engineers in previous channel dredging operations (sites B and C). One site is located north of the Columbia River shipping channel, and the other is located to the south of the channel. Neither site received additional material during the course of the study, and the last disposal operation was completed in October 1974, just prior to baseline sampling phase of this study. Two control sites were selected (sites A and D), one to north of the shipping channel and one to the south, to serve as a basis for comparison between the sites used for prior disposal and sites with no prior history of disposal (Figure B-5).

During the second phase of the study, baseline studies continued at the four initial sites, and a fifth site (site E) was selected in July to serve as the experimental disposal site. This site is located to the south of the shipping channel and has no prior history of disposal. Bathymetric surveys performed after the disposal operation revealed that a semicircular mound approximately 760 m in radius and 1.5 m deep at the center had been created (Sternberg and others, 1977).

Samples were collected using an 8-m semi-balloon shrimp net with a 38-mm mesh net and a 12-mm cod liner. Two parallel tows of five minutes each were conducted at each site on a monthly basis, weather permitting. Samples were not collected at all sites from December through March due to
Figure B-5. Location of demersal sampling stations. From Richardson and others, 1977.
a heavy concentration of commercial crabbing gear in the area. Depths at the sampling stations varied between 17.5 m and 40 m. The experimental site was sampled more frequently during the actual disposal operation to assess direct impacts on numbers of finfish and decapod shellfish species. A subsample of the numerically dominant fish collected in tows from January 1975 through April 1976 was measured to determine the size structure of the population, and stomach contents were taken to determine trends in food utilization.

Diversity at the four comparative sites was variable, especially during the November 1974 through May 1975 sampling period (Figure B-6), largely due to the presence or absence of schooling northern anchovy in the study area. When high numbers of anchovy were caught, low diversity values resulted. Seasonal changes in species populations may occur but would require further investigation and exclusion of the variable catch of northern anchovy.

The range of diversity values observed at the test site did not differ substantially from the range of values observed at the other sampling stations. However, values at the test site were lower than those at the comparison sites for several months after disposal, then returned to values similar to those of the other sites within seven months of the disposal operation. This latent decrease in community diversity may be related to sediment deposition.

Species richness showed a lower trend based on fewer fish and species at the test site after disposal. Species richness values at the test site did recover by February 1976 and were similar to those values at the four comparative sites.

Evenness, or the distribution of individuals among species, also showed an instability from November 1974 to June 1975 due to presence or absence of northern anchovy. Afterwards, difference in evenness values were minimal at all sites, including the test site. This observed trend at the disposal site indicates a relatively consistent number of species apparently tolerant to
Figure B-6. The indicated diversity of demersal-associated finfish within the test site after disposal (October 1974 through April 1976).

Sampling at test site E began July 1975.
deposition were present at the site during and after the disposal.

Average catch per unit effort (CPUE), the average catch of fish per minute per trawling, and average monthly number of fish species caught per tow also showed seasonal variations (Figure B-7). The presence or absence of northern anchovy greatly affected the CPUE values during initial baseline study phase from November 1974 to May 1975. The CPUE values in general appeared to be higher at the sites located north of the shipping channel than those located to the south, thus indicating spatial variations for some dominant species. Whitebait smelt, English sole, and Pacific tomcod were present at all sites. Pricklebreast poacher and showy snailfish were predominant at the sites north of the navigation channel, and butter sole and sanddabs were predominant at the sites south of the navigation channel. Northern anchovy and longfin smelt were present at all sites except the test site. Average monthly number of species taken per trawl effort suggest seasonal variations in the number of fish species present. Generally, more fish were caught in the winter and spring than in the summer and fall (Figure B-8).

The CPUE values at the test site during and after disposal were consistently low. The number of species present at the test site was low during disposal and remained low afterwards. Average trawl catches at the test site had the lowest number of species of all sites sampled during the disposal, and at one and three months after the disposal. Seven months after the disposal, the average monthly number of species caught at the test site was similar to those values observed at the comparative sites.

