WASHINGTON STATE

COASTAL WASHINGTON
A Synthesis of Information

OFFSHORE OIL & GAS

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About the Ocean Resources Assessment Program

In April 1992, the Minerals Management Service (MMS) of the U.S. Department of the Interior (DOI) plans to conduct Lease Sale 132 for offshore oil and gas exploration and development in federal waters on the outer continental shelf off the coasts of Washington and Oregon. This agenda has been the driving force behind recent Washington state actions on this issue. (Earlier, the State Department of Natural Resources had imposed a moratorium on leasing for oil and gas inside state waters.)

The Governor of Washington has asked MMS to delete about half of the lease sale area off the Washington coast and has joined Oregon, California, Massachusetts, and the National Resources Defense Council, an environmental group, in lawsuits against DOI, challenging its current Five-Year OCS Oil and Gas Leasing Program. Meanwhile, MMS is sponsoring several pre-lease environmental studies, and, at this writing, the first step in the sale process is less than one year away. In November 1989, MMS plans to request that oil and gas industry members indicate their level of interest in Lease Sale #132. Under the present plan, if industry interest is sufficiently high, successive steps in the lease sale process will proceed.

Through the Western Legislative Conference in 1986, members of the Washington Legislature became concerned that the state was unprepared for the potential development being planned by the federal government. Engrossed Substitute Senate Bill (ESSB) 5533 was the result. It became effective law on July 26, 1987. Of the $800,000 originally requested, the Legislature appropriated $400,000 to Washington Sea Grant to conduct the studies mandated by this law.

Why Sea Grant? First, the University of Washington has a renowned College of Ocean and Fishery Sciences, and Sea Grant is an effective pathway to that expertise. Second, Sea Grant is experienced in interdisciplinary research design, procurement, and administration. Third, Sea Grant has a communications network with other universities, giving Washington State quick access to nationwide expertise. Fourth, part of Sea Grant's mandate is to work with academe, government, and industry, without political advocacy, in a non-regulatory, information-support role. Last, Washington does not practice statewide planning, and assigning responsibilities of ESSB 5533 to a mission-oriented state agency might have created concerns over objectivity and fairness.

This law is ocean information oriented, as compared to Oregon's C-ESB 630, which is ocean management oriented. Management could be the next step for Washington State. Through its Ocean Resources Assessment Program (ORAP), Washington Sea Grant is synthesizing existing scientific information. The Legislature's Joint Select Committee on Marine and Ocean Resources acts as oversight committee for ORAP. In the 1989 Legislative session, convening in January, ORAP is to report its findings about information gaps and research needs and to present a plan for future studies.

In designing ORAP, an overall guideline was the determination to benefit from the experience of others and to not duplicate past and current studies. Thus, ORAP has sponsored little original research but has concentrated on synthesis and planning. ORAP consists of seven projects, including the study from which this book is derived:

- ***Coastal Washington: A Synthesis of Information***—a report on existing information, information gaps, and research needs.
- ***Coastal Oceanography of Washington and Oregon***—a regional oceanography text, making contributions to science on 15 of the 22 subjects mentioned in the law. Multi-edited and authored, the hardcover book presents the results of many years of research. Sea Grant funded the final efforts needed to make the book available in time to influence OCS decision-making and future research.
- ***An Assessment of the Oil and Gas Potential of the Washington Outer Continental Shelf***—an assessment by the Washington Department of Natural Resources, to help identify geologic formations that might be of potential interest to industry.
- ***State and Local Influence Over Offshore Oil Decisions***—a study of the roles and mechanisms of state and local governments in offshore oil decision-making, as revealed by experience in other states.

• ***Information Priorities: Final Report of the Adivsory Committee***—Sea Grant recognized the need for broad educational base-building among the policy-makers in state and local governments, tribal authorities, and citizen groups. Ten legislators, equally split by party and body, were members of this advisory committee. Sea Grant devised an innovative approach to help the 32 members of this committee educate themselves quickly about the offshore oil and gas industry and its typical facilities, equipment, operations, and impacts. The committee functioned like a task force and reported to Sea Grant on information needs and priorities. This project is a worthy model for others who must deal on a tight schedule and budget with new, complex issues of high public concern.

• **Conceptual Framework for Future OCS Research**—a workshop to develop a framework to help determine "what's important?" and ensure that future research is both targeted and well-founded scientifically.

• **OCS Studies Plan: A Report to the Washington State Legislature**—a plan developed by Washington Sea Grant, as required by law, building upon the other ORAP projects and other studies.

Washington Sea Grant is publishing reports of each of these projects, except for the coastal oceanography text, which is being published commercially by Elsevier Science Publishers. Meanwhile, the Legislature's Joint Select Committee on Marine and Ocean Resources is grappling with statewide policy alternatives and may propose legislation for the 1989 regular session.

B. Glenn Ledbetter, Manager, ORAP
November 1988

Preface

This book represents an attempt to survey a very large amount of material in a relatively small space. Some aspects of the subject matter, such as the generic fates and impacts of oil, had been summarized recently by experts, making our job easier. However, the main task of this project—to assemble and integrate existing knowledge of the natural and human environment of coastal Washington—had never been done before in this way. This information vacuum needed to be filled rapidly, because of the inexorable schedule of the Outer Continental Shelf leasing process. Washington state needed to gear up as soon as possible, and the instructions to Sea Grant from its Legislature were strict. For preparation of this book, from conception to completion, only ten months were available.

The tight scheduling and budget restrictions, and the breadth of the task, meant that many compromises had to be made, and reasonable shortcomings tolerated. This document is therefore intended as a starting point in studying and understanding Washington's coastal environment, and how it may change if and when offshore oil and gas development takes place. We hope that it stimulates further thought and research, and helps the state minimizes its costs and maximize its benefits whether or not oil and gas are ever produced.

Richard Strickland
Daniel Jack Chasan
December 1988

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We prepared this document under the direction of B. Glenn Ledbetter, manager of the Washington Sea Grant Ocean Resources Assessment Program, and Louie Echols, director of Washington Sea Grant. The Sea Grant staff showed tremendous patience and understanding during the writing process. Special thanks go to Dr. Alyn Duxbury, who gave freely of his time and extensive oceanographic background and expertise.

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Executive Summary

Offshore oil and gas development may reach Washington's Pacific coast around the turn of the century. If the state were to wait until the first drilling rig appeared offshore, it would already be too late to maximize state benefits and minimize risks. Now is the time to assemble what is known about offshore oil and gas, about the natural and human resources of Washington they could affect, and about the state's options for responding to a new coastal industry.

Petroleum hydrocarbons (oil and gas) are essential to the economy and national security of the United States. Ninety-five percent of the energy that drives America's transportation system comes from petroleum. The nation consumes 16 million barrels of oil a day, and will continue to depend heavily on oil and gas well into the next century. Currently, the United States imports about 43 percent of its petroleum, adding to the trade deficit and weakening national security. There are many possible ways to deal with the nation's need for petroleum and its dependence on imports: through a comprehensive national energy policy, by tightening mileage standards for American-made cars, and by promoting home-heating efficiency and alternative energy research, to name a few. One way the federal government has decided to meet the nation's energy needs is to develop more domestic oil and gas supplies on the outer continental shelf, where an estimated 30-60 percent of undiscovered U.S. petroleum reserves are believed to lie.

SCENARIOS FOR DEVELOPMENT

Leasing of federal lands for petroleum development on the outer continental shelf (OCS), between 3 and 200 miles offshore, is conducted by the Minerals Management Service (MMS), a branch of the Interior Department. The Minerals Management Service's current Five-Year Plan calls for a sale of tracts off Washington and Oregon in April, 1992. Under this schedule, if industry buys leases and finds commercial quantities of hydrocarbons in test wells, oil and/or gas production would begin around the year 2000.

The MMS leasing process gives Washington state no direct power to decide whether oil development will proceed. State government can request that large or special areas of the outer continental shelf be deferred from leasing, and it (or other groups) can try to oppose or delay the process in court. Beyond that, the questions become how to maximize state revenues and local jobs; how to site, schedule, and establish stipulations for offshore oil activities in ways that will minimize harm to fish, shellfish, birds, mammals, fishing, and tourism; how to preserve coastal aesthetics; and, in the case of a larger-than-expected find, how to cushion the social and economic impact of large numbers of workers funneled into small communities.

MMS currently estimates there are economically recoverable undiscovered oil and gas reserves equivalent to 50 to 60 million barrels of oil in the proposed Washington/Oregon lease area. That figure can be compared with estimates of 340 to 770 million barrels off southern California, and 7.7 to 8.7 billion barrels in the western and central Gulf of Mexico. *The current Washington/Oregon supply estimate is enough to fuel the nation for about three days.* MMS argues, though, that to dismiss a few days' supply as insignificant would be missing the point:

> Suggestions are sometimes made that the relative importance of developing a prospect can be gauged in terms of the number of days it alone could satisfy national petroleum needs. However, if the test for proceeding with oil and gas development in a prospect were whether it contained more than several days' supply for the nation, little energy would be developed domestically. . . Over 80 percent of all known OCS oil and gas reserves are in fields containing 1 day's supply of oil or less. . . It is the cumulative contribution of all these small fields, along with the few really large ones, that constitutes the nation's domestic petroleum production.

This document was produced under the direction of legislation (ESSB 5533) passed by the Washington State Legislature in 1987, with instructions to report to the 1989 legislative session. The assignment was "to conduct a comprehensive synthesis and analysis of existing data, studies, and expertise about human, environmental, and natural resources" in the state that could be affected by offshore oil and gas development, and to identify gaps in that knowledge and research plans to fill those gaps. In response to this legislation, the Washington Sea Grant Program has issued a family of reports under the heading *Washington State and Offshore Oil and Gas.*

This report summarizes existing knowledge about natural and human resources of Washington's coastal region and outer continental shelf, and about factors that will determine the effects of offshore oil and gas development on those resources. This report also identifies gaps in that knowledge that may limit the ability to analyze potential oil and gas impacts. It was beyond the scope of our effort in assembling this knowledge to generate data, studies, or expertise that did not already exist. It was likewise beyond our scope to develop or analyze formal scenarios for offshore development and its impacts, or to conduct a rigorous risk assessment.

In this document, we present information gaps but offer no prescription for how they should be filled. We assign no priorities for future research, nor do we describe or endorse particular studies. These questions are addressed by others, in a plan for further research published as a companion volume in the series *Washington State and Offshore Oil and Gas.* We recognize that future studies will be subject to time and funding constraints, and must be targeted at specific activities and questions arising from the petroleum development process. Therefore, our identification of topics on which knowledge is lacking is not intended as a call for endless, indiscriminate research to be conducted in advance of decision making.

This document is not a formal environmental impact statement (EIS) for petroleum development off Washington. It is a generalized overview intended to provide the state with an advance look at information and issues that are likely to be important in assessing environmental impacts. As the federal offshore leasing process proceeds, formal impact statements will be required of the Minerals Management Service and the industry. Those EIS's will be much more detailed and will analyze site-specific, project-specific impacts. As a result, general figures and concepts presented in this document may no longer apply or may be revised.

The authors of this document were directed to make judgments about the state of knowledge of resources and potential impacts, and have done so. These judgments do not constrain the outcome of research and analysis yet to come. Future studies and forthcoming EIS's, conducted by different individuals using this body of knowledge and some different methods and information, may reasonably produce different judgments.

This document does not evaluate or advocate policies or management measures for the state to adopt supporting or opposing offshore oil and gas development. Instead, it presents information to be used in developing such policies. A review of policies and management responses in other states is published as a companion volume in the series *Washington State and Offshore Oil and Gas.*

This document reviews only superficially what is known about the magnitude, location, and chemical nature of petroleum deposits off the Washington coast. This subject is dealt with in greater detail in a companion volume in the series *Washington State and Offshore Oil and Gas.*

The geographic scope of this report is the Washington outer coast from Cape Flattery to the mouth of the Columbia River, including the Grays Harbor and Willapa Bay estuaries. Although they possess significant resources that could be affected by oil and gas development on the outer continental shelf, the Strait of Juan de Fuca and the Columbia River estuary were generally excluded from this study. The resources of these water bodies have been the subject of previous reviews. *There has been little study, however, of the potential impact of offshore oil and gas development on the Columbia River estuary, a subject that deserves further study.*

MMS also considers the possibility of a larger-than-expected find, and wants all coastal areas of the nation to share the benefits and environmental risks of offshore production.

In fact, if oil is found off Washington and Oregon, MMS expects more than 50 to 60 million barrels. That may seem paradoxical, but the 50-60 million figure takes into account an 80 percent probability of finding nothing. Assuming something is found, MMS's estimates of reserves increase to the equivalent of 243 million barrels of oil (58 million barrels of oil and 1.043 billion cubic feet of gas). A single production platform would drill about 30 wells and stay in place for up to 35 years. The oil or gas would be brought to shore by tanker or pipeline. This scenario of 243 million barrels equivalent and one platform is referred to here as the "low case." MMS also projects a "high case" scenario, in which roughly three times as much oil and gas would be found and three platforms would be needed. However, *MMS's reserve estimates and the methods used to obtain them remain open to question. Independent estimates of oil reserves might give different results.* That is why the lease sale process is conducted by sealed bidding.

In general, both the positive and negative risks of petroleum development are proportional to the scale of that development. The projected scale of development off the Washington and Oregon coasts is modest. Therefore, the impacts would probably be modest, too. If the projections of oil and gas deposits off the Northwest Coast prove low, then the current projections of impact will be low, too.

Whatever the scale of development, *the economic and national security benefits of offshore oil and gas production would flow largely to the nation as a whole and to the industry*— which, at a minimum, would net $130 to $486 million over the life of the field, depending on the price of oil. *But the social and environmental costs of development would be borne largely by the coastal communities and states.*

The main benefit for coastal communities would be jobs. The number of jobs created would be directly proportional to the scale of development. The Washington coastal economy is chronically depressed. Unemployment has been significantly higher than the state average. The development stage, in which production platforms are installed and wells are made ready for production, would provide the largest number of jobs. In its socioeconomic impact, development would be like a large construction project on the coast. Most of the employment would consist of construction jobs, rather than skilled positions on the offshore rigs. Not all the jobs, and virtually none of the highly skilled jobs, would go to local residents. MMS's low case scenario predicts offshore oil would provide 1,176 jobs during the development stage. After production began, the work force would shrink rapidly. MMS predicts 124 long-term jobs. If there were more oil and gas than expected, the number of jobs would be higher. *Offshore development on the scale that MMS predicts would create few jobs but, in the more sparsely populated areas of the coast, they might be especially welcome.*

Negative impacts can be characterized as minor or major. In this industry, minor impacts have a high probability of occurring, and major impacts have a low probability. "Minor" does not mean "negligible." Minor impacts can affect human and natural resources, and can require mitigation. They can arise from either gas or oil development. Major impacts on marine resources would most likely result only from a large oil spill—caused by a well blowout or a tanker or pipeline accident—that struck a sensitive area of the coast.

IMPACTS IN THE ABSENCE OF A MAJOR SPILL

SOCIAL EFFECTS

The more workers who were attracted to the coast from other places, the greater the impact on coastal communities. Experience in Grays Harbor County during the Satsop nuclear construction project and elsewhere during oil development suggests that an influx of workers might increase: housing prices; certain kinds of crime; traffic on some roads; the demand on social services; the need for government spending. Local government revenues might or might not increase substantially; at best, revenue growth would probably lag behind the demand for spending.

TOURISM AND AESTHETIC EFFECTS

The visible presence of offshore rigs might or might not diminish the coast's attractiveness to tourists, its big economic hope for the coming decades. Tourism in southern California and elsewhere has flourished despite the presence of offshore platforms. That experience does not necessarily translate accurately to the Washington coast, however. Unlike southern California, the Washington coast does not attract people primarily to enjoy the sunshine or to do things in the water. Tourists who come to fish or dig clams would probably not be deterred by offshore platforms. People who come to enjoy the look and feel of the coast might be, although the one to three platforms that MMS predicts for the Washington/Oregon area might not have much effect. *A visible platform might have a severe effect on the experience of visiting the wilderness beaches along the north coast.* An industrial structure would be jarring and incompatible with the wilderness experience.

EFFECTS ON AIR QUALITY

Offshore oil and gas production can degrade local air quality through emissions of nitrogen and sulfur oxides, carbon monoxide, particles, and organic fumes. These gases originate from the flaring of excess gas; the emissions from motors on the platform, vessels, and onshore facilities; and releases of petroleum fumes from normal operations and spills. Emissions are regulated by the Interior Department, Environmental Protection Agency, and local air pollution control districts, and can be reduced by some mitigating measures. Their impacts depend on local meteorology and existing air quality conditions. MMS projects low impacts along the coast, with some effects possible in the Puget Sound Basin. However, there could be effects on Olympic National Park, a Class I zone in which air quality degradation is prohibited. *This report did not locate sufficient meteorological and air quality data for Washington coastal areas to conclude confidently that air quality impacts would be low under all development scenarios.*

SPACE-USE CONFLICTS

A platform would probably not disrupt migration patterns of whales, birds, or fish. If a platform were located right at the edge of an underwater canyon where fish congregate and feed, on a groundfish spawning area or rockfish reef, or at a spot where ocean currents converge and seabirds gather to feed, it might have some effect. *Inventories of convergence zones, spawning areas, and reefs where offshore platforms could pose conflicts have not been made on the Washington shelf.*

A platform could also interfere with commercial fishing. While platforms can serve as artificial reefs that actually attract fish and sport fishermen, commercial boats cannot approach them safely and, depending on the characteristics of the platform, are excluded from an area of ocean around them. If a platform were placed in an important bottomfishing area, the effect on trawlers might be significant. The effects on trollers would probably be minor.

The oil and fishing industries coexist in many other parts of the country and the world. Negative effects of routine oil operations on commercial fisheries are widely discussed, but impacts on fishery yields have not been documented. Fishermen have tended to believe that fisheries have been affected, though; at the very least, *some friction between the two industries seems inevitable. It can be reduced by formal, ongoing discussion and negotiation between the two. The industry-to-industry communications should be established before oil exploration and development begins.*

SEISMIC EXPLORATION EFFECTS ON FISHERIES

Seismic survey vessels map undersea geologic structures by interpreting the reflections of sound from underwater air guns and hydrophone arrays towed behind them on two-mile-long cables. The towed gear can entangle crab pots and other fixed fishing gear. Companies operating the survey vessels also suffer costly losses of time and equipment from collisions with fishing gear, and try to avoid such collisions. Nevertheless, *if seismic surveys are not well coordinated with fishing activities, conflicts can occur. Experience shows that active industry-to-industry communication is vital to minimizing these conflicts.* There is already some backlog of suspicion among Washington Dungeness crab fishermen because of an incident with the seismic survey vessel *Geco Alpha* in 1980. The *Geco Alpha*'s cables snagged the marker buoy lines of an estimated ten percent of the crab pots on the Washington coast and carried the pots away, where they were lost to the fishermen and presumably caused damage for months by continuing to catch crabs.

Under experimental conditions, the acoustic signals used in seismic exploration have been shown to decrease catches of some sensitive rockfish species. *The significance of these effects* *under realistic exploration and fishing conditions cannot be determined without further study. It is also uncertain whether seismic surveying causes premature release of rockfish larvae. No inventory has been made of the locations of rockfish habitats on the Washington shelf.* The same acoustic signals can kill small organisms such as fish eggs, larvae, and adults within a few feet of the generating apparatus at the sea surface, but do not seem to have significant effects on population abundance. *The effects of seismic signals on marine mammals, which are sensitive to and dependent on sound, remain a matter of dispute.* Some alteration of swimming behavior has been observed in gray whales, but no clearly deleterious effects have been documented, and effects on communication abilities have not been studied.

PRODUCED WATERS AND DRILLING FLUIDS

Produced (or formation) waters are brought to the surface when oil or gas is produced. Drilling fluids, known as "muds," are slurries of clay in water or oil (with some heavy minerals added) that are used to lubricate a drill's cutting head and to maintain pressure in a well during drilling. Both produced waters and muds must be disposed of. Produced waters that have been treated to reduce their oil content, muds that are not oil-based, and the rock cuttings created by drilling may all be discharged into the ocean around a drilling platform. In some cases muds and cuttings are required to be transported to shore for disposal, and produced waters may be reinjected into the ground.

The short-term effects of these discharges are localized and temporary. Muds and cuttings form piles over the ocean floor for a few hundred meters around a platform, and disperse under the action of storms and bottom currents. They physically bury bottom-dwelling organisms, but have low levels of toxicity. The physical effects become more harmful if they accumulate near rocky reefs or other hard-bottom areas. Efforts to locate such reefs on the Washington shelf and steer platform placements away from them would minimize such impacts. *No inventory has been made of the locations of rocky reefs and other hard-bottom areas on the Washington shelf.*

Produced waters and muds can elevate levels of petroleum hydrocarbons and trace metals in the water within a few hundred meters of the discharge point, but seem to have little biological impact in the short term. If numerous production platforms are located in a small area with restricted water circulation, there may be some long-term effects. These conditions are not expected to arise on Washington's outer continental shelf.

EFFECTS OF MINOR SPILLS

Small oil spills (defined by MMS as less than 1,000 barrels) account for nearly all of the spill events in U.S. waters, but for only about 28 percent of the total volume of spilled oil. *On the average, about 1-2 barrels are spilled during routine operations for every million barrels of oil produced from offshore platforms.*

Small oil spills tend to dissipate rapidly on the open continental shelf. They can affect organisms in the immediate vicinity of the spill—near a platform, or near a leaking transfer point at a tanker or pipeline. Frequent small spills, together with produced water discharges, may cause detectable and persistent accumulations of oil in water or sediments, and localized and temporary mortalities of birds, fish, and bottom animals. These effects are very difficult to separate from variability in populations caused by unexplained natural events. Theoretically they could become significant if many platforms were located in shallow water or an area of weak water circulation. *Scientists consider long-term effects an open question, and recommend continued well-planned monitoring programs.*

POTENTIAL IMPACTS OF A MAJOR SPILL

PROBABILITY OF A MAJOR SPILL

Large spills (more than 1,000 barrels) are rare and result in losses of a very small fraction of oil that is produced. At oil platforms in federal waters, about 0.56 large spills occur for every billion barrels produced, a rate that reflects roughly a 50 percent decrease in the last decade. The loss of oil from major spills in U.S. and state waters ranges from 0.15 to 1 barrel of oil spilled for every million barrels produced. Over the last 15 years, a well blowout has occurred about once for every 160 wells drilled on the U.S. outer continental shelf; few of these resulted in large spills.

The frequencies of large spills from submarine pipelines (0.67 per billion barrels) and oil tankers (1.3 per billion barrels) are slightly higher but in the same range. However rare large spills may be, though, the worst of them release tremendous amounts of oil: 1.6 million barrels from the worst tanker spill (the 220,000 deadweight ton *Amoco Cadiz*), and 3.5-10 million barrels from the worst well blowout (*Ixtoc I*).

MMS has presented more than one estimate of the likely rate of oil spillage off Washington/Oregon if oil development takes place. Using its low case scenario and an assumption of tanker transshipment, MMS calculates an 11 percent chance of one or more large spills over the life of the field, and projects that 0.23 large spills would be expected to occur. Under the high case scenario, these numbers increase to 16 percent and 0.51 spills. Adding in the effects of oil imports and transshipment along our coast of oil produced elsewhere, MMS comes up with a 96 percent probability of one or more large spills, and a projection that there will be 3.16 such spills over the life of the field. However, *MMS's spill probability estimates and the methods used to obtain them remain open to question. Independent estimates of oil spill probability might give different results.*

If MMS's spill probability estimates are accepted, they suggest that *offshore production would add slightly to the oil spill risk that is already created by tanker and other vessel traffic into and past the state, traffic that will grow in future years* if the scenarios in MMS's current Five-Year Plan are realized. Statistically, the additional danger from a platform appears to be less than the danger posed by routine tanker shipments of crude oil that already come into Puget Sound without arousing much concern. Statistics indicate that a spill from a tanker is more than twice as likely as a spill from a platform. Yet *each year, vessels bring into Washington more than 150 million barrels of oil—nearly three times as much as MMS's low case scenario projects would be produced during the entire 30- to 35-year life of an offshore oil platform.* This is not to say that oil platforms would pose negligible additional risk, just that the risk should be seen in perspective.

SUSCEPTIBILITY OF WASHINGTON WATERS AND COASTAL AREAS TO MAJOR SPILLS

Oil spill susceptibility is defined as the probability of a location or an organism being struck by a spill. Oil spill sensitivity is the degree of damage suffered by an environment or organism struck by a given amount of oil. The vulnerability of a place or species is a combination of its susceptibility and its sensitivity.

Oil spilled onto the ocean travels from its point of origin under the influence of winds and currents. Surface slicks are driven mainly by the wind; dissolved fractions flow with surface currents; and heavy fractions follow bottom currents. The fate and ecological impacts of spilled oil would of course depend on the amount and location of the spill, as well as conditions at the time of the spill. One example of a worst-case scenario for oiling of the Washington coast might be developed out of the 1978 grounding of the 220,000 deadweight ton *Amoco Cadiz* , in which 190 miles of the Brittany coast were oiled. Based on this incident, *a catastrophic oil spill from a supertanker or a platform blowout, at the wrong place and time, potentially could oil all 150 miles of the Washington coast.*

The use of mathematical models to predict oil spill trajectories is a major part of environmental impact assessment for offshore oil production. MMS has generic oil spill transport models it adapts to conditions in specific areas. No model has yet been developed for use along the Washington shelf, and there are substantial obstacles to developing one. Almost no synoptic large-scale data are available on water currents in the three most critical areas for determining spill trajectories—the upper 20 meters of the water column, the nearshore waters shallower than about 50 meters, and the waters near estuaries. The level of detail in wind data over the shelf is also poor. A long period of data collection is required to fully characterize the level of variability. *Physical oceanographic knowledge of Washington coastal waters does not appear adequate for constructing even minimally reliable real-time models of oil spill trajectories for use in cleanup. Knowledge may be adequate for broad-scale identification of susceptible areas that should be considered for lease-sale deferral. It is not known whether MMS's existing models used for spill trajectories will produce realistic results for this purpose, however.*

Spills Traveling Offshore

Spills that travel seaward appear to cause less observeable biological impact than those that contact land. Studies of past spills that remained offshore in other regions have documented damage to individual organisms, but there has been little or no indication of significant decreases in adult fish, bird, or mammal populations. This apparent lack of impact may be due to such factors as lack of detection or disappearance of dead organisms, avoidance capabilities of animals, and the difficulty of measuring changes that are small compared with natural variability in populations. The hypothetical potential for such impacts remains; for example, damage might occur if floating oil encountered a frontal zone where large numbers of fish eggs, larvae, and diving birds congregated. *The existence and location of fronts, and the degree to which animals congregate around them, have not been studied systematically off Washington.* The Washington shelf is a major feeding area for large numbers of seabirds and marine mammals, so the susceptibility of offshore waters to oil spills deserves study.

An offshore spill would exclude fishing for salmon, groundfish, crab, and shrimp from an area around the slick. Whether fish, especially salmon, which are found near the surface, would avoid the spill area is not known. Depending on the season of the spill, the size, transport, and duration of the slick, and the availablility of alternate fishing grounds, the displacement of fishing effort might or might not affect total catch for the year. *Indian tribes restricted to certain fishing grounds would suffer losses if a spill displaced them from those grounds.*

Spills Traveling Onshore

Spills that strike the coast can have considerable and long-term effects, especially if the oil contacts sheltered, soft-bottom habitats such as estuaries, salt marshes, and mudflats. The Washington coast is very susceptible to landfall of large oil spills, based on average wind, wave, and current directions. On the average, winds and surface currents over the shelf travel northward and shoreward in winter. Mean surface currents reverse in summer, with transitional periods in spring and fall. Mean wind directions switch to southward in summer but retain a strong shoreward component. Wave directions are shoreward at all times of years. The seasonal average surface current pattern is indicated by the position of the Columbia River plume: northward and hugging the Washington coast in winter, southward and offshore in summer.