Sizes of dominant fish species were measured to determine if one size class was more affected by sedimentation than another. Although the small numbers of fish collected at the test site make this comparison difficult, in general, it appears that fish at the test site were usually smaller than those sampled at other sites. Butter sole was the only species common enough to provide data for post-disposal comparisons. Individuals were larger at the test site in July, significantly smaller in the
Figure B-7. Comparative numerical catch of finfish per minute of trawl sampling effort (October 1974 through April 1976).

Sampling at test site E began July 1975.
Figure B-8. The average monthly number of finfish species captured (October 1974 through April 1976).

Sampling at test site E began July 1975.
August and September, and significantly larger in April. Sanddabs, English sole, whitebait, and longfin smelts and sand shrimp were smaller at the test site than at other sites during and after the disposal operation. These observations suggest the possible effects of sedimentation on different sizes of fish.

Changes in feeding habits are difficult to assess because fish may feed in another area prior to capture within the sampling site. Fish caught in the test during and immediately after disposal showed an increase in consumption of shrimp and small fish and a decrease in consumption of cumaceans, copepods, mysids, and amphipods compared to the diets of fish caught at the other sites. This change in food habit may indicate effects of disturbance on the community or it could be a normal seasonal variation in food selection for that area. One month after the test disposal, the feeding behavior of fish at the test site was similar to that of fish at the other four stations.

Crangonid shrimp species made up 95.9 percent of the entire decapod shellfish catch, while Dungeness crab accounted for only 3.8 percent of the catch. The greatest number of decapod shellfish species were collected during the November 1975 through April 1976 sampling period (Figure B-9). Similar results did not occur for the same season the previous year, thus no consistent pattern of seasonal availability was observed. Catches at the test site were low compared to the other sites during and immediately after disposal, although site D, also located to the south of the shipping channel, showed a similar pattern of low values. Six months after disposal, the test site had CPUE values similar to those observed at the other sites.

The investigators identified the following limitations of the study:

1. The study lacked a complete year of initial baseline data to establish the temporal and spatial distribution characteristics of dominant species.
Figure B-9. Comparative numerical catch of decapod shellfish per minute of trawl sampling effort (October 1974 through April 1976).

Sampling at test site E began July 1975.
2. The designation of the test site location was made just prior to the disposal operation, thus limiting the amount of sampling at the site prior to disposal.

3. Because deposition by the dredge vessel was made in a semicircular track at various distances from the marker buoy, trawl samples were taken partially from areas not within the zone of deposition.

Despite these limitations, it appears that dredged material disposal did have an affect on the community structure values at the test site. Species diversity, species richness, and catch per unit effort values, which were similar initially to those of the other sites, fell during or after deposition but within seven months of cessation of the disposal operation returned to values corresponding to those from the other sites. Since no sampling occurred at the test site prior to disposal, it was assumed that the test site had a species assemblage similar to those at the other sites located south of the shipping channel.
Summary of Operations: WestGold, Nome, AK

In 1985, Inspiration Mines, Inc. (now Western Gold Exploration and Mining Company, Limited Partnership, or WestGold), initiated mining operations offshore of Nome, Alaska. The leased area is approximately 4 km offshore and extends 18 km along the coast, approximately 21,750 acres. A clamshell bucket and crane supported by a platform dredge were used in the start-up operation, then in 1986, the Bima, a large bucket-line mining vessel, was purchased for subsequent mining operations. The Bima is capable of recovering 45,800 m$^3$ of material per day with a process water discharge of 47.8 million gallons per day. Typically, the Bima processes between 7,600 and 15,300 m$^3$ of sediment per day. Currently, the vessel operates in 5 m to 13 m of water and digs to a depth of 10 m. In addition to actual mining activities, exploration activities (i.e., core samples) take place throughout the year, while mining is restricted to only the ice-free season, mid-May to September. After three seasons of operation, approximately 225 acres have been mined and approximately 75,000 fine ounces of gold recovered (Rusanowski and others, 1989).

Through a series of public hearings, written testimonies, and agency discussions held during the permitting process, a list of environmental concerns and issues was compiled. These concerns served as a guideline for the development of the biological monitoring program, which then focused on providing answers to these concerns. A Project Review Committee was formed, including representatives from state, federal, and local agencies, mining project groups, and special interest groups. The purpose of this committee is to comment and review the work is currently underway rather than reviewing the project on an annual basis.