Given these averages, susceptibility of the coast to oil spills is generally greater to the north of a spill site than to the south, and greater in winter than in summer. However, conditions (particularly winds) are so variable at all times of year that *these averages are almost useless for predicting specific spill trajectories. In addition, the lack of data on smaller-scale current patterns near the surface, close to shore, and in the vicinity of estuaries makes it very difficult to predict where oil would strike shore.*

Although the mean transport of surface water is seaward at the mouths of estuaries, winds and strong tidal currents and mixing dominate the exchange processes. *If spilled oil approached an estuary, wind and currents would probably carry at least some of it inside. Estuaries, especially large estuaries such as Grays Harbor and Willapa Bay, are natural traps for spilled oil because of their fine sediments and weak flushing.*

EFFECTS OF A SPILL ON TOURISM

A major spill striking the Washington coast could devastate the tourist industry for at least a season. How much of the more than $60 million that travelers spend on the coast annually would be lost has not estimated. *A spill that fouled the wide sand beaches of southwest Washington and reduced razor clam populations below harvestable levels might cost the coast millions of dollars a year for an extended period. The total effect on tourism would depend on where a spill struck and how it was perceived.* The grounding of the *Amoco Cadiz* in late spring, 1978, inflicted up to $107 million in losses on the Breton tourist industry. Tourists did not stay away entirely that summer, but there was a significant reduction in tourism that seemed to depend more on potential visitors' preconceptions of damage than on actual physical effects. In the case of the Washington coast, tourists obviously would avoid a beach that was heavily fouled by oil. Whether they also would avoid beaches that were not fouled is unknown.

SENSITIVITY OF WASHINGTON COASTAL AREAS TO A MAJOR SPILL

Effects on Habitats

The Washington coast and shelf include some of the most productive temperate marine environments in the nation. The rocky northern shores support prolific seaweed, invertebrate, and vertebrate assemblages. *The southern coast contains the three largest coastal estuaries between San Francisco Bay and British Columbia.* These embayments support rich eelgrass beds, salt marshes, and mudflats, with associated invertebrate and vertebrate assemblages, and are valuable nursery grounds for coastal commercial fish and shellfish species.

As part of its impact assessment process, MMS evaluates the biological productivity and sensitivity to oil spills of every OCS leasing area. Washington/Oregon ranks in the highest category for primary productivity among areas to be leased in the current Five-Year Plan. Washington/Oregon also ranks ninth among 22 areas, highest of any area outside Alaska, on a broader index of marine productivity and environmental sensitivity. However, some of the data used in these rankings appear to underestimate Washington's coastal resources, and MMS acknowledges that its evaluation methods have some limitations. The significance of these apparent underestimates cannot be determined without further study.

It is clear, though, that a large oil spill would encounter sensitive habitats and cause significant immediate damage at virtually any point where it contacted the Washington coast. The extent of long-term damage to a habitat and its ability to support life depends partly on the state of the oil when it strikes the shore, and on how quickly the habitat returns to background levels of oil contamination. Research in other parts of the world indicates that healthy organisms generally begin recolonizing high-energy sandy and especially rocky shores within several weeks to a few years as they are cleansed of most oil. Poorly flushed soft-bottom embayments such as estuaries can retain harmful levels of oil residues for many years and delay biological recovery. These generalizations suggest that *the southern coast of Washington would be more sensitive to the long-term effects of spilled oil than the northern coast.*

However, insufficient data are available to verify these generalizations for the Washington coast. The available information on effects of past coastal oil spills suggests that sensitivities and recovery rates of the northern coast, the Strait of Juan de Fuca, and the Columbia River are similar. Oil impacts and recovery rates of Washington coastal estuaries and sandy beaches have not been studied. Oil sensitivities and recovery rates of some key species such as kelp, eelgrass, and invertebrate prey are incompletely known. *Not enough fine-scale inventory data on Washington coastal environments have been compiled to confidently assess the sensitivity of discrete habitats and locations.*

Effects on Birds

The islands off the northern Washington coast support the largest concentration of seabird nesting sites in the contiguous United States. An estimated 240,000 seabirds of 16 species breed in this region during summer, overwhelmingly dominated by alcids, a family of diving seabirds. This region has been accorded special management status as National Park, Wildlife Refuge, Wilderness, and Marine Sanctuary. Large aggregations of seabirds—including both resident and migratory populations—also feed offshore all along the coast year-round but are poorly studied, especially in winter. These feeding birds, mostly shearwaters, alcids, and gulls, dominate the total seabird population of the Washington coast and shelf. During the spring and fall migration periods, they are estimated to number more than one million.

The southern coastal estuaries host large seasonal populations of waterfowl (ducks and geese) and shorebirds (sandpipers and similar species) as well as less numerous species such as snowy plover, herons, and terns. National Wildlife Refuges have been established on all three major estuaries to protect these bird populations. *The estuaries are important water bird wintering areas*, supporting peak populations of more than 100,000. *The estuaries are also considered critical feeding areas for shorebirds on their spring northward migrations along the Pacific Flyway.* Peak spring shorebird populations in Willapa Bay and Grays Harbor (Bowerman Basin) are each estimated at more than one million. Water bird and shorebird populations are also found along the northern coast but are poorly studied. In addition to seabirds, waterfowl, and shorebirds, by latest count 302 pairs of bald eagles and 6 pairs of peregrine falcons (both federal and state endangered species) nest along the Washington coast, and non-breeding individuals are present as well.

Marine birds are among the animals most vulnerable to oiling. The dominant alcid seabirds are particularly vulnerable due to their diving habit and their concentration in dense breeding colonies. Other species on the Washington coast, such as cormorants and some waterfowl, may be vulnerable to oiling because their local populations are low, would recover slowly, or represent a major fraction of the region's total population. Oil can kill birds by fouling the feathers—causing death by drowning or loss of body heat—or by internal toxicity if it is ingested. Oil can also cause sublethal effects—such as reproductive abnormalities and failures—and indirect effects such as reduction or contamination of food supplies. The potential short-term impacts of oil spills on the dense seabird breeding colonies of the northern Washington coast and the waterfowl and shorebird wintering and feeding grounds of the southern estuaries might be roughly equal; however, the estuaries would probably be slower to recover.

Theoretically, a worst-case oil spill striking the north or south coast of Washington could reduce marine bird populations by tens of thousands. The most vulnerable species could take years to return to their original abundance. In general, however, it is very difficult to count the numbers of birds lost in oil spills, and to demonstrate whether such losses are significant to the overall health of a population. Worldwide, some marine bird populations have clearly declined as a result of oil; other populations apparently have not suffered high mortality rates after spills; and for many species, the effects are uncertain. *Good baseline and monitoring data would be needed in order to make conclusive projections about the effects of oil spills on birds off Washington. Such data on birds currently are lacking.*

Effects on Mammals

Washington coastal waters are inhabited or visited by 30 species of marine mammals. Sea otters, which inhabit nearshore kelp beds and feed on invertebrates along the northern coast, are a state endangered species recently reintroduced after being hunted to extinction. Currently it is estimated that 136 individuals reside along the north coast, and that number is increasing. Harbor seal populations in the state as a whole probably exceed 18,000 and are thought to be growing, with main coastal concentrations in the southern estuaries. Sea lions occur seasonally at five discrete haulout sites along the Washington coast, and their populations are stable or increasing. Little is known about population levels or distributions of harbor porpoises, which are difficult to observe; a single survey estimates the Pacific coast population at about 50,000. California gray whales, a federal endangered species, migrate northward close to shore along the Washington coast in spring and southward in fall; the population is estimated at 17,000 and growing. A small number remain as summer residents along the northern Washington coast.

Marine mammals vary in their vulnerability to oil spills. The fur-bearing otters, seals, and sea lions are most sensitive because the oil can foul their fur. Sea otters are particularly vulnerable because they have limited migratory abilities and lack a blubber layer to offset any loss of insulation from their fur. *It is probable that a single major spill striking the north coast could eliminate the entire endangered sea otter species in Washington State. Insufficient information is available on local populations to evaluate their vulnerability to sublethal impacts.* Impacts on seals and sea lions would also be likely, depending on the season, but would probably not decimate coast-wide populations. *Gray whales and other cetaceans appear to migrate through areas of offshore oil development, such as Santa Barbara Channel, without obvious harm to populations, but there are few formal studies of effects of oil production and spills on cetacean populations to verify these observations.* Cetacean skin is relatively insensitive to oiling, but oil can foul baleen or be inhaled, and the ability of cetaceans to detect and avoid spills is uncertain. Gray whales and sea otters feed on nearshore bottom organisms, so would be susceptible to disruption or contamination of food supplies from oil spills. *Harbor porpoises are poorly studied but known to be sensitive, and for lack of evidence they must be assumed vulnerable to a major disruption of their environment.*

Effects on Salmonids

Seven salmonid species (mainly chinook and coho salmon, but also chum, pink, and sockeye salmon, and steelhead and cutthroat trout) feed at sea and spawn in seven major Washington coastal river systems. The Columbia is by far the dominant coastal river system for salmon production. In addition, large numbers of salmon off the coast originate from Puget Sound and Fraser River stocks, and Washington coastal waters are the migration corridor for stocks originating from rivers as far away as northern California. Many salmon stocks in Washington are seriously depleted, and continue to decline despite hatchery enhancement and strict limits on catch.

Salmonids are susceptible to oil spills mainly near the estuaries and river mouths; the risk of adult salmon being affected by spills on the open shelf is largely hypothetical and such effects would be difficult to detect. Adult salmon exposed to oil in laboratory studies show some lethal and sublethal effects, including tissue damage, narcosis, and reduction in the ability to sense "home" waters. A spill striking an estuary or river mouth might affect inmigrating adults in summer and fall. However, *it appears that an oil spill would probably not prevent adult salmon from successfully returning to spawn.* A spill in Cook Inlet, Alaska, had no observed impact on the numbers of salmon returning in 1987. The principal threat posed to salmon fisheries by offshore oil spills is that tainting of the fishes' flesh would spoil the catch's marketability, which is very sensitive to consumer perceptions about the quality of the fish.

The stage at which juvenile salmonids enter salt water in estuaries is believed to be critical for population abundance. Little is known, however, about the distribution or feeding habits of salmonids at this stage for any of the river systems except the Columbia and those entering Grays Harbor, whose estuaries are known to be important nursery areas. A spill entering an estuary or river mouth could affect outmigrating juveniles in spring and summer, or inmigrating adults in summer and fall. Juvenile salmon are physiologically sensitive to lethal and sublethal effects of oil, and would be susceptible to spilled oil in shallow areas within and near estuaries. They would have little ability to avoid a spill by swimming deeper or farther offshore, and would be vulnerable to increased predation and contaminated food as well as to direct toxicity. *The concentration of outmigrating juvenile salmonid populations as they enter salt water creates a potential for a major (if temporary) impact on a salmonid stock, reflected in decreased adult returns in later years. The distribution and duration of the residence of juvenile salmon in the coastal nearshore zone are not known well enough to predict the probable magnitude of this impact.*

Effects on Groundfish

Groundfish are species associated to a variable degree with the sea bottom. Tonnage of groundfish catch off Washington has grown to be much greater than that of salmon. Dominant commercial and sport groundfishes include rockfishes, flatfishes (Dover sole, English sole, petrale sole, and arrowtooth flounder), and roundfishes (Pacific cod, Pacific hake, lingcod, and sablefish). Most of these species are known to spawn on or near the bottom along the outer shelf and slope; their eggs and larvae typically float freely near the surface over the shelf, and their juveniles dwell on the bottom, often near shore. Some species such as English sole and lingcod live as juveniles in estuaries. Many rockfishes pass the egg stage within the body of the female. The specific state of knowledge about most groundfish life cycles is poor, but their early life history stages, like those of salmonids, are known to be critical to later fishery abundance. *There is little understanding of the abundances or distributions of populations except when they are fished as adults, or of environmental factors that control their abundance. Adult populations are fished where they concentrate in certain offshore areas such as edges of submarine canyons, but there has been almost no formal compilation of routinely collected catch data to analyze the distribution of preferred fishing areas for various species.*

Groundfish may be vulnerable to spilled oil at all life cycle stages. Adult flatfishes are known to accumulate hydrocarbons and suffer tumors and malformations as a result of contact with oil-contaminated sediments. These conditions could be expected to some extent from large quantities of heavy oil spilled offshore, or from spillage penetrating an estuary. Such abnormalities would be more detectable than decreases in catch resulting from exposure of adults to oil. Publicizing of a spill or such problems, and the possible tainting of fish caught in the vicinity of a spill, could reduce the marketability of Washington coastal groundfish, even if most of the catch was unaffected.

Juvenile groundfish in shallow water would be vulnerable to direct effects of oil spills that came ashore, and also would be susceptible to disruption or contamination of food supplies. *Groundfish eggs and larvae are abundant in the surface microlayer, where they are vulnerable to oil slicks. The potential magnitude of impacts on these life stages cannot be predicted without further knowledge of their seasonal and spatial distribution and abundance.* Theoretically, a large spill striking a critical onshore or offshore area (such as an estuary or a convergence zone with high concentrations of larvae and juveniles) at a certain time of year could eliminate enough immature groundfish to reduce detectably the abundance of adults in later years.

Effects on Shellfish

Dungeness crab and pink shrimp catches are currently increasing off Washington after being depressed in the mid-1980s. Both Dungeness crab and pink shrimp spend their egg and larval stages floating in the plankton near the water surface, but there is little information on the precise spatial and temporal distribution of these life stages or of spawning adults. Crab and shrimp eggs and larvae are highly sensitive to both lethal and sublethal effects from petroleum hydrocarbon exposure. These life stages are also susceptible, at least in theory, to surface slicks and dissolved hydrocarbons resulting from oil spills. This susceptibility and the potential impacts on adult populations and catches have not been verified in the field.

Juvenile shrimp settle to the bottom in deep water, where they grow to adulthood. Juvenile crab settle in shallow water along the coast and in Grays Harbor and Willapa Bay, and later migrate into the estuaries to mature. These estuaries are considered critical nursery area habitats, where juvenile crab survival significantly affects offshore commercial fishery yield. Based on observations of spills in other estuaries, *an oil spill that penetrated the estuaries would have a significant impact on crab yield in subsequent years, an effect that would continue in these low-energy environments as long as high levels of oil persisted in the estuarine sediments—perhaps as long as a decade.* Offshore adult crab and shrimp appear to be less directly susceptible to oil spill effects, although damage to their food resources, and tainting and consumer perception of quality, could remain problematical in the wake of an oil spill.

Razor clams and Pacific oysters are found along the southern Washington coast—the clams on the outer sandy beaches, the oysters grown in culture in Grays Harbor and especially Willapa Bay. They are particularly susceptible to oil spill effects because they are immobile in the intertidal zone as adults and feed by filtering microalgae from large volumes of surface water. Both species also float in surface water as eggs and larvae (commercial oyster crops are grown mainly from laboratory-reared larvae, however). Razor clam populations, currently severely depleted by a parasite infection, support a limited sport catch which remains economically important to the tourist industry. Oyster production is well below historic levels, but production is increasing 5-10 percent annually. Willapa Bay alone now produces nine percent of the nation's oysters. Oysters appear fairly tolerant to oil exposure. The physiologial sensitivities of razor clams and their plankton food source have not been studied. *Production of both clams and oysters would suffer heavily if struck by an oil spill.* Even if adult populations survived and continued to reproduce, consumer acceptance and economic value of both species would be very vulnerable to real or perceived tainting. Due to greater persistence of oil in estuarine sediments than in high-energy outer coast beaches, *recovery would be slower for oysters, and could require up to a decade after a large spill.*

THE NORTH AND SOUTH COASTS

Most forms of development are or will be restricted along much of the north coast of Washington by National Park, Wildlife Refuge, Wilderness, Marine Sanctuary, and tribal regulations. Accordingly, Washington State has requested that the waters north of 47°N latitude (roughly Grays Harbor) be deferred from leasing. This situation raises the question of whether there are differences between the north and south coasts that merit different treatment. Is the north coast more vulnerable or more valuable than the south? Aesthetically—if one's criteria include a visual distinctiveness and harmony, the ability to evoke a memorable image, and a quality of wilderness (criteria developed in a federally sponsored study of California's coastal aesthetics)—the answer is "yes." Biologically and economically, the answer is unclear.

Large numbers of marine birds are susceptible to oil spills on both the north and south coasts, depending on the season. The north coast would probably recover more quickly from a spill because it lacks large estuaries and it has a higher proportion of rocky, high-energy shoreline. On the other hand, its inaccessibility would make cleanup and wildlife rescue extremely difficult. A spill on the north coast could eliminate the state's endangered sea otter population and decimate resident nesting seabird populations. Indian coastal lands also would be much more susceptible to impacts of oil spills that struck the north coast.

It is not clear whether the risk to fisheries would be greater in the north or in the south. The spawning and larval rearing areas for most groundfish and the nursery areas for north coast and Columbia River salmon are still unknown. Known nursery areas for salmon and English sole, and possibly for other species, in the southern estuaries would be vulnerable. A spill on the south coast could cripple oyster and other shell fisheries. If Washington employed the same cleanup response as Brittany did to spills along its coast—excavating the oiled sandy intertidal zone with a bulldozer—it would cause at least as much damage as the oil did.

It is also difficult to evaluate whether effects on tourism would be greater on the north or on the south coast. The south coast receives more visitors, but the "pristine" quality of the visit may not be so critical in this area. Overall, from a qualitative perspective, the potential impacts on wildlife and fisheries would appear to be about equal from large spills striking the north and south coasts. The aesthetic offense of fouling the protected areas of the north coast may come to mind more quickly, but the actual impacts on wildlife and fisheries from oiled sandy beaches and estuaries in the south probably would linger longer.

Overall, from a qualitative perspective, the potential impacts on wildlife, fisheries, and tourism would appear to be different, but roughly equivalent, from large spills striking the north and south coasts. From a scientific and economic point of view, the vulnerabilities of the north and south coasts to oil spill damage seem comparable. Unless new information alters this balance, determining the relative degree of environmental protection afforded these two coastal segments constitutes a matter of value judgment.

Information Management

Major information needs discussed in this report are compiled in the Summary Table. Some of these needs involve gathering of new data, and others relate to management of existing data. Two major obstacles impede efficient handling and analysis of existing data. If not removed, they will also impede future efforts.

- Several Washington state agencies have jurisdictions over and databases relating to birds, mammals, fish, and mineral resources that overlap those of some federal agencies and of the analogous agencies in Oregon. The state agencies include the departments of Wildlife, Fisheries, Ecology, Agriculture, and Natural Resources. The federal agencies include the U.S. Fish and Wildlife Service, National Park Service, National Oceanic and Atmospheric Administration, Northwest Power Planning Commission, U.S. Geological Survey, and Minerals Management Service. It is not always clear which agencies possess data on which topic, how comparable the existing data are, whose data are more reliable, and how discrepancies can be resolved. In some cases apparently no agency has responsibility for compiling such overview data as total size of salmon runs in the Columbia River, or total seabird population along the Washington coast. *Increased cooperation among state and federal agencies might improve management of both data and resources.*
- *Natural resource data that do exist in the state are generally not organized geographically.* This is particularly true, for example, of fishery catch and effort data, which are stored with geographic coordinates but are not routinely analyzed geographically except by port of landing. *Geographic organization of existing and future natural resource data would greatly improve the state's ability to comprehend and respond to the routine impacts of oil production or of a major spill.* A first step in this direction would be to take inventory of existing data and geographic database resources available to the state to assess the scope of needs and current capabilities, and to compare these findings with the experiences of other states such as Oregon.

Summation

There are limitations on how conclusive scientific answers can be to such complex questions as oil and gas impacts. One major limitation is the difficulty of observing possible impacts in many situations. Impacts often amount to subtle alterations in physiology or behavior, or relatively small changes in population numbers of birds, fish, or other animals. There are many logistical problems in collecting such data: animals move about, they are obscured by weather and water, they are distributed in clumps over a wide geographic area, and they do not all behave alike.

Science is also limited by the funds and time provided. Large amounts of data are needed to measure accurately natural population numbers, which vary tremendously, and natural mortality rates, which are consistently high. Great effort also is required to detect with statistical confidence small changes amidst that variability. And finally, cause-effect relationships are elusive. Sometimes no amount of data can demonstrate that observed changes are caused by oil development rather than by simple natural variability or by impacts of other human activities. In practice, impacts must be large before they can conclusively be linked to a specific cause.

These limitations dictate that science cannot answer all the questions about potential impacts of offshore oil and gas development. Statistics can tell how frequently accidents have occurred in the past, but they cannot predict exactly whether, when, or how they may happen again. And after the scientific research that time and funds permit is complete, uncertainty will still remain about the impacts that may ensue if an accident occurs. Decisions will have to be made despite these uncertainties.

In part those decisions will rest on an evaluation of probabilities that impacts will occur and projections of their magnitude. There will at least be some numbers, however speculative, to guide decision makers on these matters. But in large measure decisions will ultimately rest on matters that cannot be expressed as numbers—that is, on matters of values.

Do all the scientific uncertainties, coupled with the potential negative impacts, mean that, economically, the benefits are not worth the risks? Not necessarily. Although no one, including MMS, knows how much oil really will be found, the potential benefits of oil development can be expressed in very large numbers. The total gross value, even at the depressed oil prices of November, 1988, before OPEC agreed to try propping up prices, of the petroleum that MMS projects will be found off Washington/Oregon is around $800 million. That figure, which covers the entire 30- to 35-year life of the field, takes into account an 80 percent chance of finding nothing. If oil and gas actually were found under MMS's low case scenario, the estimates of gross value would increase to $3.2 billion. Under MMS's high case scenario, they would be $9.6 billion. When oil prices rise (as they certainly will), those estimates will rise still along with them.

The value of fisheries can also be expressed in large numbers. By one estimate, the total 1987 ex-vessel value of coastal salmon, groundfish, halibut, and shrimp catches in Washington and Oregon was roughly $122 million. Over 30 years, assuming steady catch levels and prices, the cumulative value of these fisheries would be about $3.7 billion. Adding in crab and oyster harvests at current values increases the total to over $4 billion. Those are dollars that stay in the states, rather than being spread over the oil industry and the nation as a whole.

There is no way to eliminate all additional risk to coastal resources without simply forgoing *all* oil development. One gets either the entire 30-year benefit or none of it. On the other hand, neither history nor science suggests that an *entire* 30-year revenue stream from fishing or tourism or any other coastal industry would be at risk from oil development. If a major spill occurred, precedent does not indicate that the total revenue from either industry would be lost for even one year, or that any part of either industry would be lost permanently. For example, the 1969 Santa Barbara spill had no documented long-term effect on commercial fisheries in the Santa Barbara Channel. No significant long-term effects have been observed from any other spill, either—although realistically, it is difficult, in Santa Barbara or anywhere else, to distinguish the effects of a spill from natural variations in fish populations and the impacts of other human activities.

It is not enough, however, to say that 30 years' oil revenue would be a lot of money, and that 30 years' catch value of the coastal fisheries would not be at risk. *A definitive economic comparison between oil and fisheries, tourism, and other coastal industries would be complex and has not been performed.* How would the coastal fishing and tourism industries and the offshore oil industry compare under various plausible scenarios in terms of net present value? To whom would the economic benefits of oil production flow? How much of the net revenue would stay in the state? How much would stay in the coastal communities? How would the indirect economic benefits of oil production compare with those of the current coastal industries? What would be offshore development's monetary cost to coastal communities and to the state? What might be the total monetary cost of a major spill?

And what might be the other costs? It is easy to put a dollar value on, say, the Willapa Bay oyster industry, the temporary loss of which may constitute the greatest plausible risk. In 1986, the gross value of the Willapa Bay oyster harvest was almost $5 million. The industry should not be seen in strictly economic terms, however. Like the salmon fishery, it has a cultural value, an historical value. Like all the finfisheries and the crab fishery, it represents a way of life. It has been there for 140 years, and with any luck it will still be there long after any offshore oil platform has been disassembled. It is hard to measure such things in dollars and cents.

It is even harder to measure some of the other resources of the coast. What value does one place on sea otters? On shorebirds? On the "look and feel" or even the abstract concept of wilderness? One can add up the number of people who visit the beaches each year and calculate what they contribute to the coastal economy, but those calculations are largely beside the point. What matters is not just the number of people who experience the wilderness beaches, but also the quality of the experience. The value is aesthetic, perhaps spiritual. It can be important not only to people who visit the beaches but to people who have never seen them, who like to know they are there, unspoiled, for the ages.

All the big questions, as Washington contemplates offshore development, are questions of values. Could the damage caused by a major oil spill be widespread, long-lasting, even catastrophic? Yes, it could be, at least for several species of birds, mammals, and shellfish. Is there much risk of such a spill fouling the wilderness beaches or the estuaries or another part of the coast? Statistically, the answer is "not much." Is the risk worth taking? That's not a question that statistics can answer definitively. And so it goes. This does not mean that the state should avoid tackling the narrower, more pragmatic issues. It should press ahead now with the task of data gathering and analysis. But it should also realize that while the natural sciences and socioeconomics can establish a framework and an information base for discussion of the big questions, they cannot provide all the answers.

Summary Table

Information Gaps

Topics Not Covered in this Analysis

- There has been extensive research on the Columbia River estuary, but little study of the potential impacts of offshore oil and gas development on it.
- MMS's estimates of oil reserves and oil spill risks off the Washington coast, and the methods used to obtain them, have not been critically evaluated in this report. Independent estimates of these quantities might give different results.
- It appears that offshore production would add slightly to the oil spill risk that is created by existing and future tanker and other vessel traffic into and past the state. However, a more thorough analysis is needed to determine the magnitude and severity of possible impacts.

Physical Environment Information Needs

- This report did not locate sufficient meteorological and air quality data for Washington coastal areas to conclude confidently that air quality impacts would be low, as MMS projects, under all development scenarios.
- The state of physical oceanographic knowledge of Washington coastal waters does not appear adequate for constructing real-time oil spill trajectory models. MMS's models may be adequate for identifying prospective area deferrals, but their results will need to be examined closely. The lack of data on variability of winds; on smaller-scale current patterns near the surface (upper 20 m), close to shore (shallower than 50 m), and in the vicinity of estuaries; and on exchange processes between estuaries and the ocean makes it very difficult to predict whether and where oil would strike shore.

Biological Effects Information Needs

- The significance of impacts of seismic exploration on rockfish catches under realistic exploration and fishing conditions cannot be determined without further study. It is also uncertain whether seismic exploration causes premature release of rockfish larvae.

- The effects of seismic signals on marine mammals, which are sensitive to and dependent on sound, remain a matter of dispute.

- Good baseline and monitoring data on distribution, abundance, natality, mortality, and natural variability would be needed in order to make conclusive projections about the effects of oil spills on birds off Washington. Such data currently are lacking.

- There is inadequate knowledge of life cycles and ecology of local sea otter and harbor seal populations to determine the long-term effects of chronic low-level oil spillage on these resident mammals.

- Insufficient biological information is available on local harbor porpoise populations to evaluate their vulnerability to acute or chronic impacts of offshore oil development. There are few formal studies of effects of oil production and spills on cetaceans in general to verify indications that effects of these activities on their populations are negligible.

- The distribution and duration of the residence of juvenile salmon in the coastal nearshore zone are not known well enough to predict the probable magnitude of impacts from oil spills entering estuaries and river mouths.

- There is little understanding of the abundances or distributions of groundfish populations except when they are fished as adults, or of environmental factors that control their abundance.

- The potential magnitude of impacts of oil spills on groundfish eggs and larvae in the surface microlayer, and ultimately on fishery yield, cannot be predicted without further knowledge of their seasonal and spatial distribution and abundance.

- The sublethal effects of oil are not well known for larval, juvenile, or adult razor clams or their phytoplankton food source, nor for oysters.

- The susceptibility of planktonic larvae of crab and shrimp to oil spills, arising from both vertical and horizontal distribution and transport patterns, is not well known.

- Long-term effects of oil development on the environment—including cumulative effects of produced water and muds/cuttings discharges, and of small spills—are considered an open question, which implies the need for continued well-planned monitoring programs.

Geographic Information Needs

- Inventories of offshore convergence zones, fishery spawning areas, and reefs (where offshore platforms could pose space-use conflicts) have not been made on the Washington shelf.

- The existence and location of convergence zones, and the degree to which animals congregate around them and might be susceptible to offshore oil spills, have not been studied systematically off Washington.

- No inventory has been made of the locations of rockfish habitats that might be affected by seismic exploration on the Washington shelf.

- No inventory has been made of the locations of rocky reefs and other hard-bottom areas on the Washington shelf that might be impacted by disposal of drilling muds and cuttings.

- There has been almost no formal compilation of routinely collected catch data to analyze the distribution of preferred offshore fishing areas for salmon and groundfish.

- Not enough fine-scale inventory data on Washington coastal environments have been compiled to confidently assess the sensitivity of discrete habitats and locations.

Socioeconomic Information Needs

- A definitive economic comparison between oil and fisheries, tourism, and other coastal industries would be complex and has not been performed.

- Social structures of the coastal Indian tribes and the the non-tribal coastal communities have not been analyzed.

- Realistic unemployment (and underemployment) figures and their relationship to official unemployment figures; proportion of the chronically unemployed or underemployed employable by oil companies or contractors if production takes place; numbers of coastal residents who depend on commercial fishing and on tourism; and the nature and extent of the "underground economy" are unknown.

- The true effects of offshore development on fisheries in the Santa Barbara channel, the North Sea, and elsewhere; fishermens's allegations of significant losses from offshore petroleum operations; and the degree to which one can extrapolate to Washington from other communities' experiences with major offshore developments have not been objectively verified or analyzed.

- Estimates of tax revenues that would flow to state and local governments; of infrastructure needs and expenses depending on location and nature of a petroleum find; of training needed to maximize local employment have not been made.

- Strategies for maximizing economic benefits and minimizing costs, and mechanisms for spreading benefits over the largest possible coastal area, have not been developed.

- Ways in which the offshore petroleum industry might affect the marketing of the coast as location for tourism or business, the availability of capital in coastal communities, and the available space in coastal ports, have not been analyzed.

Overview & Integration

- Information is lacking to support development of a system of thought (conceptual framework) for organizing how natural and socioeconomic resource interests interact and for sorting out priorities.

- A risk assessment of occurrence of undesirable events, and severity of consequences of those events, integrating natural and socioeconomic resource risks, has not been performed.

1

The Setting

From the beaches and bluffs of Washington's Pacific coast, where waves break on seastacks while eagles circle overhead, oil platforms may be visible by the end of the next decade. If they are, their presence will reflect both America's economic needs and a high-level federal decision about how those needs will be met. Ninety-five percent of the energy that drives America's transportation system comes from petroleum. The nation consumes 16 million barrels of oil a day, and will continue to depend heavily on oil and gas well into the next century. Currently, the United States imports much of its petroleum, adding to the trade deficit and weakening national security. There are many possible ways to deal with the nation's need for petroleum and its dependence on imports: through a comprehensive national energy policy, by tightening mileage standards for American-made cars, or by promoting home-heating efficiency and alternative energy research, to name a few. One way the federal government has decided to meet the nation's energy needs is to develop more domestic oil and gas supplies on the outer continental shelf (OCS), where 30 to 60 percent of undiscovered reserves are thought to lie.

The current Five-Year Plan of the U.S. Minerals Management Service (MMS),[1] the Interior Department agency that manages oil and gas development on federal lands, calls for a sale of oil and gas leases on the outer continental shelf off Washington and Oregon in April, 1992. By this schedule, if industry buys the leases and finds commercial quantities of oil or gas in test wells, routine production would probably begin around the year 2000. Where now the only man-made object visible above the waves is the occasional passing boat, at least one 10-story structure of concrete and steel would appear. People's responses to that sight would vary, as would their responses to a host of possible changes that can accompany offshore oil and gas development.

By MMS's estimates, the hydrocarbon deposits off Washington/Oregon could be as little as a three-day supply for the nation, if any are found at all. The federal government nevertheless deems exploration off Washington/Oregon to be worthwhile because of the possibility of a larger-than-expected find, and because of a desire for all areas of the nation "to share equitably in the developmental benefits and environmental risks" of OCS production. MMS[1] also argues for the need to develop even small finds:

> Suggestions are sometimes made that the relative importance of developing a prospect can be gauged in terms of the number of days it alone could satisfy national petroleum needs. However, if the test for proceeding with oil and gas development in a prospect were whether it contained more than several days' supply for the nation, little energy would be developed domestically... Over 80 percent of all known OCS oil and gas reserves are in fields containing 1 day's supply of oil or less. . . It is the cumulative contribution of all these small fields, along with the few really large ones, that constitutes the nation's domestic petroleum production.

Washington, especially the population center of Puget Sound, has a recent history of conflicts over oil. Offshore oil production would be a novelty in Washington, but a perceived conflict between oil and a pristine environment would not. Starting in the late 1960s—with images of the Santa Barbara oil spill fresh in people's minds and the Trans Alaska Pipeline the subject of a national environmental dispute—Puget Sounders started to worry that a supertanker carrying Alaskan oil would run aground, collide with another vessel, of suffer another kind of accident that would spill millions of gallons of oil into the Sound. Concern increased during the 1970s and, in 1977, Washington's then-senior senator, Warren G. Magnuson, fired the final shot by pushing through federal legislation that prevented the construction of an oil port on the inner Sound. An alternative scheme, unloading supertankers at Port Angeles and pumping their oil to the Midwest through a pipeline, became equally controversial; in 1982, then-Governor John Spellman finally killed it by executive act.

Washington's ocean coast—more remote, less developed, more pristine—was largely overlooked during the oil controversies of the 1970s and early 1980s. Its environmental and aesthetic values were not juxtaposed against the oil industry, as those of Puget Sound repeatedly were. And the coast's vulnerability to oil impacts did not receive the extensive study that was lavished on northern Puget Sound and the Strait of Juan de Fuca while pipelines and supertankers were the issues. (Much oceanographic research has been done off Washington, however, and has recently been summarized.[2])

Consequently, people simply do not know so much about the coast as they do about the upper Sound. They do know that the oceanography and the natural environment are different. They know that the economic and social environments are different, too. Some people and local governments on the outer coast may welcome the promise of oil jobs and oil revenues in a way that citizens and elected officials on Puget Sound did not. Unemployment is much higher on the coast than in the urban areas of Puget Sound. Per capita income is lower. The forest products industry, which has always been the foundation of the coastal economy, has cut its operating costs by eliminating jobs, so that while lumber and log prices are high, the industry employs many fewer people than it did in the late 1970s. There are still no serious alternatives to forest products.

Because of the coast's remoteness from markets and suppliers and urban amenities, its prospects for economic development are limited. Tourism is the great economic hope. The Minerals Management Service estimates that oil development off Washington and Oregon will produce 1,176 jobs at its peak, and 124 long-term jobs. The MMS "high case," which assumes greater quantities of petroleum are discovered, might produce roughly three times as many jobs. In the context of Puget Sound, where Boeing alone employs nearly 100,000 people, that's not much. In the context of the coast, where the oyster industry has become one of the top two employers in Pacific County by providing the equivalent of 630 full-time jobs, it could be significant, depending on how many of those jobs are filled by local residents.

But the imminent prospect of oil development off the coast would clearly be controversial. It would be controversial within coastal society, as fishermen and oyster growers and people who had moved there for the tranquility all feared for the future. And it would be controversial within the state, conceivably developing into a showdown between the environmentalists of Puget Sound and the would-be mineral extractors of the coast, a clash that could echo the wilderness preservation versus logging jobs disputes that have periodically troubled both the Olympic Peninsula and the Cascades.

There are few easy answers, not only to questions about the probable effects of offshore oil development but also to questions about desirability off Washington. There are, however, plenty of facts about the industry. Oil has been produced for decades on continental shelves around the world. Offshore production is a mature and impressive technology, and since the 1960s its environmental impacts have been studied extensively. While many questions remain, it is clear that offshore development does not lead inevitably or even frequently to environmental disaster. Fish populations remain large and the fishing industry remains economically significant despite massive petroleum development in the North Sea, the Gulf of Mexico, and the waters off southern California. There are conflicts between the fishing and oil industries. There are allegations of damage. There have been routine environmental impacts and occasional large-scale blowouts and spills. The debate continues over the point at which damage becomes "significant" or "long-lasting." Still, despite lingering images of the big 1969 Santa Barbara spill and the powerful symbolism of oil in the sea, and despite ongoing low-level conflicts, offshore oil development has not doomed fish or marine mammals, fishing or recreation in other states and countries.

On the other hand, in those other states and countries, petroleum has not been extracted within easy spilling distance of a 50-mile stretch of national park wilderness with world-class aesthetic and biological properties. Nor has it taken place off the three largest Pacific estuaries north of San Francisco Bay. To what extent can we apply experiences from such places as the California coast, the Gulf of Mexico, and the North Sea to the possible effects of oil development off Washington? Are some places off Washington's northern coast safer for oil development than others? How would development affect the wilderness beaches? How would it affect birds and sea mammals? How would it affect coastal fishing and aquaculture? How would it affect tourism? How would it affect Indian tribes and non-Indian communities?

If and when the first drilling rig appears offshore, it will already be too late for the state to plan in a way that enables it to maximize benefits and minimize risks. Now is the time to assemble what is known about offshore oil and gas, about the natural and human resources of

Washington they could affect, and about the state's options for responding to a new coastal industry.

In this report, we have not attempted to load the dice either for or against offshore oil development. We may dwell more on the negative than on the positive, but only because the range of positive effects is narrow and the nature of those effects is relatively well known. Clearly, the State of Washington will have to make some difficult choices. In order to make them intelligently, it must know what natural and human resources exist in the coastal zone and how they might be affected by the discovery and extraction of oil or gas. We have tried to provide some of that critical information. Our analysis is equally applicable to oil and gas development in state or federal waters.

Because few people in Washington are familiar with the offshore production of oil and gas, we start by describing the petroleum development process. Next, we describe some basic positive and negative effects of petroleum development. Third, we survey the natural and human environments of Washington's coastal region, and suggest how they might be affected by petroleum activities; we also identify significant gaps in research and knowledge. Finally, we summarize the major resources and plausible impacts, characterize the levels of uncertainty about them, and highlight important issues at which the state should take a closer look.

CHAPTER 1 REFERENCES

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2. Landry, M.R. and B.M. Hickey, eds. In press. *Coastal Oceanography of Washington and Oregon.* (Elsevier Applied Science, London and New York).

2

The Oil Industry and Its Impacts

OFFSHORE OIL—ON THE WAY?

In April, 1987, the U.S. Department of the Interior's Minerals Management Service (MMS), which is in charge of oil and gas leasing in federal waters, issued its latest Five-Year Plan.[42] On its list for lease offerings to the oil industry was the Washington/Oregon planning area, where petroleum leasing has not been conducted since 1964, where a commercial find has never been made, and where production has never taken place.

MMS has authority over minerals development in the submerged lands of the outer continental shelf (OCS) inside the 200-mile Exclusive Economic Zone and outside the three-mile limit of state jurisdiction. It has a well-defined and congressionally mandated procedure it follows in offering areas for lease, the specific steps of which are outlined in Table 2.1 and Figure 2.1. In Washington State, the process would culminate in a lease sale in April 1992. In that scenario, exploration of the leased tracts would then begin, and if a commercial find was made, production probably would begin sometime around the year 2000.

The area offered for lease off Washington is shown in Figure 2.2. State waters (inside three miles) are not included. Areas seaward of roughly 1,000 meters depth are *deferred* and not considered for leasing in this Five-Year Plan. Areas north of the 47th parallel (about the latitude of Grays Harbor), and those within 12 miles of shore south of 47°N, are *highlighted* at the state's request. The northern waters are highlighted because they are off an important coastal and nearshore conservation area, containing Olympic National Park, three federal wildlife refuges managed as wilderness, and a newly designated marine sanctuary. The southern nearshore waters are highlighted because of the Grays Harbor, Willapa Bay, and Columbia River estuaries, which also are the sites of wildlife refuges. The highlighted areas are open to leasing so far, but receive special attention in the environmental assessment process, which culminates in the draft Environmental Impact Statement (EIS) to be issued in March, 1991, and the final EIS in September, 1991. This attention could lead to the deferral of portions of these areas that may be ecologically sensitive or otherwise unsuitable for development.

The Washington and Oregon offshore area (officially to be offered as MMS lease sale 132) is designated as a "frontier area" for the industry, that is, an area in which there has been little exploration and for which relatively little information is available on petroleum potential. Washington/Oregon in 1986 ranked 15th in the level of oil industry interest among 22 areas being offered for lease under the current Five-Year Plan.[42] Another request for industry interest is to be issued in November, 1989.

MMS has issued various estimates of how much oil and gas may be off Washington/Oregon. The most recent and conservative estimate is that there probably are undiscovered economically recoverable oil and gas deposits with the energy equivalent of 50-60 million barrels of oil in the lease sale area, depending on prices.[42] (One barrel of oil equals 42 gallons; 5,620 cubic feet of gas is the energy equivalent of one barrel of oil.)[44] This appears to be a relatively modest amount, about enough to fuel the nation for three days. By way of comparison, MMS figures its northern California lease area holds 150-330 million barrels equivalent, its southern California area 340-770 million, and its three Gulf of Mexico areas 7.9-9.2 billion.

MMS provides evidence that reserves off Washington/Oregon could be much greater than this most conservative estimate indicates. This estimate takes into account what MMS calculates is an 80 percent chance of finding nothing. (It also is based on a maximum oil price of $32.50 per barrel, which could be an underestimate if another energy crisis arises.) If it is assumed that oil or gas is found, the reserve estimates in the lease sale area roughly quadruple—to 58 million barrels of oil and 1.043 billion cubic feet of gas, together the equivalent of 243 million barrels of oil.[40] MMS projects that these reserves would support a single offshore platform, which would begin

TABLE 2.1 STEPS IN THE PROPOSED LEASING PROGRAM FOR THE WASHINGTON OCS
(Source: MMS 1987a)
(* indicates public participation opportunity)

1) *November 1989: Request for interest Because lease sale #132 is a frontier exploration sale, a special reassessment of industry interest will be conducted as the first step of the presale process as well as during the annual review of the program. If interest is insufficient, the process can be delayed and a Request for Interest reissued on an annual or less frequent basis until interest is sufficient to proceed, or the sale may be cancelled.

2) *March 1990: Call for information and nominations/Publishing of the notice of intent to prepare an environmental impact statement and scoping This notice informs the public of the area under consideration for oil and gas leasing and solicits comments from states and all interested parties on areas or subjects that should receive special attention and analysis. Comments are to be due in April, 1990.

3) June 1990: Area identification MMS develops and evaluates options for area identification. Blocks (a block is a roughly 3-mile square area of the OCS) that should be studied further and considered for leasing are selected. The intent of this step is to consider environmental concerns and to allow industry wide latitude for making its investment decisions and testing various exploration strategies.

4) *March 1991: The draft environmental impact statement MMS prepares an EIS before the Secretary of the Interior decides whether to hold the proposed lease sale. The EIS includes an estimate of the oil and gas resources; reasonable alternatives to the leasing proposal; detailed analyses of environmental, socioeconomic and cumulative effects; and any unavoidable adverse environmental effects.

5) *April 1991: Public hearing on draft EIS Between 30 and 60 days after publication of the draft EIS, one or more public hearings are held in the vicinity of the proposed lease-sale area. Final public comments are due in May, 1991.

6) September 1991: The final environmental impact statement This final EIS assesses comments received during the public review of the draft statement. About 3 to 5 months after the public hearings, the final statement is filed with the EPA, announced in the Federal Register, and distributed to other federal agencies and to state and local governments. Copies are available to the public.

7) *November 1991: Proposed notice of sale The proposed notice of sale identifies blocks that are available for lease, stipulations and other restrictions to mitigate impacts of the sale, proposed bidding systems and lease terms, and other pertinent information useful to interested parties and potential lessees. The notice is generally available for public comment about 1 month after the final EIS is filed with EPA. The proposed notice of sale also serves as the basis for the next step of consultation with the Governors of the affected states.

8) *January 1992: Governor's comments due Governors of the affected states are provided 60 days in which to submit comments on the size, timing and location of the proposed lease sale. These comments provide a framework for the discussion and resolution of any remaining concerns the states may have.

9) March 1992: Final notice of sale A final decision memorandum that analyzes all issues is prepared for the Secretary of the Interior. Governors' recommendations on the size, timing, and location of a proposed lease sale must be accepted if the Secretary determines that they provide for a reasonable balance between the national interest and the well-being of an affected state.

10) April 1992: The sale At least 30 days after the final notice, the competitive lease offering occurs, usually in the city in which the offshore regional office is located. The offering consists of a public opening and reading of the sealed bids.

11) Immediately after lease sale: Bid acceptance or rejection MMS begins determining whether bids can be accepted and leases issued. Acceptance of a bid is primarily based on the receipt of fair-market value. Phase 1 of a two-phase process is conducted on a tract-by-tract basis and is normally completed within 3 days of the bid opening. High bids not accepted in phase 1 receive further evaluation in phase 2.

14) Issuance of the lease The oil and gas mineral lease grants the right to explore, develop, and produce oil and gas for a specific term from a specific tract of submerged OCS land.

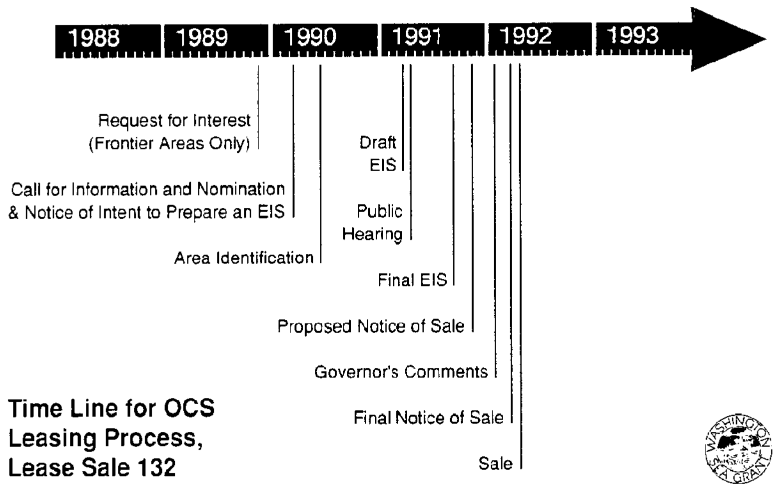

Figure 2.1 Scheduled timeline for Lease Sale 132 off Washington/Oregon (data from MMS 1987a).

operating about the year 2000, drill about 30 production wells, and remain for up to 35 years. MMS also calculates, to account for the chance of larger-than-expected find, a "high case" scenario that roughly triples those numbers: reserves equivalent to more than 700 million barrels of oil, and three platforms. Finally, as its most liberal estimate, MMS [44] calculates a five percent chance that further reserves in the deferred areas could bring the total amount of hydrocarbons off Washington/Oregon to 540 million barrels of oil and 3.63 trillion cubic feet of gas, the energy equivalent of 1.2 billion barrels of oil.

Just as the Washington OCS is a frontier area for MMS and the oil industry, offshore oil and gas production is a frontier area in terms of the technical and political experience of the State of Washington. The technology and management of the oil industry are unfamiliar here, and there is a fear of petroleum production so close to our shores, yet under the control of faraway interests.

In fact, the state does have limited authority over petroleum operations off its shores.[41,43] It issues permits for onshore developments, and can request "stipulations" on what practices are allowed and what precautions are required of operators in federal waters. In addition, the Outer Continental Shelf Lands Act Amendments of 1978 provide state and local governments with the right to participate in the offshore policy and planning decisions of the federal government. And the Coastal Zone Management Act (CZMA) gives states that have approved coastal zone management programs (as Washington has) a voice in federal and federally assisted activities in U.S. waters. Activities conducted by or supported by federal agencies must, to the maximum extent practicable, be consistent with federally approved state coastal zone management programs. This "consistency provision," however, is controversial, and its interpretation is still uncertain. If Washington is to minimize its costs and maximize its benefits, the state will need to study and prepare thoroughly in order to know when and how to exert its influence.

Oil Industry Practices

The marketplace for oil and gas is the prime mover in the process of oil and gas development. In most cases, governments and private groups react to the decisions or desires of industry based on its perceptions of markets.

Since very little is known about what petroleum resources lie off Washington's coast, any exploration, development, and production could be expensive. Therefore, the Washington/Oregon lease sale will probably interest major companies rather than small independent operators.

Despite their size and sophistication, major oil companies often contract out many technical and support operations, such as seismic testing, drilling, or operation of supply boats. There may be contractors, subcontractors, and sub-subcontractors working simultaneously on any given oil project, perhaps on any given oil platform. The heavy use of contractors creates a

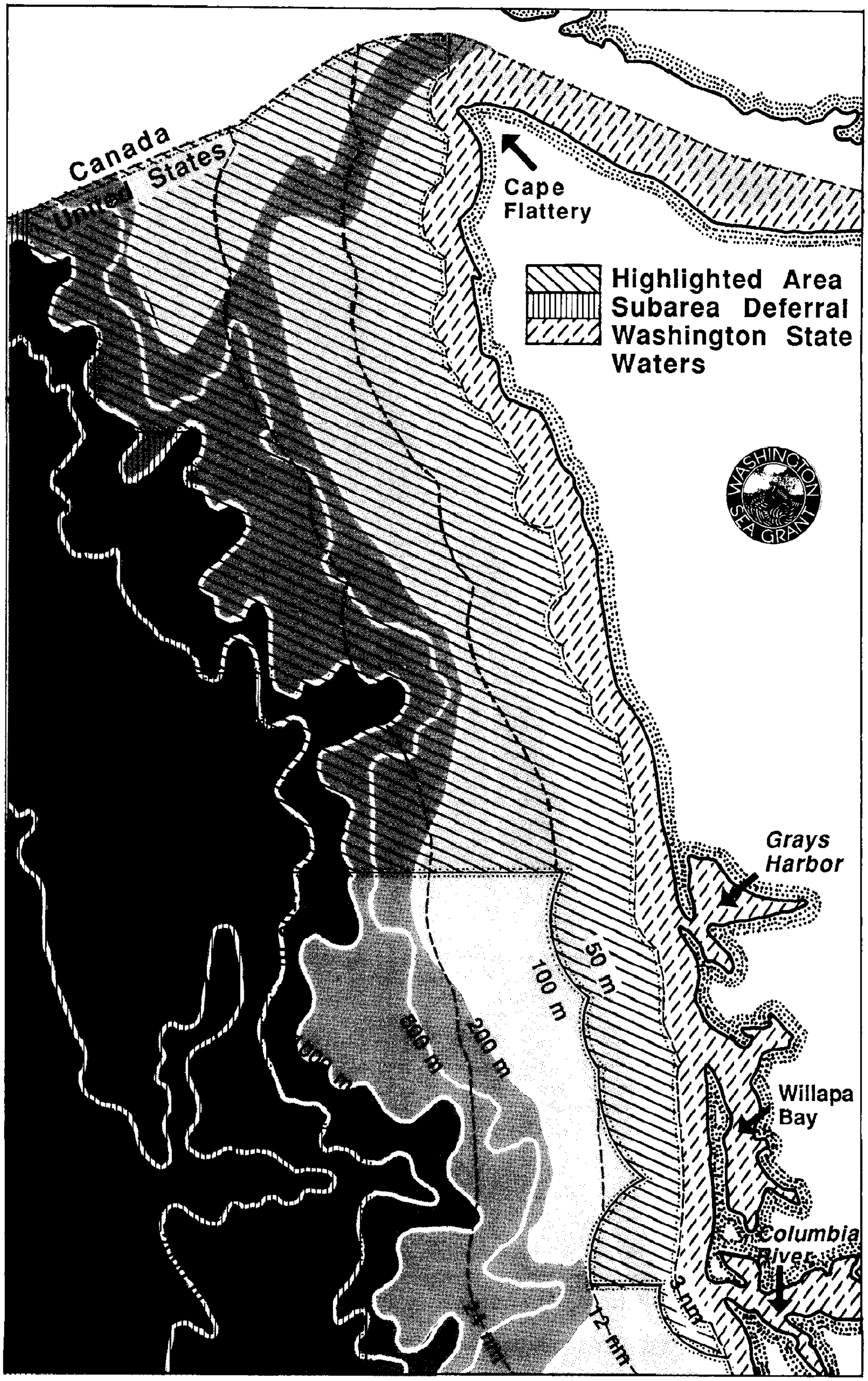

Figure 2.2 Map of MMS planning area off Washington. Shading indicates deferred and highlighted areas and state waters (data from MMS 1987c).

system in which accountability and responsibility can grow fuzzy, depending on the terms of contracts among contractors.

FIVE PHASES OF OIL AND GAS DEVELOPMENT*

The development of oil and gas resources has five phases: leasing, exploration, development, production, and shutdown.

Leasing

The leasing phase for offshore oil and gas evolves from the MMS's five-year lease sale process. When an outer continental shelf area appears in MMS's Five-Year Plan, MMS and industry prepare for the lease sale. Governments of the designated areas must use the same time to prepare their responses.

Industry's search for offshore oil and gas begins when individual companies thoroughly analyze an area's geologic characteristics. To help select the lease offerings on which to bid, companies use whatever geologic and geophysical information they can accumulate; they rely greatly on their interpretations of seismic surveys to identify geologic formations that may contain oil or gas. (Formations can be studied more thoroughly if MMS authorizes a group of companies to drill a continental offshore stratigraphic test [C.O.S.T.] well, in which core samples are taken to identify geologic features and strata suitable for oil production.)

Exploration

During the early part of the exploration phase, the company that obtains a lease may conduct seismic surveys and geologic sampling and, when needed, cultural and biological surveys. The lessee must submit a comprehensive exploration plan and environmental report to MMS for review.

Once a lessee has obtained all the permits necessary for exploratory drilling, it may drill exploratory wells to determine whether oil or gas is present in commercial quantities. If petroleum is found, additional wells are drilled to identify the extent and characteristics of the find. Exploratory wells are temporary; they are not used for production. When they are abandoned, federal regulations require complete removal of all parts and casing below the mudline.

Development

After a company has decided that a leased site merits commercial development, and after its planning and permitting are complete, it installs a stationary platform designed to remain in place for the life of the field (about 30 years). A typical California platform may serve 30 or more wells, depending on the characteristics of the oil or gas and the size and characteristics of the field. Any necessary onshore and transshipment facilities (pipelines, terminals, new tankers or barges) will be built at this time.

The development phase requires more manpower and support services and has greater impacts than any other phase.

Production

When oil or gas starts to flow, production begins. This is the principal phase in which profits are made by the lessee. Even though the platform will probably continue to drill more wells after production starts and may explore further, all systems for transshipment and for treatment or processing must be operational. In terms of employment, production is less of a boom and more of a steady-state phase than development; fewer workers are needed to operate offshore oil and gas facilities than to build them.

Shutdown

The final phase of oil and gas production, generally 30 or more years after production begins, is shutdown. Whenever production from a site is no longer profitable, industry will stop it and begin the shutdown phase. Under federal law, offshore facilities must be removed after

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* The following section is condensed from another report in the series on *Washington State and Offshore Oil and Gas.*[1]

shutdown, unless they have been designated artificial reefs. Typically, the well pipes are cut off at least 15 feet below the mudline and are sealed with concrete. Pipelines are usually left in place. Onshore facilities may be shut down, dismantled, or converted to other uses.

INDUSTRY ACTIVITIES AND FACILITIES*

Exploration

The formation of oil and gas in commercial quantities requires long geologic times and very specific conditions. First, the *source* rock, a sedimentary rock containing dead organisms, must be subjected to the right temperature and pressure for up to millions of years to transform the organic matter into petroleum. Then, petroleum must migrate from the source rock into a porous *reservoir* rock that can hold large quantities of it. Above the reservoir rock, a *trap* rock must form a seal, preventing the petroleum from escaping to the earth's surface.

Petroleum geologists and geophysicists look for structures that suggest the presence of a petroleum reservoir: traps, reservoir rock, and source rock. Geologists study subsurface well data, analyze core samples, and compare sedimentary systems, structural forms, and faults with what is known elsewhere. Geophysicists study seismic reflection data in order to understand the layers and structural forms of the offshore substrate.

Seismic reflection data provide the most detailed information that can be gathered about the offshore substrate without drilling. The data are collected by seismic vessels equipped with acoustic energy sources (generally compressed-air guns, water-guns, sparkers, and occasionally, in surf zones, primacord explosives) and sensitive receivers that record reflected sound waves. As a seismic vessel traverses the area being explored, it triggers the sound source, creating acoustic pulses that travel through the water and reflect off the various structural layers or strata beneath the sea floor (Figure 2.3). These reflections are recorded by the receivers, which are mounted on two-mile-long streamers that trail behind the boat. The data collected are analyzed by computer and converted into tracings that represent the structural layers. Although seismic information can indicate geologic structures that may be traps, it cannot reveal the composition or depth of each layer. Geophysical data are collected to determine placement of platforms relative to petroleum deposits; to locate hazards such as faults and slump zones; and for guidance in drilling though rock strata.

Regardless of how much geological and geophysical data are collected, the only way to know whether or not a site contains oil or gas is to drill. After the leasing company's plans are accepted by MMS, it arranges for exploratory drilling. Exploratory drilling is generally done by a contractor.

As the well is drilled, rock cuttings and muds from the hole are tested for hydrocarbons. Electric equipment is sent down a newly drilled hole to collect geologic data. Rock cores cut with special equipment may also be examined. Gas or oil found by these tests is called a *show*. Once oil or gas is found, more exploratory wells are drilled until the field has been delineated. Offshore exploration is supported by temporary service bases. Industry contracts with boat or helicopter groups for supplies and support from existing port and airport/heliport space nearby. As with production drilling (see below), muds, cuttings, and produced waters are generated by exploratory drilling and must be disposed of.

Development and Production

Once construction begins, industry enters the development phase of designing and building the necessary facilities. When oil or gas starts to flow, the production phase of operating these facilities begins. Any production system is relatively permanent, designed to remain in place for as long as the wells produce oil or gas profitably.