The major environmental issues are as follows:

1. Possible interference with present subsistence uses of the area through the loss of habitat, user accessibility, or animals avoiding the mined area.
2. Protection of renewable resources, particularly cod, salmon, herring fry, clams, shrimps, king crab, and seals.

3. Potential mercury contamination of the food chain, bioaccumulation, or increased mercury levels in some species (the area offshore has naturally high levels of mercury due to the covariance of mercury and gold, and from historical mining operations that used mercury (U.S. Department of the Interior, 1988)).

4. Increasing mercury levels in the natural environment through the resuspension of mercury already in the sediment.

5. Degradation of the natural environment due to increased turbidity, smothering of habitable substrate, or possible interference with salmon migration.

6. The need for baseline data for the area to use as a basis to assess impacts.

7. Disruption of benthic habitat, specifically, the alteration of bottom topography or substrates, and the possible impacts these changes may have on benthic invertebrate communities, colonization rates, and king crab utilization of the area.

8. Possible impacts on the king crab fishery through loss of habitat or food sources or avoidance of mining area.

9. Dangers due to possible fuel spills or weather-related damage.

10. The ability to modify the monitoring program to address new issues or concerns.

Briefly, the monitoring program consists of a water- and sediment-quality component and a
biological component designed to assess the potential effects of mining on the local ecosystem and subsistence resources. The program was developed in two phases, a pre-mining phase initiated in 1985 to collect biological and physical data in the Nome offshore area, and a second long-term monitoring phase initiated in 1986. This long-term environmental monitoring program consists of five areas that focus on the issues and concerns identified during the permitting process.

Side-scan sonar and bathymetric surveys are performed annually to assess changes in the seafloor topography. Sites are sampled in the mined area, in control areas, and at subsistence-use areas to provide a basis for distinguishing between changes resulting from the mining operation and those from natural occurrences. Surface-sediment samples are collected from each station used for benthos collection, using a 0.1-m² grab to a depth of 10 cm. Three replicates are obtained from each station, once per year.

Belt transect surveys are conducted once per year at each benthos station to assess king crab abundance and distribution. During the ice-covered season, a remote operated underwater vehicle (ROV) is used to videotape selected locations. The number and size of observed king crabs is used in the assessment of crab abundance and distribution. Sediment type is noted during crab observations to correlate preferred substrates with crab abundance and distribution. Also during the ice-covered season, daily and short-term movement of king crabs are assessed by capturing crabs, then releasing them with sonic tags. Catch rates for king crabs are also compared for mined and non-mined areas.

Benthos samples are collected at six sites within the mined, control, and subsistence use areas. Samples are collected from a 0.1 m² area using a Venturi-jet suction pump and a 1.00-mm mesh collection bag. Infauna are collected once per year during the ice breakup period in mid-May. A series of 35-mm photographs are also taken to document the sample site. Results are compared between seasons to look at recolonization rates of the mined substrate.
Water- and sediment-quality parameters are monitored according to a sampling regime specified in WestGold's National Pollutant Discharge Elimination System (NPDES) permit administered by the U.S. Environmental Protection Agency (EPA). The monitoring program includes the measurement of turbidity, salinity, temperature, and dissolved oxygen levels as well as testing for eight priority trace metals (As, Cd, Cr, Cu, Pb, Hg, Ni, Zn). Sampling locations include Bima process waters, the down current plume, and background control locations. These results are submitted in monthly Discharge Monitoring Reports to the Water Compliance Section of the EPA. This information is also provided in the annual report of the Project Review Committee (Rusanowski and others, 1989).

Six sampling stations were established within the leased area. Two sites, R6 and R7, were selected within the "footprint" left by mining activities. Two sites, C2 and C3, were used as controls and were located adjacent to the mining sites, and two sites, S2 and S3, were subsistence-use sites, located approximately 10 km away from the mining sites. The two subsistence-use sites were also considered as control sites (Figure C-1).

During the 1988 mining season, data were collected for a three dimensional water quality and sediment-plume model, Disposal From a Continuous Discharge (DIFCD), developed by the US Army Corps of Engineers Waterway Experiment Station (Demlow and others, 1989). The plume-monitoring program consists of a moored, up-current monitoring station that serves as a control station and a down-current station that provides information on the dispersal pattern of the effluent plume. Turbidity, conductivity, and current speed and direction are measured as well as wave frequency, magnitude, and tidal changes. Portable instruments are used to make transects through the plume to define the shape and extent of the plume. Turbidity is measured using a nephelometer, which optically measures the amount of suspended particles in the sample. Sediment traps are samples provide information as to how far different sediment types travel from the point of discharge until they eventually resettle. Sediment samples are collected directly from the bucket line at the dredge site to identify the substrate composition currently being mined. The data collected located through out the study area at various distances from the point of effluent discharge. The
Figure C-1. Map of sampling stations for WestGold mining operations. From Rusanowski and Gardner, 1989.
data collected during this sampling phase is used as input for the Wave-Current Sediment Resuspension Prediction model (WCSRP), which was developed to analyze the resuspension of bottom sediments.

The DIFCD model and sediment-resuspension model were used to determine at what distance from the point of effluent discharge water-quality standards are met, what range of conditions can be expected to be encountered during the life of the mining project, and which discharge configuration (discharge depth, discharge rate, diameter of discharge pipe, use of deflectors, etc.) results in the lowest possible turbidity and trace-metal concentrations at the edge of the plume mixing zone.

Results from the sediment surveys and side-scan sonographs revealed observable changes in the seafloor sediment type at the control area (Table C-1). This area was monitored to observe impacts from naturally occurring disturbance to the area and to assess natural sediment migration of the area. This site was not subjected to mining activity. In general, changes in overall seafloor sediment type composition were observed over the 1985-1988 sampling period, with the cobble fraction decreasing, and the sand/silt fraction increasing compared on an annual basis. These fluctuations are considered to be natural, but further evaluation of this area will be necessary to establish sediment migration. Results for the mined areas showed an overall increase in coarse-grained material, with an overall decrease in fine-grained material. This is probably due to the sorting of tailings at the outfall and considerable amounts of suspended fine grained material being removed from the area through current movement thus exposing the coarse-grained materials.

A survey of catch rates of red king crab was conducted in March of 1988, including site R6 (mined in 1986), site R7 (mined in 1987), and control site C2. Over a 10-day period, a total of 98 crabs were caught at the three sites (Jewett and others, 1989). The catch per unit effort values were not significantly different among sites. Similar results were observed during the 1987 sampling season.
Table C-1. Multi-year comparison of the percent composition of seafloor sediment at each sampling station. (From side-scan sonar surveys)

Control Area C2

<table>
<thead>
<tr>
<th>Sediment Type</th>
<th>1985</th>
<th>1986</th>
<th>1987</th>
<th>1988</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobble</td>
<td>58.2</td>
<td>62.0</td>
<td>N/A</td>
<td>53.9</td>
</tr>
<tr>
<td>Sand Wave</td>
<td>3.9</td>
<td>0.7</td>
<td>N/A</td>
<td>7.0</td>
</tr>
<tr>
<td>Sand/Fine Gravel</td>
<td>0.0</td>
<td>0.0</td>
<td>N/A</td>
<td>0.0</td>
</tr>
<tr>
<td>Sand/Silt</td>
<td>37.8</td>
<td>37.3</td>
<td>N/A</td>
<td>45.4</td>
</tr>
</tbody>
</table>

Mined Area R6

<table>
<thead>
<tr>
<th>Sediment Type</th>
<th>1985</th>
<th>1986</th>
<th>1987</th>
<th>1988</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobble</td>
<td>11</td>
<td>mined</td>
<td>0</td>
<td>42</td>
</tr>
<tr>
<td>Sand Wave</td>
<td>4</td>
<td>mined</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Sand/Fine Gravel</td>
<td>44</td>
<td>mined</td>
<td>30</td>
<td>11</td>
</tr>
<tr>
<td>Sand/Silt</td>
<td>41</td>
<td>mined</td>
<td>70</td>
<td>42</td>
</tr>
</tbody>
</table>