Offshore production platforms must be large enough to support the fluid and pipe-handling systems needed for drilling; to contain at least minimal separation and treatment facilities and possibly some oil storage capacity; and to store safety gear and equipment for handling wastes and produced water. They must connect with transportation systems for oil and/or gas; and they must provide comfortable accommodations for crew members, who generally live on the platform

* The following section is condensed from another report in the series on *Washington State and Offshore Oil and Gas.*[1]

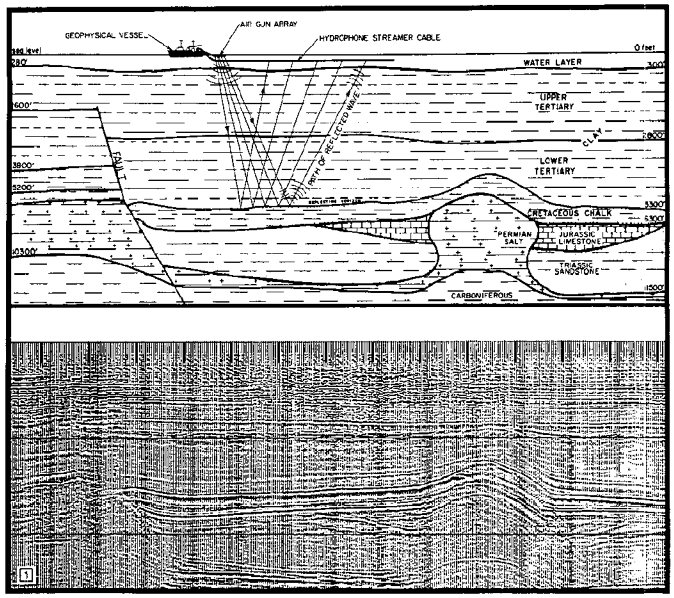


Figure 2.3 Schematic diagram of seismic surveying, indicating air gun source of acoustic signal, propagation through rock strata, reception by streamer, and sample graphic output (Source: Craig Griffin, Geophysical Services, Inc.).

for a week or more at a time. Because people and supplies must be taken on and off, a platform must have a helipad and dock.

A fixed-leg production platform is a massive steel structure that may rise 170 feet above the ocean surface, with three deck levels and many separate rooms. It will usually have eight legs implanted in the seabed. It is designed to minimize the chance of damage from accidents, waves, storms, or earthquakes. As many as 60 or more oil or gas wells can be drilled from a platform, with the wells reaching perhaps 10,000 feet below the ocean floor. To reach much of the oil field, individual wells can slant away from the platform for a distance about equal to the drilling depth.

Subsea production systems also have been used in several offshore areas during the last 20 years. Each well is completed on the sea floor, with no permanent structure above the waves. The well is attached to pipelines that carry the oil or gas to a platform where it is treated and from which it can be taken to shore. In 1988, a subsea well off the coast of Brazil was completed in 1,614 feet of water.

To supply and staff a platform during development and production, a permanent service base must be established on shore. Crew members, food, fuel, pipes, and drilling muds will usually be transported to the platform by independent contractors. A service base must provide a helipad, harbor services for berthing and supplying boats, pier space for loading and unloading supplies, warehouse and open storage space, and work space for supervisory and communications personnel. A base must have ample parking and some isolation to protect the surrounding area from noise. If an area has several lease sales, it is especially necessary to ensure that there will be adequate warehousing and construction space. If existing port space and storage yards are available, they may be used. Often, a new private base will be built. In California, existing port facilities must be fully utilized before the state will approve a new one.

Drilling Techniques and Equipment

Even though wells vary greatly in depth and in the types of rock formations they penetrate, the processes for drilling them remain similar. Any oil or gas drilling operation requires five basic systems: rotary drilling; hoisting and pipe-handling; drilling fluid; well control; and power.

Although it is a fairly simple technology, rotary drilling equipment must still be capable of drilling to great depths, through various kinds of rock, at unknown underground pressures. Rotating a drill bit with downward pressure forces the rough teeth of the bit to break through the rock strata.

The bit is attached to lengths of drill pipe, which can be screwed together. Each length of pipe is about 30 feet long. The upper portions of the *drill string*, as the entire assembly is called, include parts that allow the string to rotate. The drill pipe is hollow, allowing drilling fluids to pass through it.

The hoisting and pipe handling system supports the rotary drilling equipment in the hole and moves the drill pipes. Each time the bit drills the length of a joint, a new joint must be added to the string. Usually, joints are added or subtracted three at a time (the basic three-joint unit is called a *stand*). Each time the drill bit needs replacing, either because it has struck a new type of rock or because it requires maintenance, the entire drill string must be lifted out of the hole. Adding joints and removing them from the hole require special equipment: a towerlike derrick stands directly over the hole; drilling lines lift and move the pipes and other equipment; racks store the pipe.

Drilling fluid system carries rock *cuttings* to the surface and maintains pressure in the hole to prevent water, oil, or gas in rock formations from getting in. The system includes the fluid itself, which is known as drilling *mud*, and equipment to circulate the mud. The main ingredients of drilling mud are water (either fresh or seawater), clay, and heavy materials such as barite that increase the density of the mixture to maintain pressure. Other ingredients may be added and the proportions adjusted to suit the characteristics of the hole.

The mud is pumped down through the drill string and the bit. From there, the pumping pressure forces it through the space between the drill string and the wall of the hole. As the mud rises, it carries the rock cuttings to the top of the hole, where they are strained from the drilling fluid. The mud itself is continually recirculated. Federal regulations control the disposal of muds and cuttings from offshore rigs and platforms. Depending on its composition, mud is either discharged into the water below the water surface or stored and transported onshore to approved disposal sites on land.

The *well-control system* includes equipment to control pressure and prevent blowouts. A *blowout* is a sudden release of well pressure that brings oil and/or gas to the surface and may cause an explosion, fire and/or oil spill. Blowouts are the most serious hazards of offshore oil and gas operations. While some emergency equipment is ready to deal with fire or explosion on each platform, serious blowouts require experts who travel the world to cap blown-out wells and handle accidents when they occur. A well fire or spill from a blowout may continue for days or even months before these specialists can bring it under control.

Industry tries to prevent blowouts in a number of ways. It acquires the best possible seismic and geological information to decrease the risk of unexpected pressure changes caused by geological faulting or similar geohazards. Drilling muds are formulated to maintain the appropriate pressure in the hole. Safety systems are installed to monitor pressure changes at all times. Blowout preventers are used, which shut down the well if there is any sudden increase in pressure. These devices contain valves that close manually or automatically to seal off the flow from the well hole. Because all the valves and gauges look like decorated branches, blowout preventers are often called "Christmas trees." Another series of valves at the well surface is called a choke manifold.

The *power systems* of oil and gas wells are driven by diesel engines or electric motors.

Oil Treatment and Transportation

The fluid an oil well produces is usually a complex mixture of crude oil, gases, water, and some sediments. These components must be separated before the oil can be shipped to refineries. Oil from an offshore platform generally undergoes initial separation and treatment on the platform. Gas may be treated somewhat on the platform or piped directly to an onshore processing plant.

The non-petroleum products of separation require careful disposal. Natural gas may be sent to market, used on site, or injected back into the petroleum formation. Other gases may be injected or released. The water, called *produced* or *formation* water, is treated and either released into the sea or reinjected into the field from which it came.

Oil treatment and storage can be accomplished completely offshore using a specially designed island or a vessel, usually a tanker, refitted to separate, treat, and store crude oil. Offshore storage and treatment permits the development of small fields in which the amount of oil does not justify the construction of onshore facilities or pipelines. Offshore treatment also eliminates the need for pipelines, tank farms, marine terminals, and tankers running to local shores. On the other hand, if an offshore storage and treatment facility is moored in federal waters, it is not subject to state taxes or state regulation, and state air quality standards may not apply.

Although the separation and treatment of crude oil or natural gas generally begin offshore, they are often completed onshore. Treatment facilities are often built in combination with a marine terminal, an oil refinery, or a gas processing plant. Separation and treatment require large amounts of energy to heat and process the oil, and may cause significant air pollution.

Once oil has been separated from its impurities, a refinery will convert it into a variety of commercial products, including gasoline, fuel oil, propane, kerosene, and asphalt. Different kinds of plants are used to convert crude oil into petrochemicals or convert natural gas into ammonia and urea fertilizer. A refinery requires considerable supplies of water and power. Oil is commonly transported by pipeline from a platform to an onshore processing facility or terminal, to an offshore terminal, or to another platform. Natural gas is always transported from an offshore production site to shore by pipeline. Pipelines are generally considered the safest and most efficient and economical means of transporting oil or gas. Their drawbacks are that they can be difficult to install in certain areas and they preclude changes in the product's destination.

A pipeline normally takes the shortest feasible route from a platform to onshore storage and treatment facilities. It may be laid directly on the sea bottom, but to protect it from high-energy ocean conditions and to minimize interference with trawling and crab fishing, it may be buried in a trench (commonly where the bottom is soft) or covered with sand and gravel. The high-energy surf zone in which the pipeline emerges poses special problems. At that point, the pipeline may be either buried or raised on a trestle.

Subsea pipelines are installed either by *lay barges* in deep, open water or from a staging area on the coast. The lay-barge method involves welding lengths of pipe on a barge and placing a continuous welded pipe into the ocean by winching the barge forward from large anchors placed ahead of it. When an onshore staging area is used, pipe lengths are welded onshore and pulled offshore by tugs or by powerful winches on a barge moored offshore. Both methods can leave deep scars on the bottom.

Construction of onshore pipelines requires a staging area and a 200-foot-wide construction right of way for machinery. Building pipelines in remote areas may require road improvements as well.

Pipelines usually end at marine terminals, where crude oil is transferred to tankers or barges to continue its journey to refineries. A marine terminal can be located either offshore or onshore. Either way, it must have vessel moorage, loading facilities, and oil storage tanks and piping facilities. If an onshore terminal has a fixed-berth moorage system such as a pier or wharf, it needs water frontage. If it has a floating berth, connected to the storage facilities by undersea pipeline, it does not. The storage tanks can be built either on the waterfront or somewhat inland.

Tanker transportation is used mainly for oil (except for specially designed tankers that carry liquefied gas at low temperatures). Unlike pipelines, tankers permit flexibility in sending crude oil or refined products to different processing plants or markets. Also, as long as the ship is afloat, the capital invested in tankers remains potentially productive, regardless of which fields are producing and which facilities are operating, while capital invested in a pipeline is effectively lost once the field it serves can no longer produce at a profit.

On the other hand, marine traffic faces a greater risk of accident than pipelines do, and the chance of spillage increases each time oil is transferred from terminal to tanker or vice versa.

A major environmental hazard that accompanies any oil operation is the risk of oil spillage. Oil spills are cleaned up in a variety of ways: with booms, which are intended to contain the oil; skimmers, which are boats or other devices that siphon or skim oil off the top of the water; sorbents, which absorb oil; and dispersants, which break up or disperse surface oil. Not all are indicated in every situation.

Dispersants break up the oil layer by causing the oil to form small droplets that scatter into the water (Figure 2.4). This accelerates dissolution and biodegradation of the oil. Their use is controversial because dispersants themselves are pollutants, and while they remove oil from the surface, they increase hydrocarbon concentrations in the rest of the water column and sediments. Any decision to use dispersants is a compromise: they a) will reduce the exposure of organisms on the surface; and b) will reduce the amount of spilled oil moving toward critical areas such as estuaries; but c) may damage life in the water column and bottom sediments. Recent reductions in toxicity of dispersants, and the small amount of evidence of damage caused by dispersed oil, are leading to a more widespread acceptance of dispersant use. Oil spills may also be burned off if the

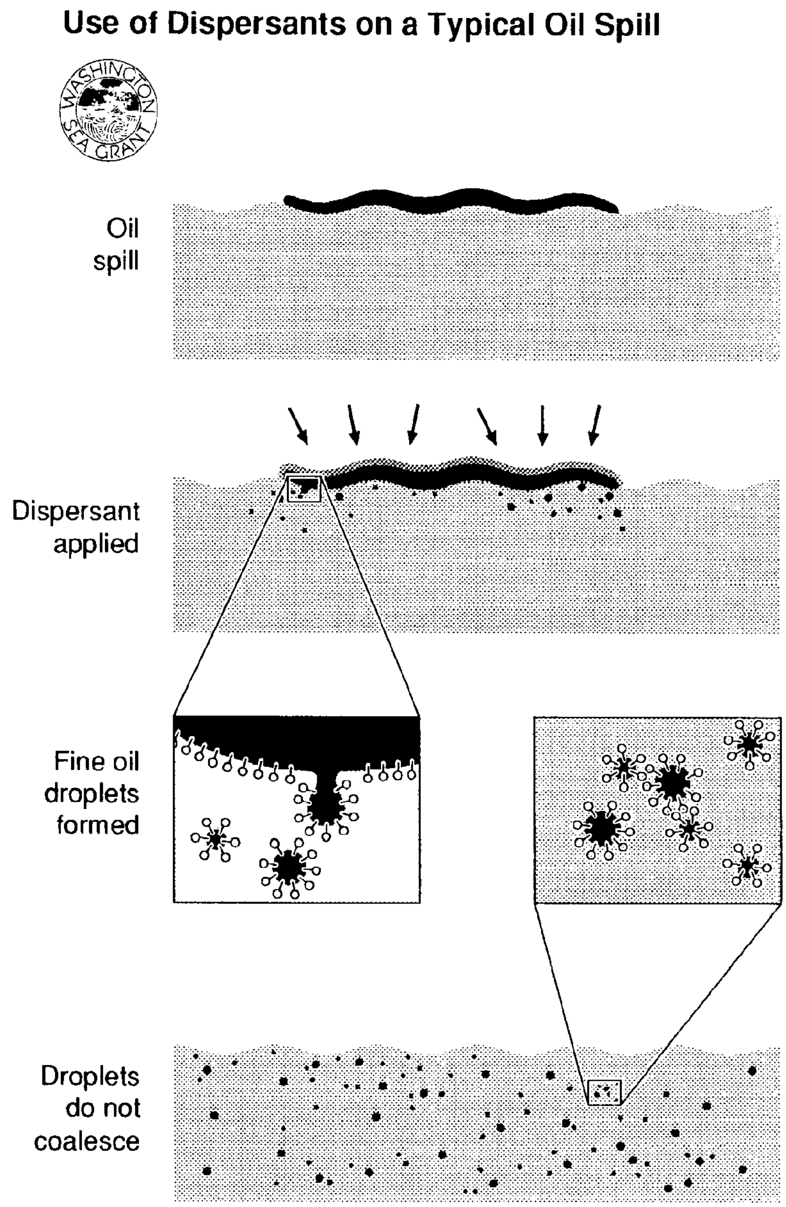


Figure 2.4 Schematic illustration of mode of action of oil spill dispersants.

condition of the slick is suitable and local air quality is not a problem. Because oil spill response is very expensive, industry has formed cleanup cooperatives in many U.S. geographic areas of oil production or processing. The cooperative provides equipment, trained personnel, and cleanup plans to the participating companies.

Cleanup technology is not effective in very strong currents, rough seas, or bad weather. In those situations, oil does not stay within the booms deployed; cleanup vessels may not be able to reach the spill; aircraft may not be able to take off to find the spill; and dispersants may not be spread effectively. High-energy seas, however, will naturally disperse and weather the oil. This will minimize damage—if the spill does not occur near or move toward sensitive coastal areas.

PETROLEUM INFRASTRUCTURE IN WASHINGTON

No oil is produced in Washington, but as of the mid-1980s, the state's oil refineries annually sold $4.5 billion worth of products, added more value than any manufacturing industry in the state except aerospace and shipbuilding, and brought in an average of more than 400,000 barrels of crude oil per day in 1986.[5]

Most of the oil coming into the state is Alaskan crude that travels by tanker to the refineries on Puget Sound. (Tankers that carry oil east of Port Angeles may not exceed 125,000 deadweight tons.) A small amount of crude also comes by tanker from Indonesia and the Middle East. Six percent comes in by pipeline from Canada. These figures amount to an annual inbound tanker transshipment of more than 154 million barrels, roughly tripling in one year the total offshore production from Oregon and Washington estimated by MMS[40,42] over the 30- to 35-year life of the field.

The refineries, located in Ferndale, Anacortes, and Tacoma, supply markets in western Washington, in Oregon, and in other states. Some 235,200 barrels a day of refined products (1986 average) pass through the Olympic pipeline to points in western Washington and Oregon.[5] Another 187,000 travel by tanker, barge and truck to points in western Washington and other states.

Crude oil makes up roughly seven-eighths of the petroleum brought into Washington state. The other one-eighth consists of refined products that are delivered to storage tanks in the Puget Sound area, the TriCities, and Spokane. The Puget Sound and Pacific coastal areas are fed by product tanker and barge shipments. The sites in eastern Washington are fed by the Yellowstone Pipeline, which carries refined products from Wyoming and Montana, and the Chevron Pipeline, which carries products from Utah (Figure 2.5). In addition to liquid petroleum products, natural gas is piped into the state from fields in Canada, Colorado, and Wyoming.[6] A small gas field in western Oregon is the only commercial source of petroleum in the Pacific Northwest. Natural gas is used less in the Northwest than either electricity or oil, but it is now the energy source for most new houses in the Seattle area.

SOURCES OF OIL IN THE OCEAN

Global inputs of petroleum to the oceans have been estimated recently [48] and are presented in Figure 2.6. These estimates are subject to considerable uncertainties. Nevertheless, worldwide offshore oil and gas production accounts directly for only a small fraction of the petroleum input to the ocean. Of the estimated 3.2 million metric tons of oil entering the oceans each year, about 50,000 tons comes from all offshore production activities, major and minor spills included. (All tonnages cited are metric unless otherwise noted.)

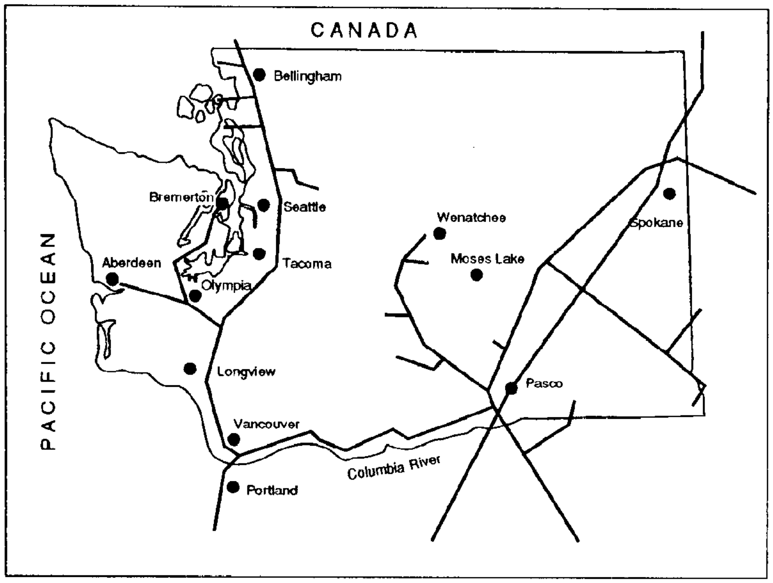
The largest documented source of oil to the sea (1.05 million tons/yr) is normal vessel traffic, including tanker discharges, spillage at terminals and drydocks, and bilge and ballast flushing and fuel discharges from vessels of all types. Tanker spills and other vessel accidents add another 0.45 million tons/yr. Together, these two shipping-related sources account for nearly half of the oil entering the sea.

Municipal sewage discharges are the second largest source of oil reaching the sea. When combined with untreated urban runoff, this source accounts for 0.86 million tons/yr. Another 0.32 million tons is discharged by industries (including refineries) or contributed by ocean dumping of wastes. These non-vessel human sources also account for nearly half of the petroleum entering the sea.

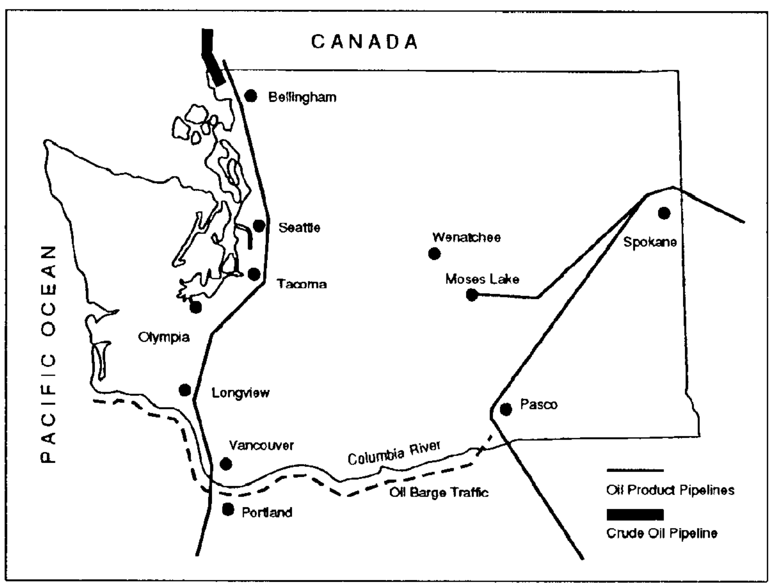
Natural seeps and erosion of petroleum-containing sediments contribute relatively little petroleum to the sea (an estimated 0.25 million tons/yr), but can be locally important in areas such as Santa Barbara. Although no oil seeps have been reported on the Washington shelf, small seeps occur on land in coastal Washington and may exist offshore as well.

PRODUCED WATER

Offshore oil and gas production releases petroleum into the sea through normal discharges of formation or produced water, which contains some hydrocarbons. A well produces 60-80 percent as much produced water as it does oil, an amount that may reach 1.5 million liters per



Natural Gas Pipelines in Washington State



Oil Pipelines in Washington State

Figure 2.5 Maps of oil and natural gas pipelines in Washington State.

day.[48] The EPA requires treatment of produced water before it is discharged to reduce its petroleum content to a daily maximum of 72 ppm and a monthly average of 48 ppm. (New proposed standards would lower these quantities to 59 and 23 ppm, respectively; all these figures refer to dispersed oil rather than hydrocarbons in solution, however, which may reach concentrations of 500-600 ppm.[50] (For technical reasons, these limitations result in a conservative estimate of about 70 ppm for the actual mean petroleum hydrocarbon content of discharged produced waters.) About 10,000 tons/yr of hydrocarbons are estimated to enter the ocean worldwide from produced waters. MMS estimates that 43.5 million barrels of produced waters would be discharged off Washington/Oregon in its low case scenario.[40]

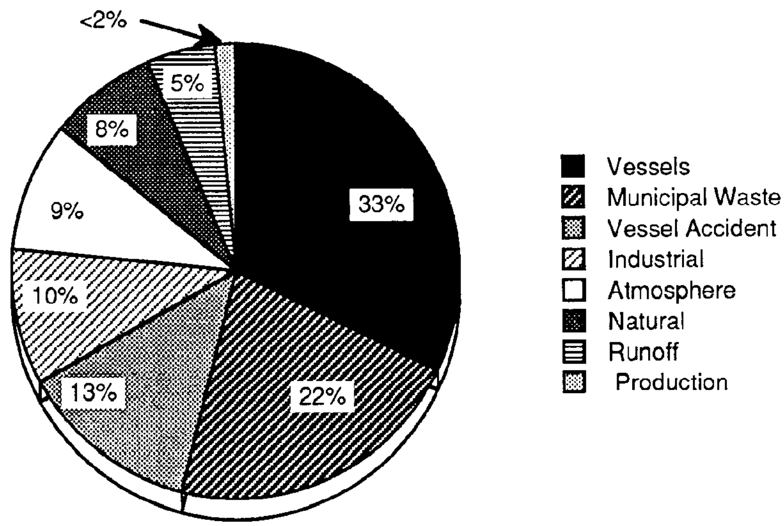


Figure 2.6 Proportions of petroleum hydrocarbons entering the sea on a global scale from routine vessel traffic operations, municipal sewage waste disposal, tanker and other vessel accidents, industrial waste disposal, atmospheric input, natural seepage, river runoff, and discharges and spillage from petroleum production platforms (data from NRC 1985).

Field studies around multiwell development and production platforms in the Gulf of Mexico and North Sea have observed some significant impacts of produced water discharges on benthic communities in shallow waters.[48] These effects were confined to areas within about 200 meters of the platforms. Concentrations of light volatile hydrocarbons in the water column off Louisiana are about 100 times higher than in pristine offshore waters, a fact attributed to underwater venting of waste gas and to discharge of produced water. In deeper waters of the Gulf of Mexico and off southern California, no significant benthic effects have been observed.

The acute and chronic toxicity characteristics of produced waters are essentially the same as those of petroleum hydrocarbons at the applicable concentrations, which are well studied. Only a small number of laboratory studies have examined the effects of produced waters directly. The results of these studies conform to expectations; that is, at the concentrations discharged and dilutions observed in the ocean, produced waters appear to be of low acute toxicity and to pose a negligible threat of mortality to organisms in the vicinity of a platform. Neff[50] argues that more species need to be tested, however, to confirm these results. In addition, almost no laboratory studies have been conducted on the long-term sublethal effects of produced waters. Neff[49] contends that research *definitely* is needed to verify the small number of indications that chronic effects of produced waters are low.

DRILLING FLUIDS

The use of drilling fluids and their environmental impacts have been the subject of recent reviews.[46,49,50] Some fluids are oil-based and can be a source of oil to local waters where they are used, but discharge of oil-based fluids is prohibited in U.S. waters. Therefore, drilling fluids are not a significant source of oil to U.S. coastal waters.

The fluids (more commonly called muds) are composed of inert clay minerals such as bentonite and other minerals such as barite (mostly barium sulfate). These constituents are suspended in water or oil with other minor bulk constituents such as lignite (soft coal) or lignosulfates, which help keep the clay in suspension in the mixture, and sodium hydroxide (lye), which aids the suspension action, reduces corrosion, and suppresses bacterial growth. Other trace additives may include small amounts of oil to act as a lubricant, and other biocides. Muds also typically contain small quantities of trace metals such as chromium (44-191 ppm), zinc (50-80 ppm), and cadmium, lead, mercury, nickel, and vanadium (<15 ppm each), which occur naturally in the clay materials used.

During use, muds are recirculated, strained to remove the cuttings, and reused. The cuttings must be disposed of, and so eventually must the muds, which lose their effectiveness after a period of use. From a technological and logistical point of view, the simplest disposal method is to discharge them over the side of the platform. In federal waters, these discharges are regulated by the Environmental Protection Agency (EPA) through the National Pollution Discharge Elimination System (NPDES) of permits, and by MMS through lease stipulations and operating orders. NPDES requires that "best practicable control technology currently available" be applied to the discharges, which cannot result in "unreasonable degradation" of the marine environment. In practice, these requirements are implemented by requiring that no oil sheen be visible at the surface from fluid discharges. In addition, the discharge of oil-based muds is now prohibited; land-based disposal (or disposal in an approved ocean dumping site) is required.

Material may be disposed of at the surface or released near the bottom. About 90 percent of particles released at the surface sink rapidly to the bottom, and the remainder form a surface plume, which is diluted many-thousand-fold within a short distance of the platform. In this plume some of the metal content of the muds dissolves. The bottom accumulation is restricted initially to within about one kilometer of the drilling platform, and the mud pile disperses over time with the action of bottom currents and resuspension. Particles released near the bottom create a smaller but more concentrated impact zone.

The amount of mud disposed of from a platform is about 200-1,000 tons (dry) of total solids per well drilled (depending on depth), along with a similar amount of cuttings.[50] A typical platform discharges about 95,000 tons of muds over its life span.[50] The resulting solids disposal over 30 years would equal less than 0.1 percent of the estimated 5-20 million ton *annual* sediment output of the Columbia River.[28] MMS estimates that 175,000 barrels of muds and cuttings would be discharged off Washington/Oregon in its low case scenario.[40] Approximately two million tons of muds are discharged on the U.S. continental shelf annually, an amount that is about one percent of the sediment discharge of the Mississippi, and is less than the discharge of dredge spoils, sewage sludge, and industrial wastes. This long track record provides a solid foundation of experience from which to draw conclusions.

The NRC study panel [46] found that under most circumstances the impacts of drilling fluid disposal under current management restrictions are minimal, temporary, and localized. The panel also found no substantial evidence that conclusions drawn from studies at one geographic location could not be applied to other locations. From the results of studies in Cook Inlet, the Gulf of Mexico, California, New Jersey, and Georges Bank, the immediate impacts of drilling fluid disposal appear to be primarily physical; that is, they accumulate on the sea bed and bury, suffocate, and abrade the gills of existing organisms.[46,49]

The long-term behavior of these accumulations has received little study, however.[49] A single study found that the biological effects of these physical accumulations are restricted to the one-kilometer zone and persist approximately one year after termination of drilling. Such recovery times in theory may range from weeks in shallow-water habitats to several years in deep sea environments. The impacts appear to be greatest on hard-bottom habitats, where the normal level of fine sediments is very low. The effects of discharges from multiple adjacent platforms also have received little study but would be difficult to distinguish from other impacts of oil and gas production.

The overall chemical toxicity of drilling fluids is considered to be low, and the bulk constituents of muds are considered essentially nontoxic at the dilution levels reached within a short distance of the platform. Almost all whole water-based muds are acutely toxic only at levels greater than 1,000-10,000 ppm.[46,49] Only two to four percent of fluids tested were toxic at levels as low as 100 ppm. Two Washington animals (Dungeness crab and pandalid shrimp) appear to be among the most sensitive organisms assayed, with lethal thresholds of 210 and 120 ppm of lignosulfate, respectively. Other sensitive local organisms include pink salmon fry and scallops. Sublethal effects of drilling fluids on organisms have been observed in laboratory studies at concentrations of 10-1,000 ppm.[46,49] Among the sublethal effects observed are reduced chemical sensitivity; abnormal growth and embryo development; and altered feeding, skeletal and gill structure, and enzyme activity. Crustaceans and juvenile stages of animals in general appear to be the most sensitive organisms.

SPILLS

Total estimated global input of petroleum hydrocarbons to the ocean from spills of all sizes at production platforms is about 11,000 tons/yr, or slightly more than is derived from produced waters.[42] Spills at the platform result from blowouts, leaks, and small releases of fuels and lubricants. Offshore oil and gas production also entails the risk of oil spills from pipelines, tankers, and barges transporting oil to shore. More than 95 percent of oil and gas produced offshore is transported to shore through pipelines.[3] Pipeline spills result from ruptures or smaller, chronic leaks. Where technologically or economically infeasible, oil transport by pipelines is replaced by offshore storage, followed by transfer of the oil to tankers or barges. Vessels are regarded as less safe than pipelines because there is an increased risk of oil spills.[3,31]

Offshore oil and gas development contributes an estimated 1.5 percent of the petroleum entering the marine environment in U.S. coastal waters.[48,50] The U.S. Geological Survey classifies spills smaller than 50 barrels (seven tons) minor and those larger than 50 barrels major. The average spillage rate of minor spills in the Gulf of Mexico (1971-1978) was 0.00024 percent of oil produced.[48] For major spills in the Gulf of Mexico over the same period the rate was 0.002 percent. The spillage rate for all spills in lower Cook Inlet (1971-1980), where somewhat newer technology is employed, was 0.0001 percent, or one barrel spilled per million produced.[50] The spill rate is higher worldwide (approximately 0.01 percent of offshore oil production is accidentally spilled into marine waters) because there is less restrictive regulation of blowout prevention outside the United States.

Spills can also be described in terms of their frequency. From 1964-1980 the average spill rate in U.S. waters was 2.05 spills per billion barrels produced.[50] The rates for pipeline and tanker transport were 1.6 and 1.3-3.87 spills per billion barrels transported, respectively. All these rates appear to have decreased significantly over the last 25 years. These data indicate that large spills from OCS production are rare; no spills over 1,000 barrels have occurred since 1981, and only three such spills have occurred since 1979.[3,31] These rates do not include spills in state waters, however.

The highest frequency of platform spills, blowouts, tanker spills, and pipeline accidents is expected in the Gulf of Mexico, where most of the offshore drilling takes place. All but one (Santa Barbara Channel) of the larger oil spills (1,000 or more barrels) on the U.S. OCS from 1964-1980 were from oil and gas wells on the Gulf of Mexico OCS.[24,31] There were no large platform spills from blowouts off U.S. shores since late 1980, and none in federal waters since 1969. Between 1981 and 1987, 2.2 billion barrels of crude oil were produced. This is the longest continuous crude oil production period without incurring a platform spill in OCS history. There have been no large pipeline spills from late 1981 through 1987.

The most recent calculated frequencies of large spills rates from OCS platforms (0.56 spills per billion barrels) and pipelines (0.67 spills per billion barrels) represent declines of 44 percent and 58 percent, respectively, since last evaluated in 1983.[3] This reduction may be due to improvements in technology, stricter safety regulations, and more experience in offshore oil production. Tanker spill frequencies for worldwide tanker transport remain unchanged at about 1.3 spills per billion barrels since 1983.[3] For the years 1971-1986, the total number of blowouts (100) in all federal waters was 0.6 percent of the number of well starts (15,922), or about one blowout for every 160 wells drilled. Few of these blowouts released significant volumes of oil, however.[24,62] For the same period, the total amount of oil spilled in blowouts (840 barrels) in federal waters was 15 millionths of one percent (0.000015%) of the total offshore production of 5.5 billion barrels.[24]

Despite the relatively low levels of average spillage and chronic input of oil to the sea described above, it is useful to examine the magnitude of spillage that is possible from worst-case accidents. From 1974-1983 more than 99 percent of spills were small (<1000 barrels), but they accounted for only 28 percent of oil spilled.[50] The largest oil spill on record was the *Ixtoc* well blowout in the Gulf of Mexico on June 3, 1979.[50] Before it was capped the following March, this accident released an estimated 0.44-1.4 million tons (~3.5-10 million barrels). The world's largest tanker spill on record was the wreck of the *Amoco Cadiz* off Brittany (northwestern French coast) in April, 1978. This vessel lost its entire cargo of 220,000 tons (1.6 million barrels) of crude oil, as well as its fuel.

Estimated Probability of Spills off Washington

MMS considers oil spills of at least 1,000 barrels (42,000 gallons) as large spills for assessing potential environmental impacts of lease sale proposals.[40] It projects the probability of large spills for petroleum development proposals by multiplying the average spill rates (spills per billion barrels) by the volume of oil produced or transported. MMS states that the recent reduction in the oil spill rate, and the associated reduction in the availability of data for spills exceeding 1,000 barrels, has made it difficult to predict spill rates needed in oil and gas resource management decisions. For analyzing spill probabilities in lease sale 132 off Washington/Oregon, MMS [40] used spill rates per billion barrels of 1.0 for platforms, 1.6 for pipelines, 0.9 for tankers at sea, and 0.4 for tankers in port. MMS applied these rates to the low case and high case production scenarios and added in risks from transshipment along the Washington coast of oil produced elsewhere.

Under the low case scenario (58 million barrels), assuming transshipment by tanker, MMS projects 0.23 spills (larger than 1,000 barrels) would occur over the life of the field, with an 11 percent probability of a large spill occurring. Under the high case scenario (180 million barrels produced), these figures rise to 0.51 large spills projected and a 16 percent probability of one or more large spills occurring. Under the "cumulative" scenario, which adds projections of non-OCS domestic oil and imported oil transported by tanker, these rates rise to 3.16 spills, with a 96 percent probability of one or more spills.

These calculations indicate that the risk of large spills from production off Washington must be viewed in the context of an apparently larger risk from oil tanker and other vessel traffic. This context cannot be fully realized without more detailed study. However, it suggests that the spill risk from existing vessel traffic into the state is already significant, and that spill risk would be increased by offshore production.

Another analysis made for the Washington/Oregon OCS region predicts 0.09 spills (>1,000 barrels) from full exploitation of oil resources, with an estimated 1,300 barrels reaching shore.[50]

PETROLEUM HYDROCARBON LEVELS IN WATER AND SEDIMENTS

The expected concentrations of petroleum in seawater and sediments must be determined in order to estimate the biological impacts on local organisms. For volatile liquid hydrocarbons (such as gasoline and benzene), unpolluted waters typically contain concentrations of 60 parts per trillion (ppt), while polluted waters may contain 500 ppt.[48] Specific observations include levels of 2 parts per billion (ppb) around a production platform in the Gulf of Mexico, 20 ppb around a gas well blowout, 120 ppb off a ballast treatment plant at Valdez, Alaska, and 400 ppb at the site of the *Ixtoc* oil well blowout (decreasing to 1-4 ppb several miles downstream). Some values in the low ppb range also are reported for light hydrocarbon gases such as methane around production and blowout sites. Concentrations of higher-weight hydrocarbons typically range less than 1 ppb in remote areas, in the low ppb range in areas of shipping traffic or petroleum production, and at higher levels approaching 100 ppb or more in the vicinity of spills or natural seeps.

Petroleum hydrocarbon concentrations are higher in sediments than in water because hydrocarbons are poorly soluble and have an affinity for particles. Levels in unpolluted sediments are usually less than 50 ppm (dry weight), whereas sediments in urban harbor areas may exhibit several thousand parts per million and areas affected by major spills may contain tens of thousands of parts per million (i.e., a few percent of the sediment is oil).[48]

Significantly elevated levels of hydrocarbons in sediments surrounding a platform have been observed only in the North Sea,where oil-based drilling muds are used, and even these amounts declined to background levels within two to three kilometers of the platform.[11] Large amounts of oil are not commonly observed in sediments beneath deep-water spills such as *Ixtoc*; however, high levels have been observed in shallow water where spills contacted the shoreline, as in *Amoco Cadiz* (200 ppm) and at Santa Barbara (1,400 ppm).

Sources of Oil in Washington Coastal Waters

No inventory has been made of the amounts or sources of petroleum currently entering Washington coastal waters. There are also few estimates of petroleum hydrocarbon concentrations in Washington coastal waters or sediments. Sediment concentrations of some hydrocarbon fractions in the low hundreds of parts per million have been observed in urbanized areas of Puget

Sound and the Strait of Juan de Fuca.[48] The main source of hydrocarbons in sediments on the shelf is the Columbia River.[55]

Silty sediments from the Columbia accumulate on the shelf in a distinct deposit. Surface concentrations of polycyclic aromatic hydrocarbons (PAH), a product of fuel combustion, in these sediments are about 200-300 parts per billion (dry weight). An estimated 30 percent of PAH in shelf sediments originate from the Columbia; another 10 percent are transported by the atmosphere.[56] This represents a 2-to-3-fold increase from pre-1900 concentrations, reflecting recent urban development in the Columbia basin.[55] However, this enrichment is less that the 10-to-100-fold increase found in more urban sediments. Observed levels of non-combusted petroleum hydrocarbons in this study were very low, indicating negligible local inputs of oil.

Global inputs of petroleum to the oceans estimated recently [48] may be used as a guideline for the magnitude of possible petroleum inputs to Washington coastal waters from future offshore production. Production of formation water is known to be 60-80 percent of the volume of oil produced, and the petroleum hydrocarbon content of discharged produced waters is known to be about 70 ppm. Multiplying these figures by the rate or amount of petroleum production projected for Washington would provide a first estimate of petroleum hydrocarbon input from this source. The spillage rate for lower Cook Inlet (1971-1980), where newer technology probably most comparable to what would be used off Washington is employed, was 0.0001 percent.[50] This factor could be applied to the rate or total amount of petroleum production to provide a first estimate of petroleum hydrocarbon input from spills. Using the MMS[42] estimate of 58 million barrels of recoverable oil off Washington, these calculations yield petroleum input estimates of 2,842 barrels (from produced waters) and 58 barrels (from small spills) over a possible 30-year life of production, or about 100 barrels per year. However, this amount could vary tremendously depending on the actual spillage rate.

These estimates could be compared with data derived from volumes of shipping traffic off the Washington coast and local inputs of municipal and industrial waste. It is reasonable to presume that petroleum input from shipping traffic is today and would continue to be a significantly larger source of petroleum in Washington coastal waters than inputs from coastal urban centers, or from offshore production in the absence of a major spill. In particular, transshipment of oil along and off the Washington coast (including the 154 million barrels brought into Puget Sound annually) already appears to present a much larger risk of both chronic input and large-scale spillage of oil into coastal waters than would be posed by offshore production. Rigorous examination of this issue would require additional research.

Fate of Oil in the Marine Environment

No two petroleum deposits are exactly alike. Crude oil contains tens of thousands of different chemical compounds. Hydrocarbons of varying weight and viscosity compose 50-98 percent of crude oil. Other constituents include sulfur (0-10 percent), nitrogen (0-1 percent), and oxygen (0-5 percent), and trace metals such as vanadium, nickel, iron, aluminum, sodium, calcium, copper, and uranium.[11,58] When crude oil is spilled on the sea, these fractions begin to separate and have different fates. Refined oil products such as diesel fuel, gasoline, and Bunker C fuel, when spilled on the sea, have fates like those of the crude oil fractions they are derived from.

When petroleum enters the sea, it undergoes physical, chemical, and microbiological weathering processes (Figure 2.7): spreading, evaporation, solution, emulsification, dispersion, sedimentation, photochemical oxidation, and microbial degradation.[4,7,11,13,19,29,37,48,58] Oil spilled on the surface of the ocean spreads rapidly to form a slick. The rate of spreading is retarded by oil viscosity (resistance to flow) and is aided by wave action, winds, currents, and higher temperatures. Oil drift velocity is approximately 3-3.5 percent of wind velocity. Oil slicks are not uniform as they expand; the largest amount of oil tends to sail with the wind at the leading edge of the slick. The amount of spreading influences the thickness of the slick, which in turn affects the rates at which other physical, chemical, and microbiological factors interact with the oil.

Evaporation of the lightest fractions, one of the first changes in spilled oil, can remove 30-50 percent of hydrocarbons in crude oil and 10 percent of hydrocarbons from Bunker C fuel oil within 10 days. The rate of evaporation increases with wind velocity, air and water temperature, wave action, and the area of the exposed oil slick. The rate of evaporation decreases with time.

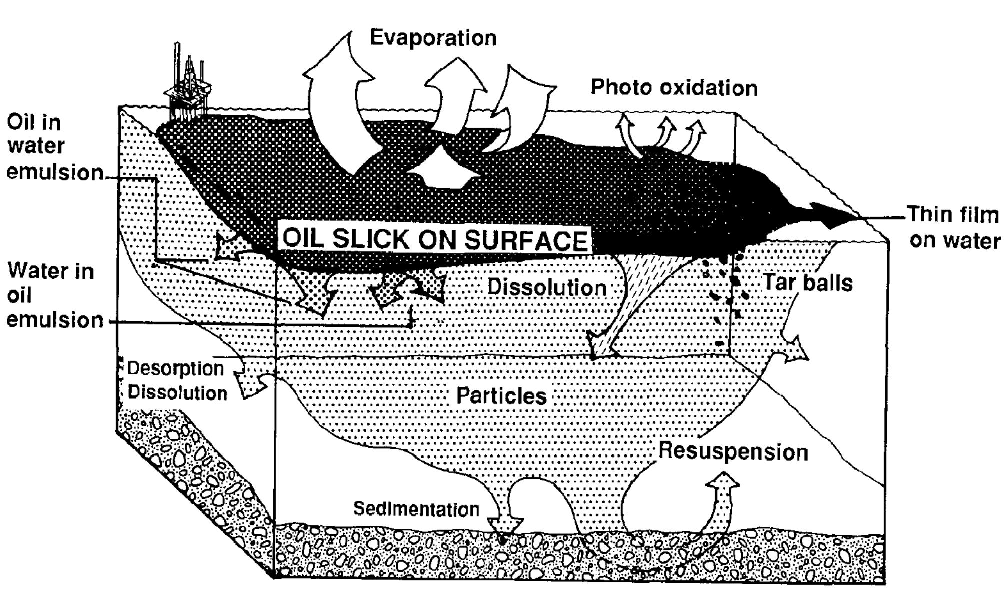


Figure 2.7 Fate of oil spilled in the ocean (modified from Clark and MacLeod 1977).

Evaporation causes considerable changes in chemical composition and physical properties of spilled oil. After the more volatile components are removed, the remaining residue will consist of heavier hydrocarbons and non-hydrocarbons such as waxes, sulfur-containing compounds, and asphalts. In addition to being denser and more viscous, this mixture includes carcinogens (chemicals that can cause cancer) with long-term potential for toxic effects on marine life.

Another major fraction of spilled oil dissolves in the water column. The solubility of typical crude oil in water is only 30 milligrams per liter (30 parts per million). However, the volume of seawater is so great in open waters that light aromatic hydrocarbons such as benzene, toluene, and xylene can move directly from oil slicks or dispersed oil drops into the water column. Within a given class of hydrocarbons, the lighter compounds can dissolve more readily than the heavier ones. The lighter compounds are also the most volatile and therefore are likely to evaporate from the water before they have the opportunity to dissolve in the water. In general, evaporation is orders of magnitude faster than solution as a process for dispersing spilled hydrocarbons. As oil weathers in air, many of its components become more soluble.

An emulsion is a dispersion of one liquid in another. Emulsification of oil increases dispersion, microbial degradation, and exposure of marine life to the oil. Emulsions are formed by wind and wave action, aided by compounds generated by microorganisms. Two types of emulsions can be produced after an oil spill: oil in water or water in oil. Oil-in-water emulsions disperse rapidly in seawater and are transported by existing currents. Heavier crude oils with high viscosities form more stable water-in-oil emulsions which are semisolid, gel-like masses called "mousse" or "chocolate mousse." They may contain up to 80 percent water and are more viscous than the component oil. Mousse weathers slowly, with the oil retaining its initial toxicity, and may become tar balls that float at or near the sea surface and strand on beaches. The transport of mousse and tar balls can increase the area and duration over which a spill is felt. Between 10 and 30 percent of oil discharged to the ocean remains in the form of tar balls, with an estimated residence time of one year. The lifetime of an oil slick on the surface of the sea is often controlled by the dispersion or vertical transport of small particles of oil or oil-in-water emulsions into the water column. The result of dispersion is exposure of marine organisms to particulate or dissolved oil.

Several studies have reported on the accumulation of petroleum hydrocarbons in the sea surface microlayer at higher concentrations than in the underlying water column. This is of concern because the elevated concentrations of toxic constituents of oil may pose a danger to fish eggs and other organisms that live at the sea surface. Wade and Quinn [66] measured high molecular weight hydrocarbons with an average concentration of 155 parts per billion (ppb) in the microlayer of the Sargasso Sea compared to 73 ppb at 8-12 inches below the surface. They suggested that the major source of these hydrocarbons in the surface microlayer was small particles of weathered tars. Marty and Saliot [36] found that concentrations of petroleum hydrocarbons were 50 times higher in the surface water microlayer in the eastern Atlantic and Mediterranean than in the underlying water. Boehm et al.[12] and Boehm[10] reported that hydrocarbon concentrations in the surface microlayer in the Georges Bank area (northwestern Atlantic) were 1.4-90 times as high as those in the water column.

Petroleum on the sea surface or dissolved in the water column can be broken down (photooxidized) by sunlight to lighter organic chemicals and ultimately to carbon dioxide and water. Oxidation products are generally more soluble than their precursors; this higher solubility may facilitate emulsification and microbial degradation. Some of the oxidation products are less toxic to marine life than the parent hydrocarbons; others may be more toxic. In general, photooxidation of petroleum is slower than physical or microbial degradation processes. The rate of photooxidation depends on the chemistry of the petroleum and the amount of sunlight. Trace metals found in petroleum promote photooxidation; sulfur-containing compounds inhibit the process. Heavier aromatic hydrocarbons are more sensitive to photooxidation than lighter aromatic hydrocarbons. The rate of photooxidation of petroleum compounds decreases with water depth because less light is available.

Heavy fractions of crude oil and heavy refined products such as Bunker C fuel oil can sink directly to the sea bottom. Weathering processes such as evaporation and solution of light hydrocarbons, and adsorption of oil onto mineral particles or plankton, also can make light fractions of oil heavier and cause them to sink to the sediments. Oil also enters the sediments from fecal pellets of marine animals that ingest oil droplets. In polluted coastal areas, hydrocarbon levels range from 100 to 12,000 ppm; by contrast, the hydrocarbon content of sediments from unpolluted coastal and deep sea areas is usually below 70 ppm. Once incorporated into sediments, oil tends to degrade very slowly. This is especially true for stable, fine-grained, anaerobic sediments found in sheltered nearshore habitats and on the outer continental shelf. Toxic hydrocarbons may persist in sediments for several years, or they can be resuspended from sediments back into the water column as a result of currents, turbulence from storms, and the activity of animals that burrow in the sediments.

Microbial degradation is an important process in weathering and eventual disappearance of petroleum from the marine environment. Some molds, yeasts, bacteria, and marine microalgae are capable of transforming petroleum hydrocarbons into more soluble and usually more reactive compounds, and ultimately into carbon dioxide and water. Biodegradation of oil is an adaptive process, as evidenced by the fact that oil-polluted sediments contain higher numbers of microbes that can digest hydrocarbons than do clean sediments. Microbes from oil-polluted areas will degrade oil more rapidly than will microbes from oil-free areas.

The rate of microbial degradation depends on the chemistry of the petroleum, number and types of microbial populations present, and environmental conditions such as water temperature, availability of oxygen, and availability of nutrients. Even under the most favorable conditions, it may take many years to convert petroleum into carbon dioxide and water. For example, microbial oxidation of one gallon of crude oil to carbon dioxide and water would require all the dissolved oxygen present in 320,000 gallons of average air-saturated seawater.[7] Laboratory experiments conducted after the 1.6-million-barrel *Amoco Cadiz* oil spill off the coast of Brittany showed that microbial degradation of that volume of oil could take 30 years.

The biodegradable portion of crude oils ranges from 11 to 90 percent. Microbial degradation will be very slow for any petroleum that reaches the deep-sea environment, where temperatures and oxygen levels are lower than at the sea surface. Petroleum that becomes incorporated in anaerobic marine sediments, especially fine-grained sediments, is resistant to biodegradation. Formation of mousse or entrainment of oil in sediments hinders biodegradation by reducing the surface area that can be attacked by microbes as well as reducing the availability of oxygen and nutrients. Availability of nutrients can also approach limiting concentrations when there is a low rate of water movement and during or immediately after a plankton bloom.

USE OF DISPERSANTS

The proper use of dispersants is still a matter of some disagreement. The earliest dispersants used, such as in the *Torrey Canyon* spill off Britain in 1967, were highly toxic and caused significant biological damage themselves.[48] Dispersants of much lower toxicity have been emerging from industry and undergoing testing under EPA supervision over the last ten years.[21] Their principal purpose to is to minimize the probability and volumes of nearshore oil spills striking land, and to reduce risk to surface animals such as seabirds. Available data suggest that the resulting impacts of dispersed oil on subsurface organisms are low.

A formal permission procedure involving the Coast Guard, the state, and EPA is followed before dispersant use is authorized on a spill in federal waters.[69] Their greatest potential usefulness in Washington coastal waters would be in sensitive areas where other containment or cleanup measures such as booms and skimmers cannot be deployed because of inaccessibility or weather and sea conditions. Results of a National Research Council study on advantages, disadvantages, and appropriate conditions for dispersant use are anticipated in early 1989.

TOXIC EFFECTS OF OIL ON ORGANISMS

Toxicity is defined as the imparting of a deleterious effect on an organism. The effect can be immediate or delayed, permanent or temporary, and lethal or sublethal. Toxic effects from oil vary widely, depending on the chemical composition of the oil, environmental factors such as salinity, temperature, and viscosity, the level of feeding and reproductive activity by the organism, and differences in sensitivity and susceptibility among species and among life cycle stages within species.

For purposes of this document, *sensitivity* is defined as the degree to which physiological effects are imparted in an organism when it is contacted by a given amount and type of oil. *Susceptibility* is defined as the degree of exposure of a given organism to oil in the environment, depending on its proximity to sources of oil and behaviors and habitats that affect whether it may be struck by spilled oil in its vicinity. Sensitivity and susceptibility combine to determine *vulnerability*, the total exposure of an organism in its environment to possible impacts from oil.

For example, salmon and trout exposed in the laboratory to toluene, a common constituent of crude oil, have shown greater physiological sensitivity to toxic effects at low exposure temperatures. Ghost crabs are more sensitive to oil hydrocarbons when they are mating than at other times of the year, because they have lowered energy reserves and the hormonal changes associated with reproduction interfere with hydrocarbon detoxification reactions. In contrast, cold-water species (such as shellfish and finfish in Washington coastal waters) may be more susceptible to oil toxicity than warm water species because toxic hydrocarbons persist longer at lower temperatures. Winter flounder are more susceptible to oil-contaminated sediments during summer than winter because they feed more and have more contact with sediments in the summer.[14,48,57,58]

A great deal of research has been done on sensitivity to oil of commercially important fish and shellfish and some non-commercial invertebrates. Less research has been done on bird and mammal species. This section will discuss existing knowledge of biological impacts based on the larger data base available for commercial species.

LETHAL EFFECTS (ACUTE TOXICITY)

High doses of oil can quickly be fatal to marine organisms. These short-term, immediate impacts are called lethal or acute toxic effects of oil and its constituents. Laboratory studies of acute toxicity are designed to estimate chemical concentrations causing 50 percent mortality in one to a few days. These concentrations are called toxic thresholds, or LC50s.

If oil strands on a beach, fish eggs and shellfish in the intertidal region will be killed by physical smothering or by absorption of toxic concentrations of hydrocarbons from the water. The numbers of fish eggs and the numbers of species affected would generally be low during most of the year. The higher vulnerability of intertidal organisms is due to the concentration of oil in a narrow band along shorelines, and from the shallow depth of the water column in intertidal areas. These factors combine to raise the hydrocarbon concentrations in the intertidal zone beyond the tolerance thresholds of most marine animals.[48,57,58]

Acute mortalities of finfish and shellfish will be lower in the subtidal areas adjacent to these oiled beaches and will depend on the concentrations and persistence of dissolved and emulsified oil. Clams and other bottom animals could be smothered by oil that coats the bottom.

The oil could then sink into the sediments, where the animals would be exposed to its toxic constituents.[48,58]

Most acute toxicity studies show that the majority of fish that die do so within the first few hours after exposure, with any remaining fish surviving several days of exposure. This finding suggests either that the toxic components are rapidly taken up by some fish and are consequently less available to other fish, or that there are individual differences in resistance.[68]

The acute toxicity of oil mainly derives from the compounds that are water soluble, and it is highest for lighter aromatic hydrocarbons such as benzene. Table 2.2 shows that refined oils are generally more toxic to fish than crude oils because they contain more of the lighter aromatic compounds.[20,57] The toxicity of specific petroleum hydrocarbons to various marine animals is determined using a standard test called a bioassay—the amount of the test hydrocarbon producing 50 percent mortality after 24 hours of exposure or 96 hours of exposure. Naphthalenes are significant contributors to the toxicity of oil; between 0.3 and 1.7 ppm produce 50 percent mortality in shrimp in the water soluble fractions of both crude and refined oil.[4]

Sensitivity of Early Life History Stages

In general, eggs and larvae of shellfish and finfish are more sensitive to the toxic effects of oil than are juveniles and adults. Table 2.2 shows that the oil sensitivity of some larvae varies with developmental stage and species. For example, larval stages of many crab and shrimp species are very sensitive to oil, but the large size and relatively impermeable exoskeleton of the adults protect them from the toxic effects of petroleum hydrocarbons. Larvae may also lack the ability, found in some juveniles and adults, to avoid oil-contaminated waters. In addition, larvae that are weakened by oil, although not killed outright, may suffer some sublethal effects, such as increased susceptibility to predation, that can result in death.[4,48,58]

Crustacean larvae are especially vulnerable to oil when they are molting. Tanner crabs exposed to oil in the laboratory during the molting process died. Molting larvae of coonstripe shrimp are five times more sensitive to oil (the LC50 is 80 percent lower) than larvae between molting periods. When molting larvae of coonstripe shrimp and king crab were exposed to high concentrations of the water soluble fraction of crude oil (1.15-1.87 ppm total hydrocarbons) for only six hours, molting success was reduced by 10-30 percent and some deaths occurred. When the larvae were exposed for 24 hours, molting success was reduced by 90-100 percent and most larvae died. The lowest tested hydrocarbon concentrations (0.15-0.55 ppm) did not inhibit molting, but many larvae died after the molting.[4,38,57] Later molting stages of coonstripe shrimp larvae, for example, are more sensitive to oil than the first molting stage.

There are some exceptions to the general trend of greater sensitivity of eggs and larvae to oil. For example, eggs of kelp shrimp and coonstripe shrimp are more tolerant of petroleum hydrocarbons than adult females. Eggs and larvae of coho salmon and pink salmon are more tolerant of short-term exposures (96-hour LC50 of 340-540 ppm for benzene) to petroleum hydrocarbons than are fry or juveniles (LC50 of 10-15 ppm for benzene in fry). The fact that oil sensitivity generally increases with salinity may account for these findings, because salmon eggs are deposited in freshwater but the fry and juveniles inhabit saltwater.