Mined Area R7

<table>
<thead>
<tr>
<th>Sediment Type</th>
<th>1986</th>
<th>1987</th>
<th>1988</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobble</td>
<td>46</td>
<td>mined</td>
<td>3</td>
</tr>
<tr>
<td>Sand Wave</td>
<td>4</td>
<td>mined</td>
<td>2</td>
</tr>
<tr>
<td>Sand/Fine Gravel</td>
<td>23</td>
<td>mined</td>
<td>18</td>
</tr>
<tr>
<td>Sand/Silt</td>
<td>20</td>
<td>mined</td>
<td>77</td>
</tr>
</tbody>
</table>

From Rusanowski and Gardner, 1989.
Indirect impacts on the king crab are determined by examining stomach contents of crabs to determine major food items on mined and non-mined areas. Crabs taken from mined areas showed no significant difference in quantity or composition of food in the stomachs (Jewett and others, 1989). In 1988, eelgrass was identified as a new food source for crabs collected in the mined areas. Observations made from ROV surveys in the mined areas showed accumulations of eelgrass in the depressions left by mining activities. It appears that mining activities did not affect king crab utilization of mined substrates. This is probably due to the opportunistic feeding habits of the red king crab.

Trace metal analyses are conducted on king crabs and on their major food items. The sampling of organisms from higher trophic levels (i.e., fishes, seals, etc.) is conducted only if organisms are provided to the program. At present, this is a voluntary task in the monitoring program. Results from trace metal analyses of king crab tissues indicate that all metal levels were within an order of magnitude of values reported in literature from other areas. The average mercury concentration values for king crab muscle tissue were within an order of magnitude those reported for other locations in Alaska. All trace metal levels except copper, were found to be present at lower levels in crab tissue samples than in sediment samples. Crab blood plasma contains hemocyanin, which is comprised of copper subunits; therefore, it would be expected that crab tissues would contain relatively high levels of copper. After three years of monitoring, king crab have shown no general increase in trace metal levels through time and do not pose a health risk to subsistence users (Jewett and others, 1988).

Since the substrate is being removed and redeposited, there is almost complete destruction of fauna in the mined area. A major component of the biological monitoring program focuses on defining the amount of disturbance and determining the rate of recolonization and the species composition of the resulting community. It is difficult to resolve such issues after only three years of data, but preliminary findings suggest that two years after mining in sand substrates, an assemblage of infauna has recolonized that is similar to those communities at unmined sites.
Comparisons of total number of taxa, density, and biomass of organisms collected from control and subsistence-use sites indicate that some year-to-year variation occurs at control stations, although no consistent patterns of increase or decrease are evident. Diversity indices and species richness values also show no apparent trends between years at any stations (Figures C-2, C-3).

Warwick (1986) suggested that the distribution of the number and biomass of individuals among species respond differently to disturbance. This difference can be demonstrated by the comparison of k-dominance curves for abundance and biomass of the species in the community. Species are ranked in order of importance on the x-axis (logarithmic scale) and percentage dominance on the y-axis (cumulative scale). In undisturbed communities, the species biomass curve will be above the species number curve; in a moderately disturbed community, the two curves will more or less coincide, and in a grossly disturbed community, the species numbers curve will lie above the species-biomass curve (Figure C-4). This procedure was originally used to detect pollution-induced effects on benthic communities but was later applied as a means of assessing natural and biological disturbance as well (Warwick and others, 1987).

Results of this analysis for the 1988 sampling season indicate that some level of natural disturbance was evident in three of the four unmined sites (Figures C-5, C-6) (Jewett and others, 1989). Control-site C2 showed some degree of disturbance for the two highest ranked species, while subsistence-sites S2 and S3 showed more moderate levels of disturbance throughout the community. Disturbances may be intense ice scouring and mounding during the ice-breakup period. Control-site C3 showed no evidence of disturbance within the community. Mined-sites R6 and R7 reflected moderate levels of disturbance (Figures C-7).