SUBLETHAL EFFECTS (CHRONIC TOXICITY)

Exposure to petroleum brings about a variety of long-term biochemical, physiological, pathological, sensory, and behavioral changes in finfish and shellfish. Collectively these impacts are called sublethal effects because they do not immediately kill organisms, but they cause long-term harm to both individual organisms and populations. Threshold levels (the lowest concentrations of petroleum hydrocarbons that produce sublethal effects) are much lower than the concentrations that cause acute toxicity, generally ranging from 1 ppb to 1 ppm. Behavioral effects on finfish and shellfish are observable at 1-10 ppb, metabolic disturbances and abnormal development at 10-100 ppb, and growth retardation at 100 ppb to 1 ppm.[14] Long-term effects of petroleum are related to the persistence and bioavailability of specific hydrocarbons, species differences in ability to metabolize various hydrocarbons, and the interference of hydrocarbons with metabolic processes that may alter an organism's chances for survival and reproduction.[14,48]

Table 2.2 Acute Toxicity of Oil Fractions to Marine Animal Groups
(Range of 96-hour LC50s, parts per million) (data of Craddock 1977 and Rice et al. 1977)

Organism	Fresh Crude	Water-soluble Oil	No. 2 Fuel Oil	Gasoline/Diesel	Waste/Residual
Finfish	88-18,000	5-50	550	91-420	1700-10,000
Larvae and eggs	0.1-100	0.1-1.0	0.1-4.0	n.d.	1-25+
Pelagic crustacea	100-40,000	1-10	5-50	n.d.	15-50+
Benthic crustacea	56	1-10	5-50	n.d.	n.d.
Molting shrimp	0.2-2.0	12 ppb*	n.d.	n.d.	n.d.
Gastropod molluscs	n.d.	10-100	50-500	n.d.	n.d.
Bivalve molluscs	1,000-100,000	5-500	30,000-40,000	n.d.	n.d.
Polychaete worm adults	12.5-17.6	n.d.	2.0-4.2	n.d.	n.d.
Polychaete worm juveniles	15.0-19.8	n.d.	4.0-8.4	n.d.	n.d.
Other benthic invertebrates	100-6,100	1-10	5-50	n.d.	n.d.

n.d. = no data

*naphthalene

Modes of Toxicity

Oil interferes with the normal functioning of the respiratory and circulatory systems of finfish and shellfish and affects their metabolism, feeding, and growth. Decreased oxygen uptake rates have been observed in crustaceans, molluscs, and finfish at petroleum concentrations similar to those measured under oil spill conditions.[48] Pacific herring, mummichog, sheepshead minnow, and Black Sea flounder embryos suffered disturbed heartbeats when exposed to low concentrations of the water-soluble fraction of crude oil.[68]

Exposure to petroleum hydrocarbons also disrupts the normal electrolyte balance of fish. For example, juvenile coho salmon exposed to soluble light hydrocarbons in saltwater showed a rise in blood concentrations of sodium, potassium, and chloride ions during the first few hours of exposure. These data suggest that the hydrocarbons affect membrane permeability, especially in the gills. These changes interfere with the ability of the fish to control the gas content of their swimbladders and to maintain their balance in the water.[68]

Reduced feeding and growth rates have been observed in molluscs and finfish after exposure to spilled oil. Growth reduction is a problem because animals that do not grow normally will be more vulnerable to predators and less able to survive in their natural environment.[48]

Uptake and Accumulation

When exposed through the diet, water column, or sediments, finfish and shellfish take up petroleum hydrocarbons and accumulate them in their tissues at higher levels than in the environment. This uptake can occur directly through the skin or shell, across the gills, and via the gut; the exposure route varies with the animal and its feeding habits. The extent of accumulation depends on the species, types of hydrocarbons, exposure route, and environmental conditions.[58]

Petroleum hydrocarbons such as naphthalene have been found in liver, kidney, muscle, brain, heart, gut, skin, eyes, gills, blood, bile, and mucus of various marine fish. Such accumulations may be associated with severe behavioral or physiological changes.[48,58] Uptake and accumulation occur within the first hour of exposure, followed by gradual release of the hydrocarbons when the fish are placed in clean seawater.[63] In general, petroleum hydrocarbons are accumulated by finfish and shellfish at higher concentrations from water than from sediments. Lighter compounds are accumulated and released rapidly, but not completely; heavier compounds are taken up more slowly and persist in fish tissues to cause long-term toxic effects.[4,14]

Bioaccumulation factors (concentration of the hydrocarbon in the animal tissue divided by concentration in water or sediment) in marine finfish and shellfish are presented in Table 2.3. Bioaccumulation factors are generally highest when the animals are exposed to hydrocarbons in water rather than in sediment. If the exposure period is longer than a few days, the bioaccumulation factors in crustaceans and especially finfish decline because most of these species have enzyme systems for converting hydrocarbons to other compounds that are more soluble and can be excreted. However, high concentrations of the conversion products (metabolites) of heavy hydrocarbons may remain bound to and undetected in some tissues.[4,32,48]

Table 2.3 Bioaccumulation Factors for Petroleum Hydrocarbons from Water and Sediment in Marine Finfish and Shellfish.[4] (Units = concentration in organism [ppm] / concentration in water/sediment [ppm])

Organisms	Bioaccumulation Range (Water)	Bioaccumulation Range (Sediment)
Bivalve molluscs	9.0-36,000	0.03-11
Crustaceans	2.0-1,136	4.0
Polychaete worms	0.0-20	1.0-6
Finfish	2.0-35,000	0.1-1.3

Mutagenicity and Carcinogenicity

The enzymatic ability of most finfish and some shellfish to metabolize petroleum hydrocarbons is induced rapidly after exposure, and may create metabolites that are less toxic. However, certain hydrocarbons (e.g., benzo[a]pyrene and benzo[a]anthracene) can be converted into more toxic chemicals: mutagens, which cause mutations and birth defects; and carcinogens, which cause cancer. In finfish, this enzyme action occurs mostly in the liver, and to some extent in the gills, kidneys, and gonads. In crustaceans, enzyme activity is localized in the green gland (analagous to the kidney), gills, testes, eyestalks, nerves, and heart. These organs may be at greatest risk of harmful effects.[58]

Petroleum contamination appears to increase chromosome mutations in fish under certain conditions. For example, fertilized English sole eggs exposed to very low levels of benzo(a)pyrene (0.1 - 4.2 ppb) showed increased chromosomal abnormalities. Mutations generally reduce genetic fitness, so contamination of coastal waters increases the genetic risk for commercial fish stocks.[4,48]

Tissue, Organ, and System Damage

Various types of structural and functional damage to tissues, organs, and organ systems of finfish and shellfish are observed in species exposed to petroleum hydrocarbons for periods of one week or more.[14,35] Effects include structural and functional changes in subcellular components, abnormal cell division, delayed development, organ abnormalities, and tissue and organ erosion, atrophy, and death. The gills, skin, liver, spleen, kidneys, eyes, and gonads of fish can all be affected. Effects typically are observed at hydrocarbon concentrations at or below 100 ppb. Sublethal effects of oil can have severe consequences that ultimately lead to the death of the exposed animal—for example, reproductive failure by inhibition of spawning, slow death by inhibition of feeding, and increased vulnerability to predation.[58]

Gill inflammation has been observed in finfish exposed to oil compounds off the Gulf Coast, in the Rhine and Elbe Rivers, and in the laboratory. Gill damage can aggravate other toxic effects of oil because the protection by mucus is diminished and toxics can enter the bloodstream more easily. Trace metals found in petroleum can also cause gill damage, an action with a lethal effect—suffocation—in trout.[25]

Fish also may suffer similar damage to the skin from oil. Exposure to oil also has produced bleeding from the liver and spleen in coho salmon, bream, and goldfish, and depletion of energy reserves (glycogen and fats) in livers of killifish. Petroleum can also damage the lens cells and retinas of fish eyes. Trace metals with toxic effects are found in petroleum and can accumulate in and damage the liver, kidneys, and gonads of fish.[25,48]

Exposure of finfish and shellfish to oil can impair growth by affecting metabolic functions such as energy mobilization and oxygen transport, appetite, feeding behavior, respiration, and digestion. Impaired growth in individual animals, in turn, can lead to greater vulnerability to predation, impaired survival, and decreased ability to contribute to the population gene pool. Such sublethal changes in energy metabolism also may increase the animal's susceptibility to disease as a result of the high energy demand of tissue repair.[25,53] Furthermore, oil can inhibit the immune system in fish, increasing the susceptibility to infection and possibly death. Several studies have shown a direct correlation between exposure to petroleum hydrocarbons and increased incidence of fish diseases such as fin erosion and liver lesions. Sublethal changes in energy distribution in fish exposed to petroleum may increase the animal's susceptibility to disease as a result of the high energy demand of tissue repair.[14,25]

Tainting

Petroleum hydrocarbons taken up by finfish and shellfish are stored in the lipid (fatty) tissue of organisms, where they cause unpalatable tastes and odors at concentrations of 40-50 micrograms per liter (ppb), which is within the range measured after oil spills. Mullet collected near oil refineries in Australia, for example, contained kerosene-like hydrocarbons and tasted oily, and eel and mullet from an oil-polluted harbor in Japan had a foul odor traced to toluene.[32,58]

Tainting reduces the public's acceptance of seafood products. These aesthetic concerns can lead to closures of fisheries and can jeopardize fishery harvest and management strategies for some species. For example, adult clams or oysters exposed to an oil spill could become tainted and not be fit for human consumption, thus affecting the commercial fishery that depends on those resources. Finfish caught through a surface oil slick could be coated and made unmarketable.[58]

Sensory Effects

Chemoreception (the ability to respond to chemicals in the environment) is an important sense in fish, mediating life processes such as feeding, spawning, habitat selection, and predator recognition. For example, low concentrations (less than 1 ppm) of petroleum hydrocarbons inhibit flicking of the antennules in lobsters and crabs, a feeding behavior analogous to sniffing for food in terrestrial animals. Exposure to very low concentrations (50 ppb) of water-souble crude oil fraction for as little as five minutes inhibited the defense responses of sea urchins for several days.[27] Low concentrations of kerosene reduce the attraction of marine snails to food extracts. Light hydrocarbons produce transient, reversible effects, while the heavier compounds produce more prolonged, irreversible effects. Animals exposed to oil are less likely to survive in the long run because they are less able to forage for food, defend against predators, or reproduce.[16,52]

Behavioral Effects

Behavioral effects on finfish and shellfish, such as avoidance, reduced burrowing, and altered swimming, schooling, and feeding behavior, have been observed at oil concentrations as low as 0.1-0.4 ppb. These effects may be caused by lack of oxygen, nervous system depression, loss of oxygen-carrying capacity of red blood cells, and damage to the heart. Effects that follow exposure to oil for a few hours to a few days may disappear when the animals are transferred to uncontaminated sea water, but recovery does not always occur immediately upon transfer.[14,60]

Some fish species are able to detect and avoid oil at sublethal concentrations. The bluntnose minnow, for example, can detect 0.5 ppb of phenol, and the rock bass can detect 5 ppm naphthalene. Other species do not avoid oil and its constituents at sublethal concentrations. For example, rainbow trout failed to avoid phenol at 1 ppb to 10 ppm.[53] Factors besides species which influence avoidance are the concentration and type of petroleum, environmental conditions, and season. Even when an animal does avoid oil successfully, it is not necessarily the appropriate response. In the process of avoiding, critical needs such as food or shelter may be sacrificed.[48]

An example of avoidance behavior that can present other problems for the animals is the tendency of several bivalve and finfish species to avoid oil-contaminated sediments by not burrowing as deeply as usual in the sediments. Littleneck and hard-shell clams in sand with oil at typical post-spill concentrations were buried less deeply and reburrowed more slowly than clams in clean sand. Sand lances spend significantly less time buried in oiled sand, and may alter their choice of burrowing substrate or not burrow at all. These behaviors may increase vulnerability to predators.[4,54,61] However, Pacific salmon, exposed for one hour to crude oil, dispersed crude oil, and dispersant alone, showed no effects on their ability to recognize home-stream water.[45]

Petroleum hydrocarbons affect swimming of larvae, juvenile, and adult fish. Exposed fish display rapid, erratic swimming movements and gulp for air at the surface of the water.[59] Schooling behavior may also be affected . For example, Atlantic silverside exposed to oil became disoriented and showed no tendency to congregate in schools, probably due to damage to the senses of smell and hearing.[59]

Feeding and breathing activity in oysters is reduced by exposure to oil; at high levels they may keep their shells closed entirely.[26]

Crude oil has a narcotizing effect on some fish and other marine animals. This effect can potentially have serious consequences for such behaviors as mating and defense.[27]

Impacts of Representative Oil Spills

Following is a description of seven oil spills that have occurred in the sea during the past 20 years. The information provided for each spill includes date and location of the accident, the volume or weight and type of oil spilled, the fate of the oil in the environment, and acute and long-term effects on shellfish and finfish. As shown in the specific case histories, the impacts of an oil spill are influenced strongly by factors such as the season of the year and the wind direction as well as the chemical makeup of the oil.

A HIGH IMPACT SPILL—*AMOCO CADIZ*

The supertanker *Amoco Cadiz* broke up off the Brittany coast of France on March 16, 1978, and, in the world's largest tanker spill to date, spilled 223,000 tons of crude oil into the Atlantic Ocean. Because of the prevailing shoreward winds, oil slicks remained in the spill area for up to four weeks after the accident. The timing of the spill coincided with the annual rebuilding phase of beaches in which tons of sand are transported onto the shallow winter beach slope. Consequently, oil and mousse were stranded on the beaches, transported along the shore, and buried in the sediments along 190 miles of Brittany coastline including estuaries, salt marshes, and a large portion of the western English Channel.

The oil-impacted coastline contained many oyster growing areas. The water column along the Brittany coast was also contaminated with oil: 3-20 ppb offshore, 2-200 ppb nearshore, and 30-500 ppb in the estuaries. Oil in the sediment's anoxic (low oxygen) zone did not biodegrade, and remained toxic for long periods of time. Six months after the spill, sediments from the intertidal zone to a water depth of 160 feet remained contaminated with up to 500 ppm oil.[4,22,48]

Following the *Amoco Cadiz* spill, there were massive kills of benthic animals such as razor clams, heart urchins, and amphipod crustaceans (a major food source for finfish) in areas where sediment hydrocarbon concentrations exceeded 100 ppm. In the Baie de Morlaix, amphipod population density declined from 6,000 animals per square meter to 10-20 animals per square meter.[48] Although shrimp, oysters, and lobsters became heavily contaminated with oil, they did not experience high mortalities. An unexpected effect was that the numbers of commercial shrimp actually increased along the north coast of Brittany in the two years after the spill, possibly due to decreased predation or to increased microbial or algal production, thus providing more food for the shrimp.[4,58]

There was some finfish mortality (rockfish, gobies, and gadids) after the spill, generally within six miles of the wreck.[48] Mortality was insignificant in commercially important species, but sublethal effects were observed. Flatfish, plaice, sole, and mullet collected from oil-contaminated estuaries showed reduced growth rates and fecundity (egg production) as well as diseased tissues. Ovarian development was delayed or suppressed. The most frequently observed pathological conditions were fin and tail rot, gill mucus cell damage, liver damage, and lateral trunk muscle fiber degeneration. The 1978 year-class of flatfish (the flatfish that were embryos and larvae at the time of the spill) was reported missing; between 40 and 90 percent of the 1979 year-class, while present in the estuaries and offshore areas, had deteriorated fins.[48,53,58,59]

A LOW IMPACT SPILL—*ARGO MERCHANT*

The tanker *Argo Merchant* ran aground and broke up on Nantucket Shoals off Nantucket Island, Massachusetts, on December 15, 1976, and spilled 29,000 tons of Bunker C fuel oil during the following month. By July, 1977, there was no oil evident in the sediments near the shipwreck; the oil was apparently carried away from the wreck along the bottom. Most of the oil that appeared on the surface was formed into large floating "pancakes" and was transported by winds 66 miles eastward, off the southern edge of Georges Bank. By the second week after the spill, the oil slick covered as much as 20 percent of the water overlying Georges Bank, which is one of the richest fishing grounds in the world. Furthermore, the heavy oil fraction evidently did not sink into Georges Bank sediments.[17,48]

Some adverse impacts on commercially important fish species were reported after the spill. Atlantic cod and pollock eggs collected from the most severely oiled waters showed a wide range of abnormalities including cell deterioration, abnormal cell division, failure of cells to differentiate into specific types, grossly malformed embryos, and fouling of the outer egg membranes with tar. About 20 percent of cod eggs and 46 percent of pollock eggs were either moribund or dead, in comparison with 4 percent of laboratory-spawned eggs. The vast majority of the cod (64 percent) and pollock (93 percent) eggs collected at the site were found to be coated with oil; 98 percent of the pollock eggs died when the eggs were brought into the laboratory.[4,14,48,58] Significant (80 percent) decreases in the abundance of sand lance larvae were also observed in the oil spill zone. Although not a commercially important species, sand lance is an important food for cod, pollock, haddock, and hake. Adverse physiological effects were also observed, such as reduced respiration of scallops and mussels and electrolyte imbalance in the blood of blackback and yellowtail flounders.[23]

Despite these effects, a fortunate set of circumstances surrounded the *Argo Merchant* oil spill. The wind was almost continuously seaward, preventing oil from reaching beaches. Oil density was low enough that the oil did not sink and contaminate the bottom. The spill occurred in the winter, when biological activity, productivity, and fishing activities are relatively low. At another time, the effects of a similar oil spill could have been much more serious.[23]

A SPILL IN A COASTAL WETLAND—*FLORIDA*

The barge *Florida* grounded on rocks off West Falmouth Harbor in Buzzards Bay, Massachusetts, on September 16, 1969, and spilled 650-700 tons of No. 2 fuel oil. A storm the following day drove the oil ashore, mixing it into the water and sediments to a depth of at least 32 feet in West Falmouth and Wild Harbors. Booms were used in an attempt to keep the oil out of the harbor, but the booms were not successful in Wild Harbor. The oil continued to spread and severely contaminate the coastal waters, salt marshes, offshore sediments, and shellfish resources. Undegraded oil continued to be released from the sediments for more than two months after the spill. Recognizable components of the spilled oil persisted in the sediments for at least eight years. Sediments from Wild Harbor had oil concentrations 50-75 times greater than unoiled sediments.[9,17,48]

Three distinct phases of events occurred after the Buzzards Bay spill. Within the first few days, there was a heavy kill of fish and shellfish that came into contact with the oil. Approximately 77 bushels of softshell clams and 11,200 bushels of seed clams were killed in Wild Harbor. In the second phase, from several days to nearly a year after the spill, the oil spread to areas that had not been affected initially, and mortality extended to these areas, although in some cases more slowly than the spread of the oil. The local commercial and recreational shellfisheries were closed because of tainting. Eight months after the spill, the affected area included 5,000 acres offshore and 500 acres of tidal rivers and salt marshes. Shellfish collected from the oil spill area, including oysters and scallops, continued to show oil contamination for several years after the spill. The third phase started about one year after the spill and lasted three to five more years. The immediate toxicity of the oil in the sediments was reduced as the oil underwent degradation. This permitted resettlement of the polluted region, first in the outlying, less affected areas by oil-resistant species, then by a more varied and normal distribution of species.[4,9,17,32,48]

Fiddler crab populations were studied for seven years after the *Florida* spill. There were long-term reductions in recruitment to the crab fishery, population density, female/male ratios of adult crabs, and settling of juveniles. Behavioral changes included slowing of movements and shallower burrowing than usual. Recovery of crab populations was correlated with the disappearance of naphthalenes from contaminated sediments, but was not complete seven years after the spill.[4,48]

Killifish taken from a marsh in Buzzards Bay after the *Florida* spill had a lower rate of lipid (fat) synthesis than killifish from an uncontaminated marsh. Parent hydrocarbons were absent from killifish in the contaminated marsh five years after the spill, although the marsh was still contaminated. The fish from the contaminated marsh had elevated levels of the enzymes that metabolize hydrocarbons , indicating that they were breaking down oil. High levels of these enzymes persisted in killifish eight years after the spill, correlated with the persistence of oil in the sediments.[48,59]

Reductions in population densities and in number and diversity of finfish and shellfish species were observed after the *Florida* spill. At minimally oiled sites, recovery was complete within a year after the spill. At moderately polluted sites, there were initial decreases in some species and increases in others, leading to high numbers of individuals but low numbers of species. Recovery was not evident until three years after the spill. Four to five years after the spill, the number of benthic species at the most heavily oil contaminated sites was still significantly lower than at uncontaminated sites.[17,48]

A SPILL DURING SALMON SEASON—*GLACIER BAY*

The oil tanker *Glacier Bay* ran aground near the Kenai River in Cook Inlet, Alaska, on July 2, 1987, and spilled approximately 100,000 gallons of Prudhoe Bay crude oil. The spill occurred just prior to the peak of the salmon run. An estimated 4.8 million salmon were predicted to be migrating north through the Cook Inlet at the time; commercial harvesting of the fish by set nets was already under way. [2]

The spilled oil moved rapidly with the strong tidal currents in the area and dissipated. The majority of the oil eventually weathered, sank, flushed out of the inlet, came ashore, or was cleaned up. As of January 1988, the fate of the spilled oil was as follows: [63]

- 35-40 percent evaporated or dissolved (35,000-40,000 gallons);
- 5 percent sedimented (5,000 gallons);
- 12-18 percent recovered (12,000-18,000 gallons);
- 5-10 percent beached as tar balls (5,000-10,000 gallons);
- 30-40 percent dispersed over several thousand square miles (30,000 - 40,000 gallons).

More than 200 salmon set nets (18 miles of nets) and 100,000 pounds of salmon were contaminated by the spill. Approximately 63,000 pounds of sockeye salmon were rejected for processing because they were tainted. Nevertheless, the overall damage was minor in comparison with the total commercial salmon harvest of 10,190,477 salmon (including 9,247,187 sockeye) from Upper Cook Inlet in 1987. To date, no wetlands or salmon spawning streams appear to have been affected by the oil spill. Other environmental damage has not been assessed. The long-term environmental effects of the oil spill are unknown at this time.[2,63]

A SPILL ON THE WASHINGTON COAST—*GENERAL M.C. MEIGGS*

While under tow from Puget Sound to San Francisco, the unmanned troopship *General M.C. Meiggs* broke loose and grounded on the northwest Washington coast 10 miles south of Cape Flattery on January 9, 1972. Approximately 7.5 tons (55,000 barrels) of Navy Special fuel oil were released. Oil globules and heavily oiled debris from the ship washed up on the beach and became incorporated in the sediments. Oil was not transported offshore due to the wind direction at the time of the accident and the ship's acting as a barrier to seaward flow.[19]

Oil persisted in the intertidal area of the contaminated cove (called "Wreck Cove") during a five-year study period following the accident, exposing intertidal animals continuously. Oil hydrocarbons had been taken up by shellfish within two months of the accident, and persisted in mussels for five years after the spill.[19]

The initial survey of Wreck Cove in February, 1972, provided no evidence of major fish kills. Some fish species could have been affected but not detected by the study methods used.[17,19] However, the abundance of barnacles and mussels declined steadily from March, 1972, to January, 1973; mussel abundance remained at an unchanging low level in 1977.[19] Damaged purple sea urchins were found in the subtidal zone near the *Meiggs* through July, 1973; at some locations dead urchins were observed and up to 70 percent of the survivors had lost their spines. There were no dead or abnormal urchins at any of the control (uncontaminated) sites surveyed.

Although the *Meiggs* spill was considered a minor spill in terms of the amount and type of oil released into the water, tangible evidence of pollutant uptake and both lethal and sublethal effects was observed in intertidal organisms. This finding emphasizes the sensitivity and vulnerability of the intertidal community of the northern Washington coast to environmental stresses such as oil spills.[19]

A SPILL ON THE STRAIT OF JUAN DE FUCA—*ARCO ANCHORAGE*

The tanker *Arco Anchorage* ran aground in Port Angeles Harbor on December 21, 1985, and spilled 239,000 gallons of Alaska North Slope crude oil into the Strait of Juan de Fuca. Since the wind was light, beach impact beyond Port Angeles Harbor was minimal, with oil primarily affecting 70 miles of sheltered beach along the south side of Ediz Hook, the elbow of Dungeness Spit, and the east-facing beaches along Agate, Crescent, and Freshwater bays.[33] The oil penetrated into coarse-grained beach sediments within much of the intertidal zone to depths of 2-12 inches. Six weeks after the spill, hydrocarbon concentrations in beach sediments ranged from 50 to 20,000 ppm and averaged 2,900 ppm; highest concentrations were in Ediz Hook and Dungeness Spit sediments.[34,39]

Contamination of the south shoreline of Ediz Hook resulted in stress to crabs and hardshell clams, and mortalities to starfish. About 12,000 pounds of hardshell clams were visibly oiled along their siphons and the tops of their shells, causing losses amounting to about $20,000. Mussels and oysters were also contaminated with oil. Finfish observed in the area (sculpins, kelp greenling, ratfish) were not stressed and appeared normal. Dungeness crab in the area were not contaminated with oil. No short-term mortalities of subtidal invertebrates were observed.[30] Salmon culture pens within Ediz Hook were oiled, but no oiling or tainting of the fish was observed.[34]

Surf smelt eggs collected from Dungeness Bay had a high mortality rate (73 percent compared with a normal 9 percent). The high mortalities were puzzling because the eggs were not noticeably contaminated with hydrocarbons. The surviving eggs appeared to develop normally. The 1986 herring spawn in Dungeness Bay appeared to be unaffected by the spill. Larvae of various fish species such as Pacific sand lance showed no physical abnormalities attributable to oil contamination.[34]

A SPILL IN THE COLUMBIA RIVER—*MOBILOIL*

The tanker *Mobiloil* ran aground near St. Helens, Oregon, on March 19, 1984, and spilled 170,000-233,000 gallons of oil into the Columbia River. Three types of oil were spilled: a heavy residual, a No. 6 low sulfur fuel oil, and an industrial fuel oil. Much of the Washington shoreline downriver of the spill site was oiled as a result. The oil moved 40 miles downriver during the first day after the spill and reached the Pacific Ocean within three days, with traces traveling as far as Copalis Beach 65 miles to the north. A portion of the oil remained in the river in the form of tarballs and oiled vegetation at least through August, 1984. The areas of the Columbia oiled by the *Mobiloil* spill were the intertidal wetlands of Baker Bay and Grays Bay, which are feeding areas for juvenile salmon and trout. A survey conducted in February, 1985, found little evidence of oil in the intertidal areas of the lower river, including the sediments. This suggests that much of the residual oil was flushed from the river during winter high flow periods.[67]

On the basis of the limited environmental data that were collected, the following conclusions were drawn about the impacts of the spill on Columbia River fish. No immediate impact was observed on benthic animals in two bays (Grays and Cathlamet) in the estuary. No impact was observed in benthic invertebrates in another bay (Baker) in 1985, but it is not known if there were impacts at the time of the spill. Intertidal sediments in Baker and Grays bays did not contain acutely toxic levels of petroleum hydrocarbons in 1985. No major fish kills were reported as a result of the spill. However, it is not known whether this was because no mortalities occurred or because none were observed; it is possible that dead fish may have been flushed from the river before the carcasses became visible on the surface.[67]

Sturgeon appeared to be the species most exposed to oil; sturgeon collected downriver of the spill site showed external/internal oiling and evidence of oil uptake. A small population of wild salmon and trout was present in the river at the time of the spill and may have been exposed to toxicants in the water column. However, the spill preceded the 1984 release of salmon and trout from hatcheries; therefore, any impacts of the spill on these hatchery-reared fish would largely have been restricted to sublethal effects of oil residues in the sediments. The potential impacts of exposure to these oil residues cannot be quantified. In general, impacts of the oil spill on fish appear to have been limited, due to the high flushing rate of the Columbia and the relatively low toxicity of the spilled oil. Environmental and toxicological data are lacking to assess sublethal impacts such as effects on feeding, growth, smoltification, migration, and reproduction.[67]

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3

Physical and Noncommercial Biological Resources of the Washington Coast and Potential Impacts of Offshore Oil and Gas Development

GEOLOGY AND LANDSCAPE OF THE WASHINGTON COAST

The outer coast of Washington is oriented in a roughly north-south direction for about 250 km (150 miles) from Cape Disappointment at the mouth of the Columbia River to Cape Flattery at the mouth of the Strait of Juan de Fuca (Figure 3.1). The coast is flanked by a relatively shallow, flat, submerged area called the continental shelf, which extends offshore to a depth of roughly 200 m (~600 feet, or 100 fathoms). At this point (the shelf break) the bottom drops off more steeply to form the continental slope, which is indented by several major submarine canyons. Beyond the shelf and slope are deep abyssal oceanic waters. Worldwide, offshore petroleum deposits occur primarily in continental shelf and slope areas rather than in the deep ocean. The area being offered by MMS for leasing in 1992 extends offshore from the 3-mile limit of state waters to about 40 miles offshore, where the depth is approximately 1,000-1,500 m (~3,280-5,000 feet, or 1,600-2,500 fathoms).

GEOLOGIC STRUCTURE AND HISTORY

The geologic history of the Washington continental shelf and coast has been dictated by powerful forces within the earth, as well as by the forces of wind, water, and ice acting on the earth's outer layer. This layer is a solid crust (the lithosphere) that rests on more fluid layers below (the asthenosphere and the mantle). Stresses within the deeper layers fracture the crust and cause the pieces, called plates, to move over the surface. These large-scale movements are known as plate tectonics.

About 200 million years ago a plate carrying what became North America continent broke loose from the plate that is now Europe and began moving west. The resulting gap became the North Atlantic Ocean. The North American plate collided with plates carrying the floor of the Pacific Ocean and some land masses. That collision added chunks of sea floor to the North American plate and created mountain ranges and volcanoes from Alaska to California. The plate movements continue today. Along the Washington coast and continental shelf, the North American plate, on the east, is colliding with oceanic Juan de Fuca plate, on the west (Figure 3.2). The North American plate is composed primarily of rock of continental origin called continental crust. Where it collides with the Juan de Fuca plate, however, rocks of oceanic origin become attached to the plate.

The Juan de Fuca plate is composed of oceanic crust, volcanic material extruded onto the ocean floor from the Juan de Fuca Ridge, a northerly trending ridge located a few hundred miles offshore. The deepest and oldest rocks that lie beneath the shelf and coastline are volcanic in origin and reach to a depth of at least 10 km below the seafloor.[155] These volcanic rocks began to form approximately 65 million years ago at the ocean ridge that preceded the present-day Juan de Fuca Ridge. At this ridge, molten rock from deep within the earth welled up to the surface and, much like toothpaste out of a tube, oozed out onto the seafloor to harden.

As the newly formed rocks were carried eastward from the ridge by the Juan de Fuca plate, sediments that originated from the continent and from marine life accumulated on its surface. Over millions of years the weight of these sediments generated enough heat and pressure to create sedimentary rocks. At times the forces of the earth driving the plates folded and faulted these sediments. In places on the Washington shelf, sedimentary rocks formed by these two processes are at least 3,000 meters thick.[155]

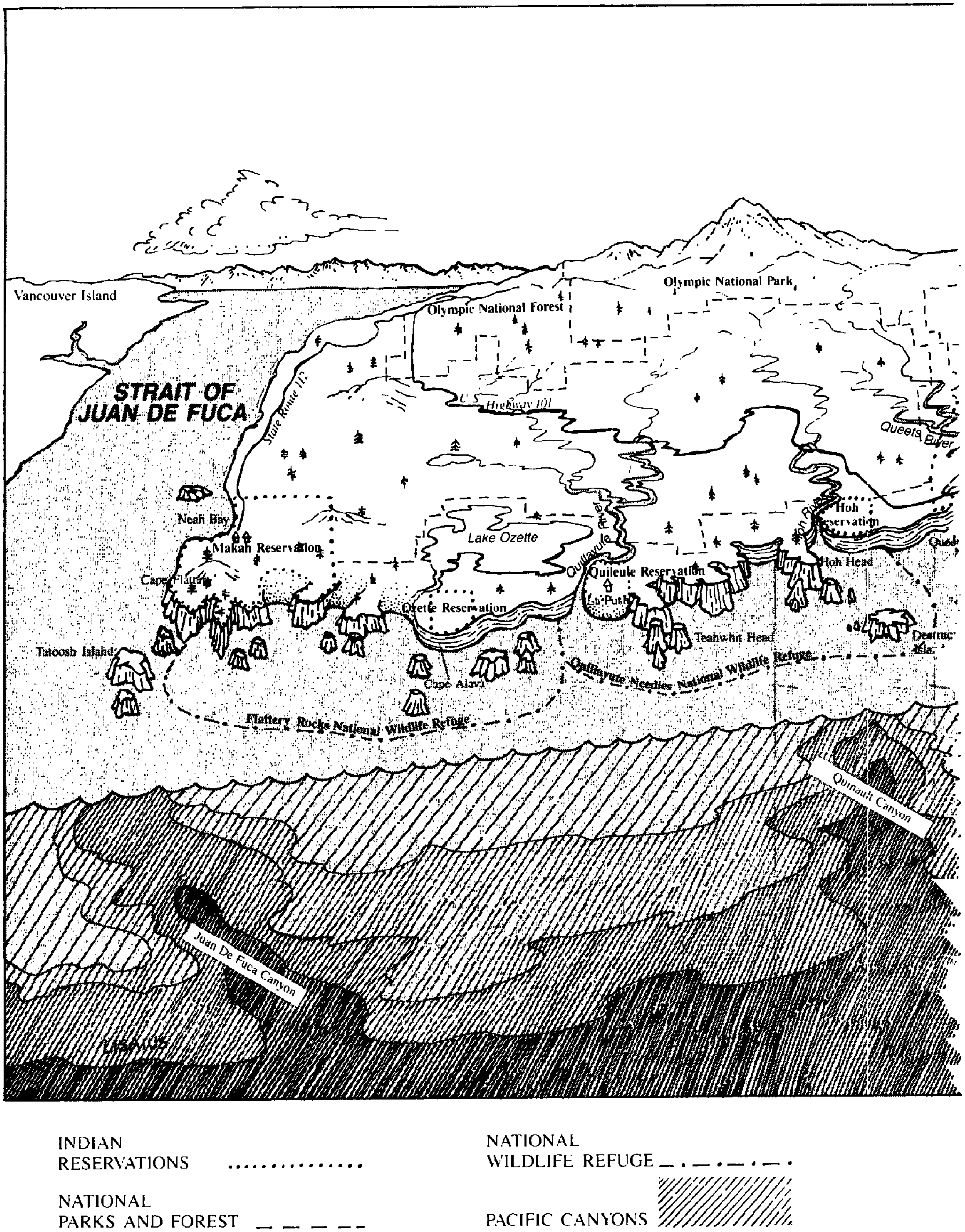
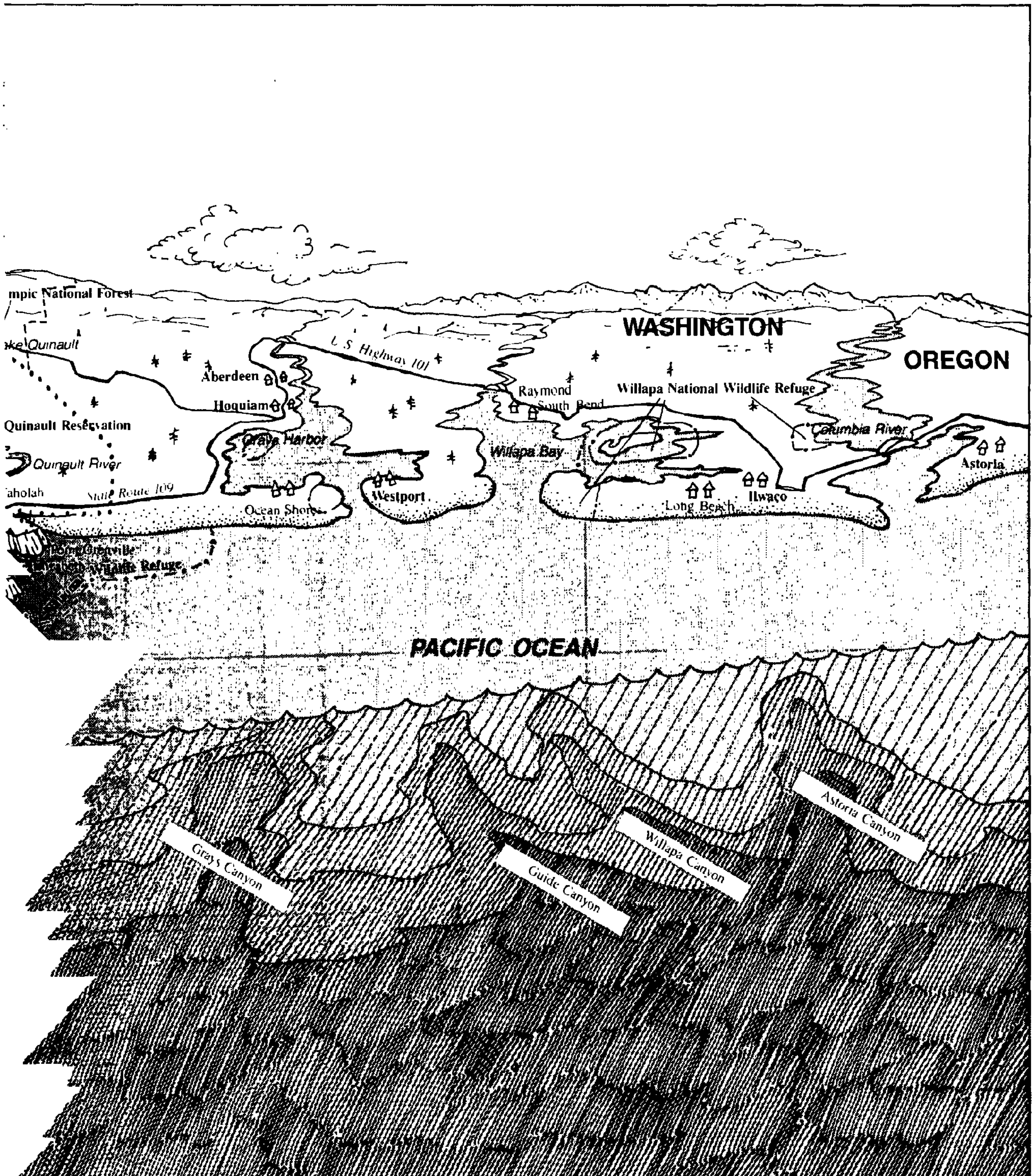


Figure 3.1 Coastal Washington viewed from the west.



ROCK HEADLANDS AND SEA STACKS

BLUFFS

BEACH

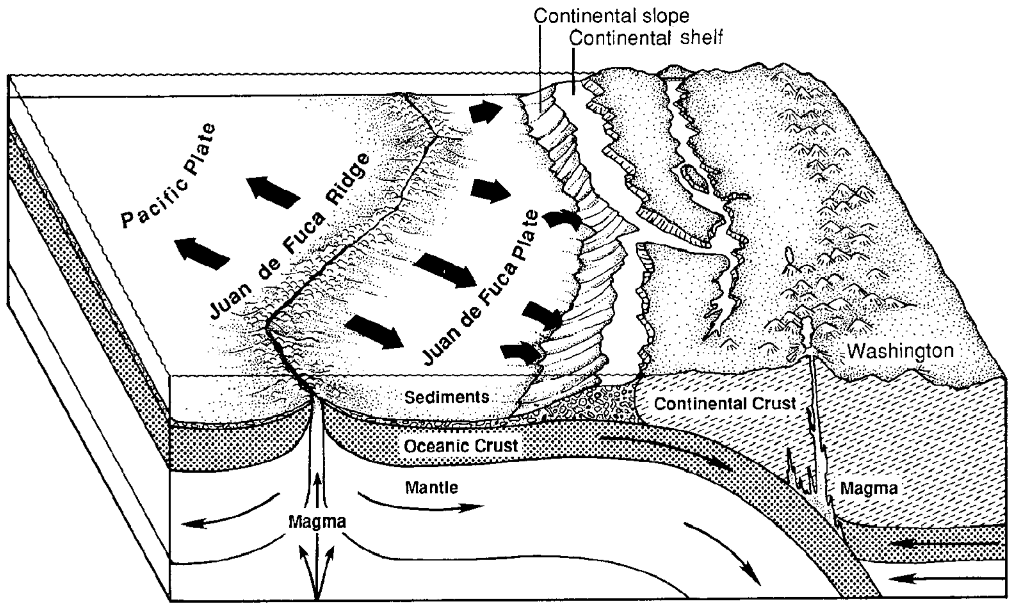


Figure 3.2 The plate tectonic structure of the Pacific Northwest continental and oceanic region (modified from Rau 1980).

Episodes of folding and faulting have occurred numerous times as the Juan de Fuca plate and the North American plate collided with each other, sometimes directly, other times obliquely. Approximately 50 million years ago, the Olympic Mountains rose from sediments from the Juan de Fuca plate that were scraped onto the North American plate.[155] Fossils of plants and marine animals may be found today high up in the Olympics. Although the Olympics were formed 50 million years ago, they contain rocks that are much older. For example, rocks at Point of the Arches, at the northwestern tip of the Olympic Peninsula, are perhaps more than 50 million years older than any other rocks exposed along the Olympic Peninsula.[133] Other material from the Juan de Fuca plate was subducted beneath the North American plate, only to melt and rise again to the east between 44 and 38 million years ago, marking the onset of volcanic activity that formed the Cascade mountains.

Two very intense episodes of plate interaction appear to have occurred 37 million and 12 million years ago when the plates collided and the layers of marine sedimentary rocks were severely fractured and faulted, forming distinct zones of rock called the *melange and broken formation*, or simply melange.[155] The melange, a complex jumble of different rock types, is visible at the surface in places along the Olympic coast, and is thought to underlie much of the inner and mid-shelf area. Along the northern Washington coast, the melange is juxtaposed with less disturbed deep marine sedimentary rocks (sandstones, siltstones, and conglomerates) of similar age. The non-melange rocks, although also subjected to some folding and faulting, tend to be more resistant to erosion. They form many of the headlands and offshore intertidal reefs along the north coast.[142] This collection of rocks, including the melange and broken formation, is included in the Hoh rock assemblage and the Ozette Melange. These rocks are considered to have the highest potential for gas generation along the Washington coast.

The south coast, like the north coast, has a basement of oceanic volcanic rock overlain by several thousand meters of Hoh assemblage rocks. Thick sequences (several thousand feet) of 1.5-6-million-year-old marine sedimentary rocks, called the Quinault Formation, lie on top of the Hoh assemblage rocks from approximately the Taholah area south, as well as in the offshore region.[110,143] These rocks, however, have suffered much less deformation than the Hoh rocks. The semi-unconsolidated nature of the Quinault rocks limits the formation of rocky headlands. Two areas where the Quinault formation and equivalent rocks are apparently thickest are the Olympic and Willapa subbasins (Figure 3.3).

The continental shelf that fringes Washington's outer coast varies in width from 25 to 60 km (15 to 35 miles) and is broken by six canyons—from north to south, Juan de Fuca, Quinault,

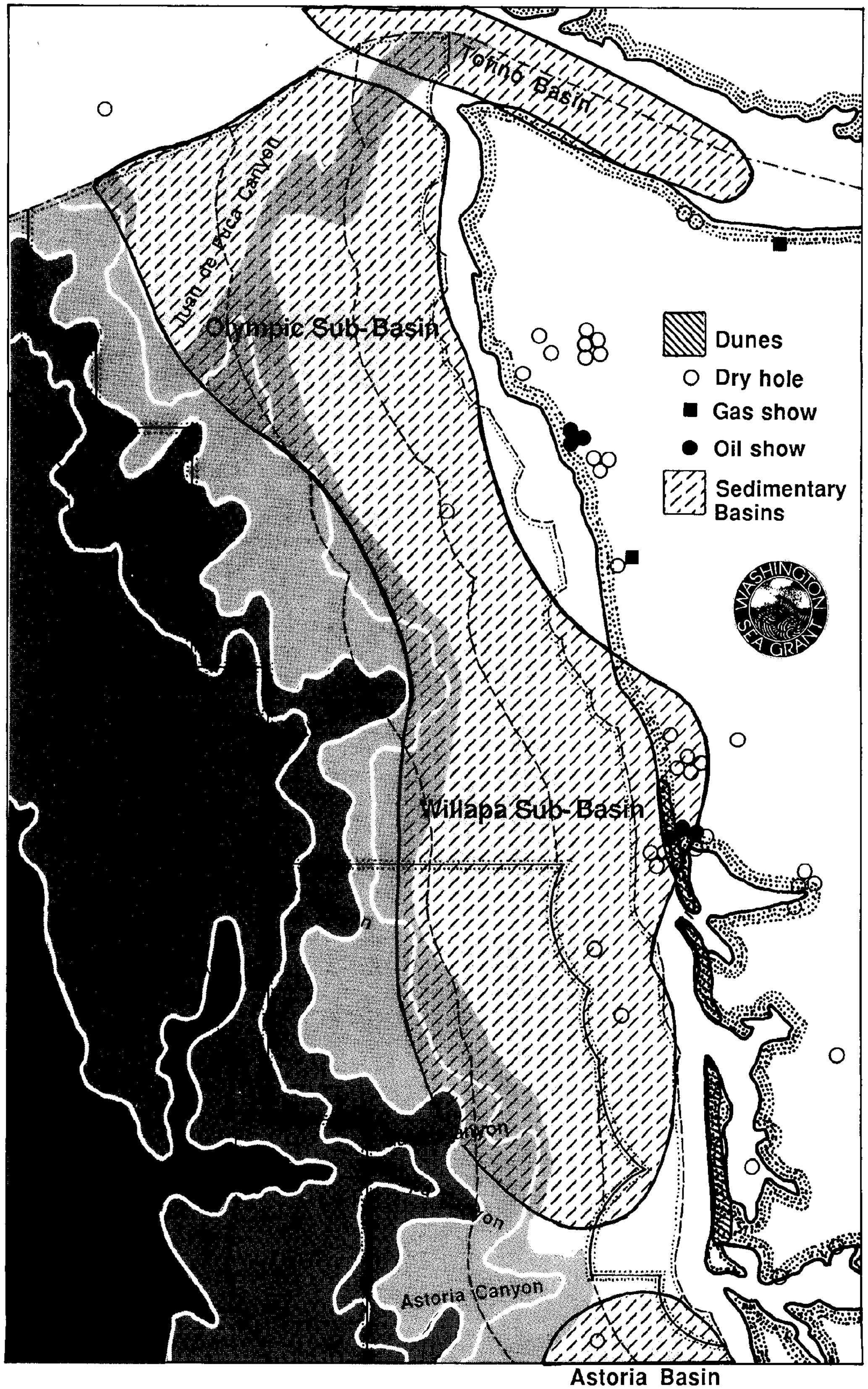


Figure 3.3 Locations of submarine canyons, onshore sand dunes, sedimentary basins, and past oil and gas wells and shows in coastal Washington (Sources: Weidemann 1984; Snavely 1987; W. Lingley, W DNR).

Grays, Guide, Willapa, and Astoria (Figure 3.3)—which narrow the width of the shelf to 15-30 km (10-20 miles) at their landward end. These submarine canyons were cut by submarine turbidity flows and landslides that dissected the soft overlying marine sediments during the past 1.5 million years when sea level was lower than it is now. The continental slope is characterized by a folded and faulted sequence of deep marine rocks ranging up to seven million years in age.[155] These rocks are deep-sea sediments accreted onto the North American plate along the plate collision boundary.

Another important geological component of the Washington coast and offshore region is material formed during the glacial episodes that began 1.5 million years ago. Glaciers, which at their maximum reached from Canada through approximately the northern third of Washington state,[3] left thick, widespread deposits of unconsolidated sand and gravel that become thinner toward the coast. Rock debris from extensive glaciation in the Olympics was transported to present-day coastal areas by meltwater from glaciers. Some of this debris was actually deposited directly by the ice, indicating that glaciers once stood near or even beyond the present-day coastline.[140] These glaciers played an important role in sculpting the land into the forms seen today. Along the coast, some of the thickest beds of this glacial material may be seen overlying bedrock sea cliffs and sea stacks just south of the Quillayute River and near the mouths of the Hoh River and Goodman Creek.[142]

The glaciers advanced and retreated several times, accompanied by dramatic changes in sea level; there is evidence of two major periods of marine deposition separated by a major erosional event. Ancient and now-elevated wave-cut platforms that occur along the coastline were formed during the higher stands of sea level, when waves notched and eroded rocks that today are several feet above sea level. Part of this change in elevation results from isostatic uplift, the rising of the Olympic Peninsula after removal of the weight of glacial ice that continues today. Alexander Island and several islets off Second Beach exhibit such platforms.[142]

MODERN LANDFORMS

The two distinct north and south coastal regions of Washington were formed by plate tectonics and have been shaped to their present form by glacial ice, ocean waves and currents, winds, and rivers. The general north-south orientation of the coastline reflects the north-south trending tectonic plate boundaries and the predominant nearshore ocean currents. These currents flow northward or southward, depending upon the season. These currents transport river and wave-eroded sediments along the coastline.

The north coast, from Cape Flattery to Point Grenville, is a region with several areas of rugged headlands and cliffs. The major headlands of the Washington coast are all located along the north coast and are, from north to south, Cape Flattery, Portage Head, Point of Arches, Cape Alava, Cape Johnson, Teahwhit Head, Hoh Head, Cape Elizabeth, and Point Grenville. This environment of headlands, separated by pocket beaches, formed because of the differing erosion-resistance of rocks composing the shoreline. Hoh Head, for example, is composed of relatively resistant sandstone rocks flanked by less consolidated and therefore more erodible melange rocks.[142] Because of these erosional differences, Hoh Head will eventually become an offshore sea stack. Point Grenville is made of highly erosion-resistant volcanic rocks that were originally erupted onto the seafloor millions of years ago.[141] Cape Elizabeth is a mixture of sandstone and conglomerates.[142]

Resistant outcrops form numerous offshore islands and rocks off the coast, including Tatoosh, Destruction, Cannonball, Ozette, Alexander, James, Tunnel, Willoughby, and Abbey islands, and Split Rock. There are also numerous nearshore rocks and islets, including Giants Graveyard and the Quillayute Needles.[141] Destruction Island, located about 3.5 miles offshore north of Kalaloch, is the largest island off the coast of Oregon and Washington and the first major island north of the Farallon Islands near San Francisco.[141] Approximately 40 acres in size, it is the westernmost major bedrock outcrop exposed above sea level along the central Washington coast and is covered by Ice Age sand and gravel deposits. The rate of coastal erosion can be estimated by comparing recent and historic land surveys of the Destruction Island area. The distance between the island and the coastline has increased by about 300 feet in the last 100 years. At this rate, assuming that coastal erosion in the area has been reasonably uniform over time, Destruction Island would have been a part of the mainland 6,000 years ago.[141]

Washington's southern coast, from Point Grenville to the mouth of the Columbia, is composed of beaches nourished by accretion, the process of adding water-borne sediments. These sediments are derived primarily from the Columbia River and are transported northward by nearshore currents. Much of the south coast is backed by sand dunes 82 km in extent (Figure 3.3). The dunes are relatively recent geological features originally formed by sediments washed seaward from melting glaciers. The dunes today are maintained by Columbia River sediments transported along the coast, and their shapes are controlled by wind, water, and stabilization by plants.[197] Dune segments form spits or peninsulas at the mouths of Grays Harbor, Willapa Bay, and the Columbia River. Foredunes, closest to the ocean, form an important defense against ocean storm damage. Dunes are fragile, ephemeral entities, however, and are easily destabilized by construction activities and destruction of vegetation. The troughs between the foredunes and the inner dunes hold groundwater reserves 35-70 m deep.

The soft southern coastline is subject to much more rapid changes than occur on the north coast. The building of the north jetty at the mouth of the Columbia River, for example, which altered the regime of currents that carried sediments, resulted in the addition of about 4,000 acres of land to the Long Beach Peninsula within an 80-year period.[168] More than 1,200 feet of width has been added to the beach in the Long Beach-Seaview area, and Leadbetter Point on the Long Beach peninsula has grown seaward by about 2,000 feet since 1950. At the same time, Cape Shoalwater on Willapa Bay is eroding at the rate of about 150 feet per year; it is estimated that about 10,000 feet has eroded since 1887.[197]

There are three major estuaries on the Washington coast: the Columbia River estuary, Willapa Bay, and Grays Harbor. The Chehalis, Humptulips, North, Hoquiam, and Wishkah rivers enter Grays Harbor; the Willapa and Naselle rivers feed Willapa Bay. Smaller estuaries are found where other rivers meet the coast: the Queets, Quinault, Hoh, Quillayute, Dickey, and Copalis. The mouths of the Queets and Quillayute rivers have migrated over time. The position of the mouth of the Queets has changed due to the sea's gradual eastward erosion of the coastline.[141] The mouth of the Quillayute has been altered due to log jams and migration of beach sediments.[142] These estuaries serve as traps for nutrients, organic debris, and sediments washed in from the terrestrial environment. They are rich, productive environments that support many important fish and wildlife resources.

GEOHAZARDS

Geological processes that can threaten the safety of offshore oil and gas production are termed *geohazards.* The primary geohazards are earthquakes and submarine landslides.

Although the Washington coastline is located at a plate margin, which tends to be a very earthquake-prone area, scientists find little evidence of present-day major seismic activity.[155] No earthquakes greater than magnitude 7.5 on the Richter scale have been recorded in Washington or Oregon in the past 150 to 200 years.[9] Various explanations are offered for this puzzling geological phenomenon, including the possibility that convergence between the Juan de Fuca and the North American plates has ceased.[155]

Some scientists have suggested that movement along this plate margin occurs during infrequent great earthquakes.[104] There is ample evidence of seismic activity in the geologic past, as indicated by the number of major faults that have been mapped both onshore and offshore (Figure 3.4). Archaeological excavations and Indian legends indicate that earthquakes have occurred in the coastal area within recent history, however. Recent geological evidence suggests that at least six major earthquakes (magnitude greater than 8) have occurred in the last 7,000 years,[9,155] suggesting a recurrence interval of just over 1,000 years between seismic events. These events were accompanied by tsunamis (also called seismic sea waves or, mistakenly, tidal waves), large waves generated by seafloor movements during an earthquake. One Indian legend recounts what may be interpreted today as the occurrence, before the early 1860s, of a tsunami that made "an island of Cape Flattery."[155]

Submarine landslides and turbidity currents presumably have been triggered by these earthquakes. Submarine landslide areas have not been well mapped or delineated.[94] Known submarine landslide areas are shown in Figure 3.4. They are most prevalent in steep submarine canyons, which are formed in part from scouring by slides. Turbidity currents are short-lived, powerful, gravity-driven, undersea currents consisting of dilute mixtures of sediment and water

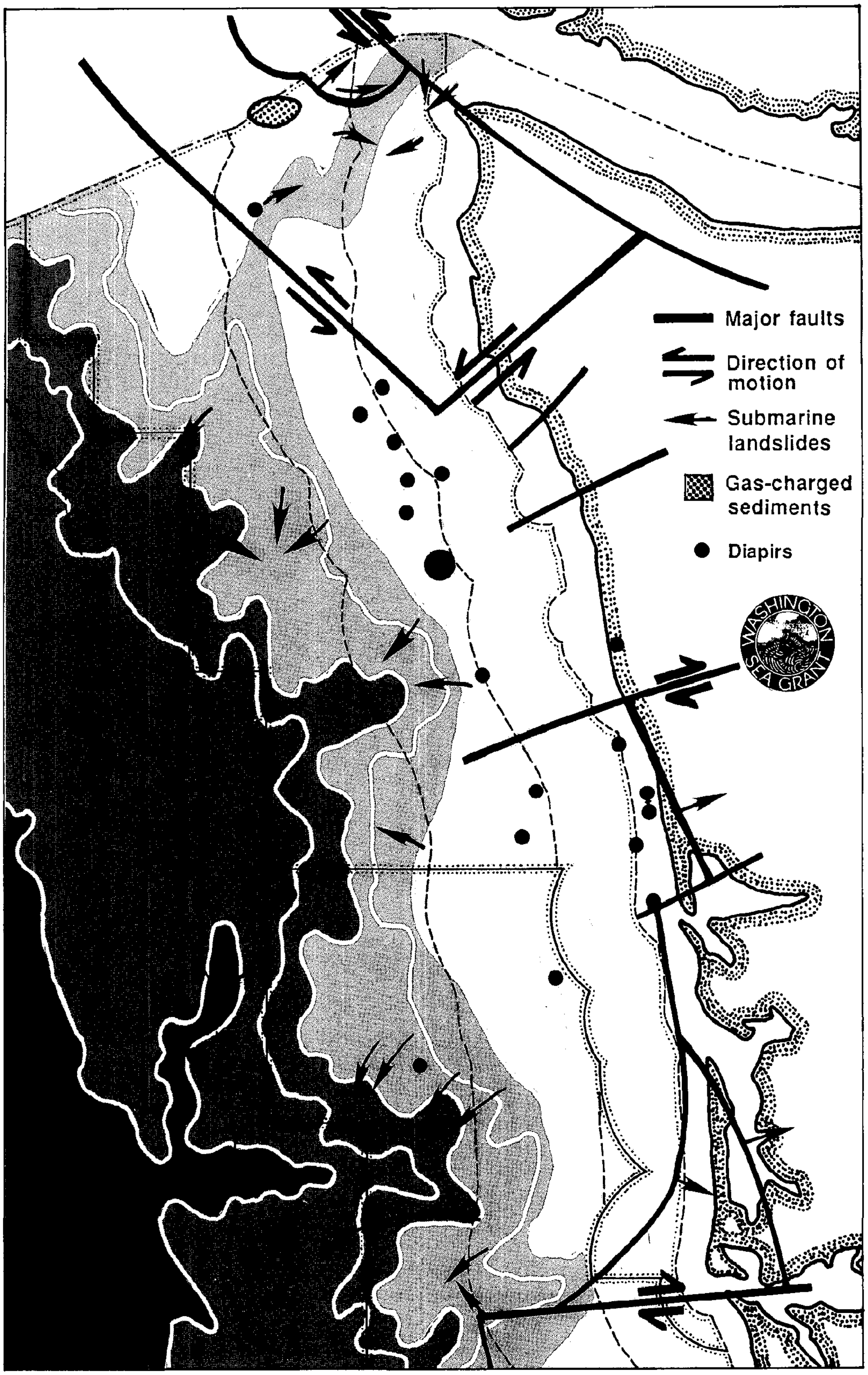


Figure 3.4 Locations of major seismic faults, submarine landslide areas, and diapirs (piercement structures) in coastal Washington (Sources: Snavely 1987; Wagner 1986).

maintained by internal turbulence.[84] Turbidity currents and submarine landslides are possible geohazards in places such as the Astoria fan, a depositional structure off the mouth of the Columbia River.[94] The possibility of turbidity currents is especially high during an earthquake. The recurrence interval of turbidity currents in Quinault Canyon over the last 5,000 years has been estimated to be 500 years.[170]

BATHYMETRY AND SEDIMENTS

The general bathymetry (submarine topography) of the Washington shelf is described as smooth[82] as a result of sediment accumulation. Some irregularities have been observed: hummocks on the outer shelf north of Astoria Canyon; small islands, stacks, and submerged outcrops on the inner shelf north of Grays Harbor; and submerged pinnacles up to 20 m high in the mid-shelf region off Willapa Bay.[82] Some of these pinnacles are *diapirs*, or piercement structures. Diapirs are plumelike areas where the low density melange formation clay stone has "floated" upward, through overlying high-density rocks. One such diapir is exposed along the Olympic coast just north of Point Grenville.[141] Other diapirs can be observed on seismic reflection profiles of the continental shelf (Figure 3.4). Diapirs can be a location for trapping of petroleum deposits.[45]

Three primary units of sediment may be found on the Washington shelf. A nearshore sand unit extends northward from the mouth of the Columbia along the coast to a depth of about 50 meters.[82] Sand is defined as sediment particles ranging from 0.0625 to 2 mm in diameter. Very fine to fine sand (0.0625 mm to 0.25 mm) occurs on the inner Washington shelf both as modern (near the Columbia River) and as relict (north of Grays Harbor) sediments. Relict sediments originate from past geological conditions—such as differing stands of sea level, or periods of glacial meltwater outwash through the Chehalis valley system—even though today they lie at the surface of the ocean floor. Clean, coarse sand deposits are also found on the outer shelf at depths greater than about 100 meters.[82] This sand contains a variety of grain sizes, indicating that the unit has a complex depositional history with multiple sources and is probably partially relict.