Two stations were selected to monitor recolonization of benthic organisms following mining activities. Station R7 was mined in 1987, and R6 was mined in 1986. Post-mining data have been collected for one year at site R7 and for two years at site R6. Results from site R7 indicated
Figure C-2. Biomass and density values for sampling stations. From Rusanowski and Gardner, 1989.
Figure C-3. Diversity and number of taxa for sampling stations. From Rusanowski and Gardner, 1989.
Figure C-4. Hypothetical k-dominance curves as described by Warwick (1968) and Warwick and others (1987). (A) Undisturbed when the biomass curve lies above the numbers curve; (B) moderately disturbed when the biomass and numbers curves more or less coincide; (C) grossly disturbed when the numbers curve lies above the biomass curve.
Figure C-5. K-dominance curves for sites C2 and S2. From Rusanowski and Gardner, 1989.
Figure C-6. K-dominance curves for sites C3 and S3. From Rusanowski and Gardner, 1989.
Figure C-7. K-dominance curves for sites R6 and R7. From Rusanowski and Gardner, 1989.
extremely low values for density and biomass compared to unmined sites. These findings were similar to those found one year after mining at site R6. The k-dominance curves for site R7 showed the benthic community to be moderately disturbed.

Density and biomass values increased between 1986 and 1987 at site R6. Faunal dominance for the site shifted from crustaceans to polychaetes. In the 1987 survey, one year after mining, polychaetes accounted for nearly 20 percent of the species abundance, while crustaceans, particularly cumaceans, accounted for 66 percent of the species abundance. In 1988, two years after mining, polychaetes accounted for nearly 75 percent of the faunal population. Although the 1988 sampling revealed increases in both biomass and density values, the k-dominance curve reflected some disturbance at the site for the highest ranking species. The curves from 1987 indicate a relatively undisturbed community, whereas the 1988 curves are more characteristic of a moderately disturbed community (Figure C-8). Although the 1987 curves revealed no signs of disturbance within the community, the number of taxa, density, and biomass values all were extremely low compared to unmined sites. The density and biomass of the community apparently decreased proportionately, thus masking any evidence of disturbance that would have been born out in the k-dominance curves. Therefore, the curves must be used in conjunction with the other parameters (Jewett and others, 1989).

In conclusion, the low biomass and density values at site R7 one year after mining were similar to those values at R6 one year after mining. The k-dominance curves also indicated disturbance at the mined site, presumably as a result of mining activities in 1987. Results for site R6 (two years after mining) showed an increase in biomass and density values over the 1987 results (one year after mining), although the k-dominance curves still indicate some level of disturbance in the community. A comparison of k-dominance curves for R6 from the 1987 and 1988 surveys indicates that the community appears to be approaching an undisturbed state.

An identical benthic monitoring program was also performed for cobble substrate. The community-structure parameters (number of taxa, density, and biomass) on cobble substrate were variable, but
Figure C-8. Comparison of k-dominance curves for site R6 for years 1987 and 1988. From Rusanowski and Gardner, 1989.
not as variable as those observed on sand substrate. No consistent patterns of increase or decrease were apparent. One year after mining the cobble substrate, the number of taxa, density, and biomass were extremely low compared to unmined sites. Two years after mining, the community was still characterized by few taxa, low numbers of individuals, and low biomass. It appears that recolonization of cobble lags behind that of sand.

Trace metals of naturally occurring elements were analyzed for sediment samples collected from stations down-current of the *Bima* processing plume and from stations located within a control area. Down-current and background trace-metal levels in the sediment were usually not statistically different. Arsenic showed a higher concentration value at the control site compared to the value from the down-current site, an average value of 65.9 mg/kg versus 56.1 mg/kg, while cadmium concentration values were lower at the control site than at the down-current site, with an average value of 0.63 mg/kg versus 2.6 mg/kg. These differences could be due in part to the effects of redistribution of particles being discharged from the *Bima*.

The State of Alaska established a 500-m mixing zone for the dilution of effluent from the mining operation. At the edge of this zone, all water-quality criteria must be met. A 100-m mixing zone for trace metals is required by the EPA. In general, trace-metal criteria for water quality for all eight priority elements were met, with the exception of copper and mercury. Where effluent copper levels exceeded permit allowances, the influent levels did as well. Due to mercury contamination in the *WestGold* laboratory during the 1988 sampling season, all mercury data are suspect (Jewett and others, 1989). Concentrations of both lead and zinc were lower in the effluent samples than in the influent samples, thus indicating the probability of particle adsorption of these elements by the sediment during the processing operation. Although the data indicates, that the mining operation is not increasing trace-metal concentrations outside the mixing zone, contamination and analytical problems do not allow definitive conclusions to be drawn at this time. A more rigorous trace-metal monitoring program is being designed to resolve these issues in the future.
Turbidity values ranged from 0 to 213 NTU (Nephelometric Turbidity Units), with 0 being considered the natural background-turbidity level for the area. The majority of readings during the sampling period fell in the 0 to 20 NTU range. A value of 25 NTU above the background level was considered an acceptable level. Values greater than 130 NTU were considered to be inflated, due to the resuspension of sediment or errors in instrument readings (Demlow and others, 1989).

Visual observations of the plume suggested that the width of the plume could vary greatly on a day-to-day basis and within a day. The variance in plume width was greatly influenced by the local oceanographic conditions and the sediment-silt content of the material being mined.

Sediment-trap samples located 1,500 m from the point of effluent discharge were comprised mainly of silt with some sand. Samples from the 500-m station were mainly fine sands. Samples collected from the bucket line showed that the substrate being dredged ranged from coarse sands to well-graded silts, with silt contents ranging from 6 to 40 percent. During periods of high wave activity, resuspension of previously settled material probably accounted for a significant portion of the turbidity observed.

A comparison of effluent turbidity data collected from the edge of the 500-m mixing zone during the 1987 and 1988 seasons indicates that substantially lower turbidity values were recorded in 1988 due to the implementation of a discharge jet that does not entrain air, which causes portions of the effluent plume to rise to the surface. However, discharge configurations (discharge depth, discharge rate, diameter of discharge pipe, use of deflectors, etc.) tested in the field indicated that no configuration resulted in substantially lower turbidity values. Any observed variations in plume width due to a particular discharge configuration could not be distinguished from variations caused by the influence of changing oceanographic conditions or the composition of the material being mined.

Using data collected on days when the turbidity level exceeded the 25 NTU above background
criterion at the edge of the 500-m mixing zone, the DIFCD model was used to predict at what distance acceptable turbidity level would have been reached. The model predicted that the maximum distance from the point of effluent discharge where the criterion would have been met was 900 m, with the average distance being 725 m.

The model was also used to determine which discharge configuration would result in the lowest turbidity values at the edge of the 500-m mixing zone. The model could not predict any one configuration that would result in the lowest turbidity values for all possible mining conditions that may be experienced during the life of the project. The model was then used to predict what turbidity level would be encountered during the life of the mining project. The model predicted that for substrates comprised of low percentages of silts (less than 6 percent) and effluent discharge rates of less than 50 million gallons per day, the turbidity level at the edge of the 500-m mixing zone would comply with the 25 NTU above background level criterion. With higher silt percentages and greater discharge rates, turbidity levels could be as high as 162 NTU at the edge of the 500-m mixing zone.

The DIFCD model makes several assumptions that limit the effectiveness of the model results. The model does not allow for the resuspension of bottom particles; once materials have resettled on the seafloor, they remain there. A second limitation is that the model was developed in such a way as to assume that the vessel speed or local currents are strong enough to cause a "bending of the jet" before the bottom is encountered. The final assumption of the model is that the settling of suspended particles occur at a constant rate.

Much of the ongoing monitoring program is focused on providing sufficient data to show that renewable resources are not being significantly impacted by mining activities. Because the nearshore surf zone is a critical habitat for short periods of time during the summer, no mining activities take place within 0.4 km of the shore or in depths of less than 2.4 m. No mining is done within 1.6 km around the mouths of all known streams with anadromous runs of fishes. Water
intakes for the *Bima* are screened to prevent entrainment of large animals, and intakes are positioned so that animals may swim by the front of the intake without becoming caught in the system.
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