Between these sand units is a mid-shelf deposit of silt, which is finer than sand (particles 0.0039-0.0625 mm in diameter). This deposit trends north-northwesterly from the mouth of the Columbia to the point where it partially intersects Quinault Canyon (Figure 3.5). It is estimated to be about 14 m thick[82] and to accumulate at an average rate of about 4 mm/year.[170] Within this unit, the sediment grows progressively finer with distance from the river. Mid-shelf deposits on the Washington coast are transient to a certain extent and often undergo repeated resuspension and redeposition by storm-induced bottom currents prior to final burial.[82,140]

The primary source of sediments deposited on the shelf is the Columbia River, which is estimated to discharge 10,000 times more sediment to the shelf than all other sources combined.[170] Damming and flood control actions on the Columbia have greatly reduced its sediment input to the coastal zone in recent years, however. Other sediment sources include the Strait of Juan de Fuca, smaller rivers in Washington and northern Oregon, and local cliff erosion.

The estimated annual sediment input from the Columbia River ranges from 5 to 21 million metric tons/year.[170] The observed sediment accumulation rate over the shelf is about 67 percent of the total Columbia River sediment discharge. Of this 67 percent, about 19 percent is thought to be transported north of the Quinault Canyon.[171] Approximately 6 percent of the annual sediment discharge is transported over the shelf edge onto the slope, and 11 percent is deposited in the Astoria, Willapa, Guide, Grays, and Quinault canyons (Figure 3.5).[82,170]

Sediment transport along the Washington coast is controlled by complex wind-driven waves and currents that change with the seasons. Bottom currents on the open shelf flow northward and slightly seaward in the winter when storm conditions are more prevalent, and northward and slightly shoreward in the summer.[82] On an annual average, sediment is transported offshore because of stronger water motions during winter. Most sediment is transported by the strong water motions accompanying winter storms.

Long-term observations of current speed and direction indicate that bottom flows strong enough to transport sediment can occur at all depths on the Washington shelf. Large storm-induced sediment transport events have been estimated to occur as frequently as five days per year on the outer shelf (167 meters depth), 53 days per year on the central shelf (approximately 80 meters depth), and 79 days per year on the inner shelf (30 meters depth).[170] Storms last about

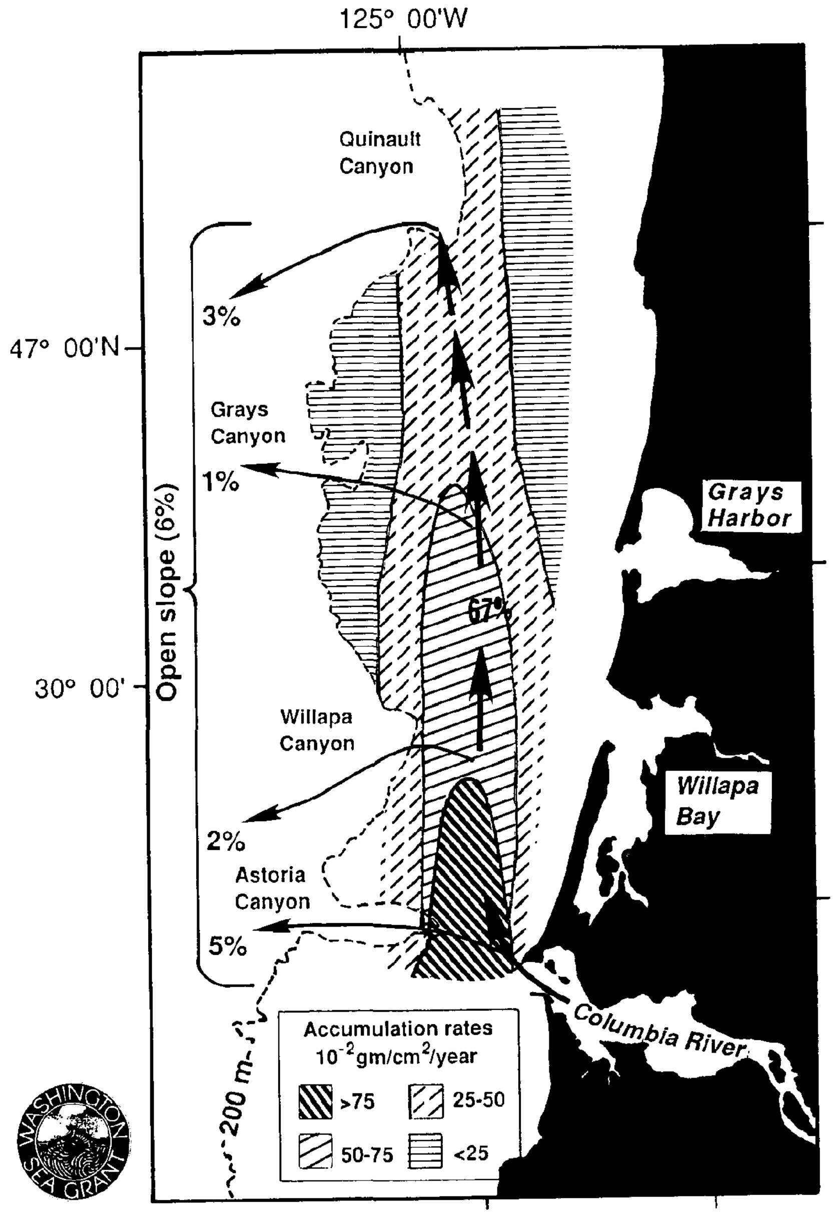


Figure 3.5 Accumulation rates and transport of the mid-shelf deposit of Columbia River silt (Source: Sternberg 1986).

two to five days and typically take place from October through March, with water motions strong enough to move sediment occurring 20 to 90 days per year.[82] A study that tracked the dispersal of ash from the May 18, 1980, eruption of Mt. St. Helens reported that the displacement rate reached 14-16 km per storm, or 73-80 km/yr, at one sampling station and 25-38 km per storm, or 124-190 km/yr, at another station near the Quinault Canyon.[170] Because storms are highly variable from year to year, estimated transport rates may vary substantially. Calculations suggest that a severe storm occurring every few years might have more geological significance than a number of more frequent but less severe storms.[170]

In general, much of today's knowledge of river-derived sediment transport and accumulation on the Washington shelf is based on inference rather than actual measurements.[171] For example, significant data gaps exist regarding past sedimentary environments on the Washington continental shelf. More careful and comprehensive coring of these sediments is required to determine the sedimentary history of the shelf. All knowledge regarding the net dispersion of fine mud particles, a question of definite interest to the oil industry when drilling, has been acquired by inference and could benefit greatly from actual measurements. Also, a more thorough understanding of the modern processes of sediment transport and dispersal during storms is needed. There have been very few actual measurements made of sediment transport during storms, even though this type of transport is considered to be the most geologically significant of local sediment-related processes. Shelf sediment transport and bottom currents are also crucial elements of oil-spill transport models.

SEDIMENTARY MINERALS

There has been no offshore mineral production in Washington state in either state or federal waters, although titaniferous sands (sands containing the metal titanium) and gravel deposits have been identified offshore. The sulfides of various metals that are found on the Juan de Fuca Ridge occur more than 200 nautical miles seaward from the Washington coastline and are therefore beyond the federally declared Exclusive Economic Zone. Titaniferous, or "black," sands have been delineated in the intertidal zone and as much as two miles offshore in Baker Bay in the Columbia River estuary, at Benson Beach and off Fort Canby on Cape Disappointment, and at Leadbetter Point, all in Pacific County[92] (Figure 3.6). Black sands have also been explored off Point Brown in Grays Harbor. Titaniferous sands at Moclips and Copalis have been characterized and contain minor amounts of gold. Recent data suggest other black sand deposits on the Washington and Oregon shelf that may have economic potential.[88]

The most valuable known offshore mineral resource is gravel. Large deposits are found from Cape Flattery to Grays Harbor, clustered around the mouths of the Hoh, Quinault, and Chehalis rivers (Figure 3.6). Studies have shown that they are associated with ancient shore lines at depths of 20 to 280 meters. The U.S. Geological Survey has estimated that offshore Washington deposits may contain 1.5 billion cubic meters of gravel. The technology exists for mining these deposits using suction dredges, a method that is currently in use in the English Channel.

There evidently is little non-petroleum mineral potential in the rocks underlying the Washington shelf.[93] It is also unlikely that placer deposits (mineral deposits formed by the mechanical sorting action of water currents) of tin, chrome, gold, or diamonds will be found there. Commercial development of titaniferous sands is considered unlikely within the next 20 years. The best potential for non-petroleum mineral development may be for gravel deposits around the year 2000, when Washington's currently exploited onshore and Puget Sound gravel resources are expected to be depleted and shortages may begin to appear.[94] Such gravel mining would appear to pose little conflict with offshore oil and gas activities, but might conflict with fishing.

The majority of existing data on non-petroleum offshore mineral resources are considered to be of a very preliminary nature.[93]

THEORY OF OIL AND GAS FORMATION

Oil and gas are hydrocarbons, compounds whose molecules are chains of carbon atoms with hydrogen atoms attached. These hydrocarbons are derived from marine plant and animal life that accumulated on the sea floor millions of years ago. Under a special set of geological conditions occurring after deposition, this organic matter was chemically transformed into and preserved as oil and gas. For commercial petroleum deposits to be formed and preserved there must be a source of oil and gas, a porous and permeable bed of reservoir rock, and a barrier to fluid flow that acts as a trap so that accumulation can occur.[135]

- *Source*—Most of the organic debris on the seafloor is eaten or oxidized rather than preserved. Under anaerobic conditions, in which oxidation does not occur, however, organic matter can escape decay in the ooze and mud on the seafloor. The weight of the accumulating sediments compacts and heats the material to form rocks. Over millions of years the trapped organic residues are gradually transformed into liquid hydrocarbons. If the heat becomes too great, however, the sediments will be transformed into slate or other metamorphic rocks, and the organic matter will be transformed into a non-hydrocarbon carbonaceous material of no value.

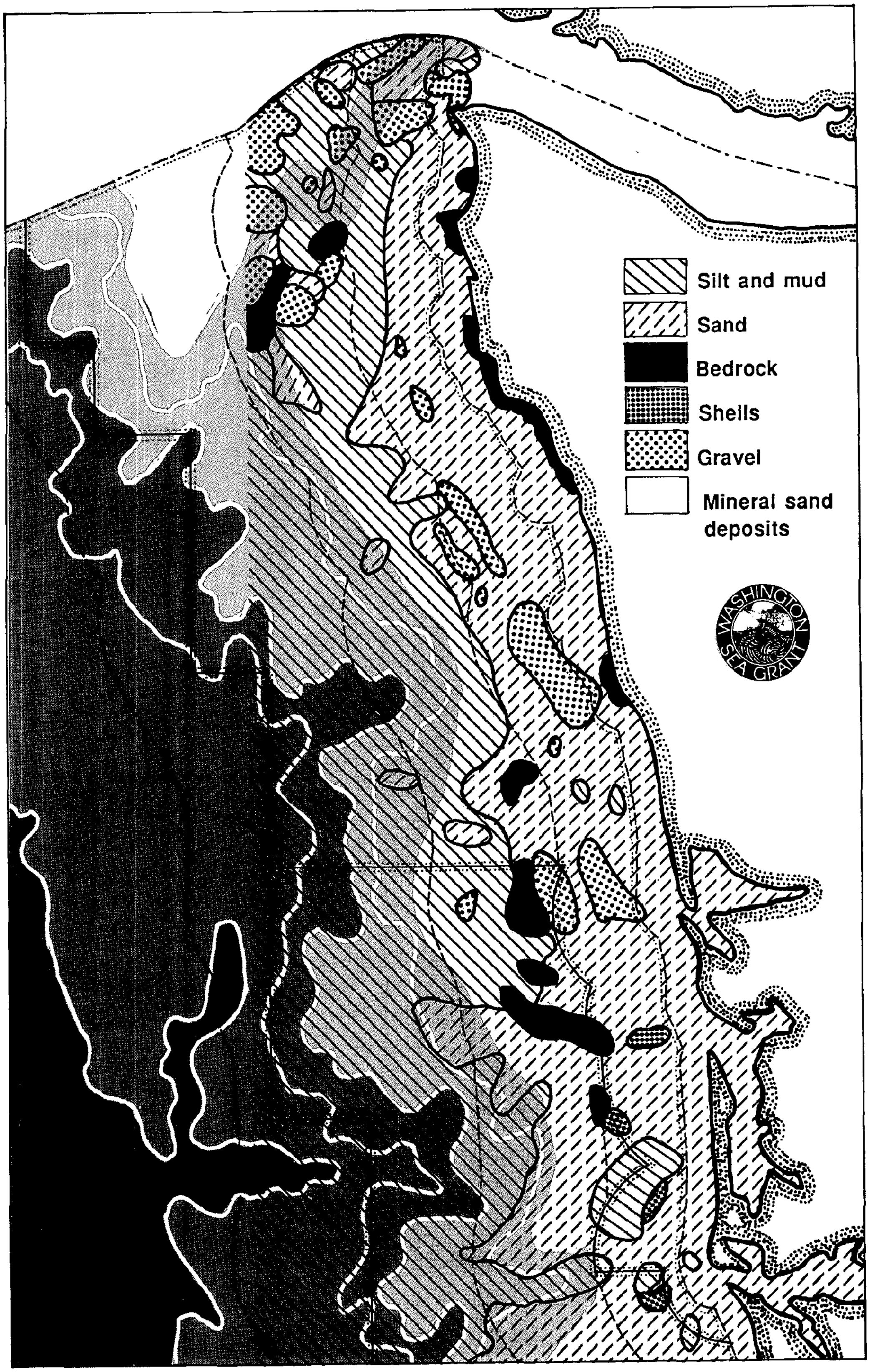


Figure 3.6 Distributions of sediment types and black sand minerals on the Washington shelf (Source: R. Lasmanis, WDNR).

• *Reservoir rock*— The now-fluid hydrocarbons will not be extractable by drilling if they remain widely dispersed in dense sedimentary rocks such as the shale in which they formed. If there are adjacent beds of porous rock such as sandstone, the hydrocarbons may migrate into these formations. Such migration results in exploitable reservoirs from which oil and gas can profitably be pumped.

• *Trap*—Hydrocarbons that migrate into permeable reservoirs can also keep on migrating out of them. Only beds in which a barrier is present to trap the fluid can accumulate commercial oil and gas deposits. Usually this occurs where porous beds are deformed by folding or faulting (structural trap), or are overlain by different types of rocks (stratigraphic trap), to impose an impermeable layer as a barrier. Typically, oil is trapped where sandstone layers are domed and oil migrates upwards until trapped by an overlying layer such as shale. Structural deformation must not be too severe, because widespread fracturing may permit leakage. The reservoir beds also must remain buried lest the oil be dissipated by surface erosion. The reservoir, furthermore, must not be exposed to groundwater containing large quantities of clay minerals, which can clog the rock pores and reduce the extractability of the oil.

The hydrogen and carbon that compose petroleum occur in varying proportions. Crude oil contains about 10-15 percent hydrogen and 80-89 percent carbon by weight. In its natural state oil may also contain minor amounts of sulfur, nitrogen, and metals. Oil is commonly found associated with natural gas and saltwater within porous rocks. Gas is less dense than oil or water and tends to accumulate at the top of any reservoir. Oil, heavier than gas and lighter than water, accumulates below the gas and above the water.

Petroleum geologists locate likely oil-bearing formations using sophisticated tools to reveal the geological structures beneath the sea floor. The most widely used tool is the seismic reflection survey. An air-gun or similar device at the water surface is used to generate high-energy acoustic shock waves powerful enough to penetrate seafloor rock layers. These impulses are reflected back to detection devices at the surface and are recorded electronically. As in sonar or radar, the pattern of returning waves maps the structures within its range. Geologists also survey the magnetic and gravity fields of the area, and may drill test holes near structures of interest to study more closely the composition and properties of the rock layers. Worldwide, thousands of structural or stratigraphic traps favorable to oil accumulation have been located. Only a fraction of them have proved to contain commercial quantities of oil or gas, however. The existence of favorable structures alone is not enough—there must be oil available to migrate into them.

EXISTING KNOWLEDGE OF OIL AND GAS RESERVES OFF WASHINGTON

Scientific assessments of petroleum potential on the Washington continental shelf are statistical models based on very limited data.[98] Few seismic survey and test well data exist in the public domain. The seismic reflection data that are available are generally antiquated and have limited coverage, and no exploratory wells have been drilled since the 1960s.[109,153,154,192] Outcrops of seafloor rocks and the deep, structural geologic framework of the continental margin are poorly understood.[155,187] The Washington shelf may contain no commercial petroleum accumulations, or it may be similar to Cook Inlet, Alaska, where six giant fields were discovered despite discouraging initial reservoir and geochemical assessments.[99]

Based on limited geochemical analyses, the rocks on the Washington coast and shelf considered to have potential to generate hydrocarbons are the melange wedges of the Hoh formation.[155] These rocks underlie much of the inner and mid-continental shelf and crop out along the coast between the Quillayute and Quinault rivers.[141,142] Analyses have confirmed that these rocks have been subjected to enough heating and that they are of sufficient organic richness to be considered a potential source rock for hydrocarbons.[155]

Several natural oil seeps occur in the Hoh melange along the Washington coast, and test wells have shown traces of both gas and oil. Natural gas seeps are found near Point Grenville, and active seeps of gas and oil include the Garfield gas mound north of Taholah, the Pysht River gas seep south of Clallam Bay, and the Jefferson and Lacey oil seeps near the mouth of the Hoh River.[99] What are called "smell muds" (because they emit a strong petroleum odor) occur in places along the Washington coast. Some of the best examples of smell muds occur in the

Hogsback area south of the Raft River, where one of the most impressive outcrops of melange rocks is exposed continuously for four kilometers in sea cliffs.[142] These intensely deformed strata are probably the source rocks for gas and oil found in seeps encountered in test wells in this area.[155]

The locations of petroleum wells in the study area are shown in Figure 3.3. The first oil well on the Washington coast was drilled near Third Beach (La Push) at the turn of the century, although the exact date of operations is unclear.[142] Reports indicate that a depth of 650 feet was achieved on this first well and that definite petroleum shows were encountered in the form of strong petroleum odor. Drilling operations were fraught with difficulty, however, and the operation was abandoned without any oil or gas recovered. Two other early wells were drilled in 1913 a short distance inland from Jefferson Cove in the Hoh River country near the Jefferson Seep. Well depths of 1,000 feet were achieved and substantial amounts of oil and gas were found, although not in commercial quantities.[142]

This exploration encouraged the drilling of a number of onshore wells in the 1930s. Eleven wells were drilled about two miles northwest of Oil City between 1931 and 1937. At first, as much as 100 barrels a day were reported to be flowing from some of these wells, although quantities soon decreased.[142] In the 1960s, during a phase of exploration that included the first offshore wells being drilled, subcommercial quantities of oil were produced onshore from the Sunshine Mining Company well, Medina No. 1, which was drilled on the coast north of Grays Harbor. This well, drilled to a depth of 1,262 meters into melange bedrock, produced about 12,000 barrels.[155] Also, natural gas produced by the Samson-Johns Units No. 1 well, drilled one-quarter mile from the Medina No. 1, was sold for a short time to a residential development in Ocean Shores.[133]

Only four wells, all of which were dry holes, have been drilled off the Washington coast.[194] These offshore wells, which reached total depths of between 2,460 meters and nearly 4,000 meters, apparently did not penetrate oil-producing reservoir rocks[99] although minor shows of gas were encountered in the Shell P-0150 well drilled in the Willapa Bay/Grays Harbor Basin.[155]

In general, the Washington coast and shelf are deficient in sandstone rocks that might serve as suitable reservoirs for oil and gas.[155] Although some coastal sandstones are reminiscent of other hydrocarbon-producing regions of the world,[99] these rocks have been intensely faulted and fractured, which may render them unsuitable to serve as sealing traps, since any accumulated petroleum would escape. Porous rocks suitable to serve as reservoir rocks may be present among the great thicknesses of sedimentary rock that are present in the offshore basins of the continental shelf. Also, faulting may be less ubiquitous in the offshore region.[99] It has been suggested that the flanks of the diapiric structures on the Washington shelf may form traps for upward-migrating petroleum, and may be better exploration targets than the cores of melange and broken formation.[155] Seismic data indicate that, besides the diapiric structures, folds and less complex faults favorable for trapping petroleum are common on the Washington continental shelf.[99]

Geochemical studies indicate that the rocks drilled to date on the Washington shelf have little potential to generate oil and only a fair potential to generate natural gas.[98] Overall, the potential for oil is has been rated low, and that for gas moderate.[155] A better understanding of the Hoh source rock stratigraphy and geochemistry is needed in order to clarify the conflict between the low potential for oil generation suggested by laboratory analyses and the frequent oil seeps and oil shows in exploratory wells drilled along the coast.[133]

Meteorology and Physical Oceanography of the Washington Coast

METEOROLOGY

The Washington coast has a mild and moist climate due to the air masses that advance inland from the Pacific Ocean. In the winter (generally mid-October through mid-March), low-pressure systems and associated storms generated in the Gulf of Alaska and carried by the jet stream approach the coast.[97] The strongest lows always come from a southerly direction, however, and have their origins in the subtropics or tropics, sometimes more than 2,000 miles away. During the fall and winter months, these storms may develop into what are called "superstorms." Some recent examples of superstorms and their tracks are provided in Figure 3.7. These low pressure systems can bring occasional devastating winds to the coast and may travel over the ocean at speeds from about 5 to more than 60 knots. During summer, high pressure builds from the south, the jet stream is diverted north, and fewer storms strike the coast. Movement of both lows and highs is slowest during the summer months and much faster in winter, due to the location of the jet stream.[97]

Accompanying these pressure systems are weather fronts, the boundary areas between high and low pressure areas. Fronts usually, but not always, come from the SW-W-NW sector and move E to NE. In most cases the ocean is affected by a moving series of weather systems, but sometimes lows or highs may stall over the coast and long periods of "bad" or "good" weather ensue.[97] The pressure gradients associated with these fronts generate predominant wind directions that are northerly during fair weather and southerly or southwesterly during storms.[82] During winter the prevailing winds are from the south and southwest about 70 percent of the time and storms are frequent.[153] At North Head at the mouth of the Columbia River, winds exceed 32 mph about 10 percent of the time during December. At Tatoosh Island off Cape Flattery, winds exceed 32 mph 9.1 percent of the time.[127]

The highest wind speeds recorded on the Washington coast are 150 mph at North Head at the mouth of the Columbia in January, 1921, and 94 mph at Tatoosh Island in November, 1942.[127] For the years 1979-1984, 67 knots was the maximum peak wind gust recorded at a weather buoy at the mouth of the Columbia.[119] The highest wave for the years 1979-1984 at the weather buoy was 10 meters.

Representative data on seasonal patterns of wind speed and direction for the Washington coast are presented in Figure 3.8. Mean seasonal patterns of visibility and wave height are presented in Figure 3.9. More detailed monthly averages of data on wind speed, wind direction, visibility, ceiling height, ceiling visibility, air and sea temperature, wave height, and surface currents off the Washington coast for the years 1850 to 1974 are available in the *Climatic Study of the Near Coastal Zone, West Coast of the United States.*[120]

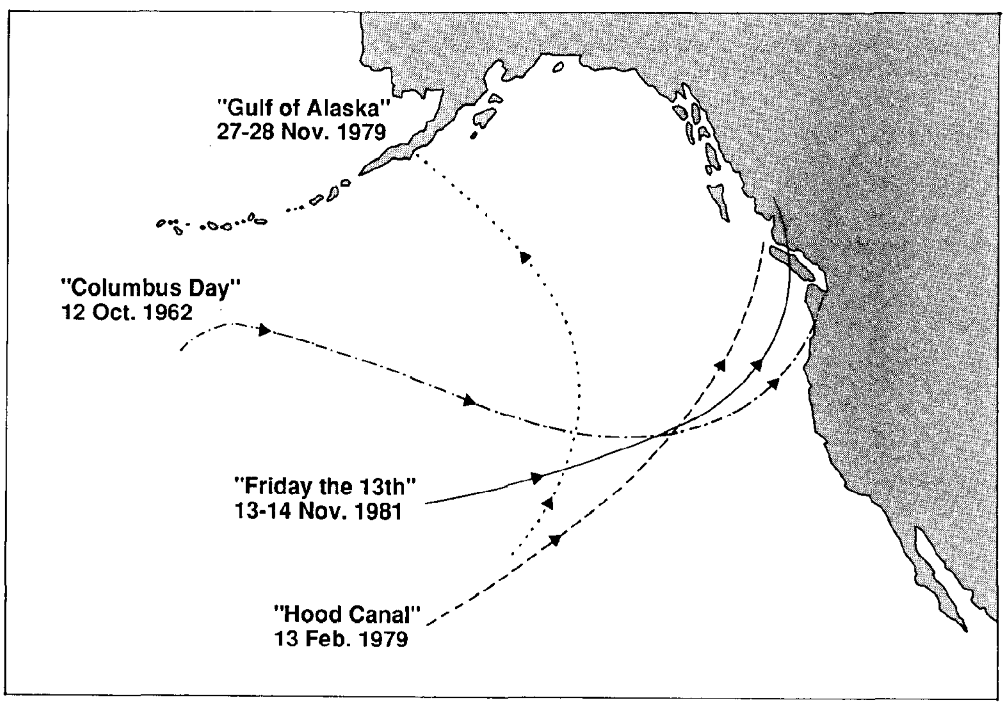


Figure 3.7 Storm tracks of selected "superstorms" in the northeast Pacific Ocean near Washington state (after Lilly 1983).

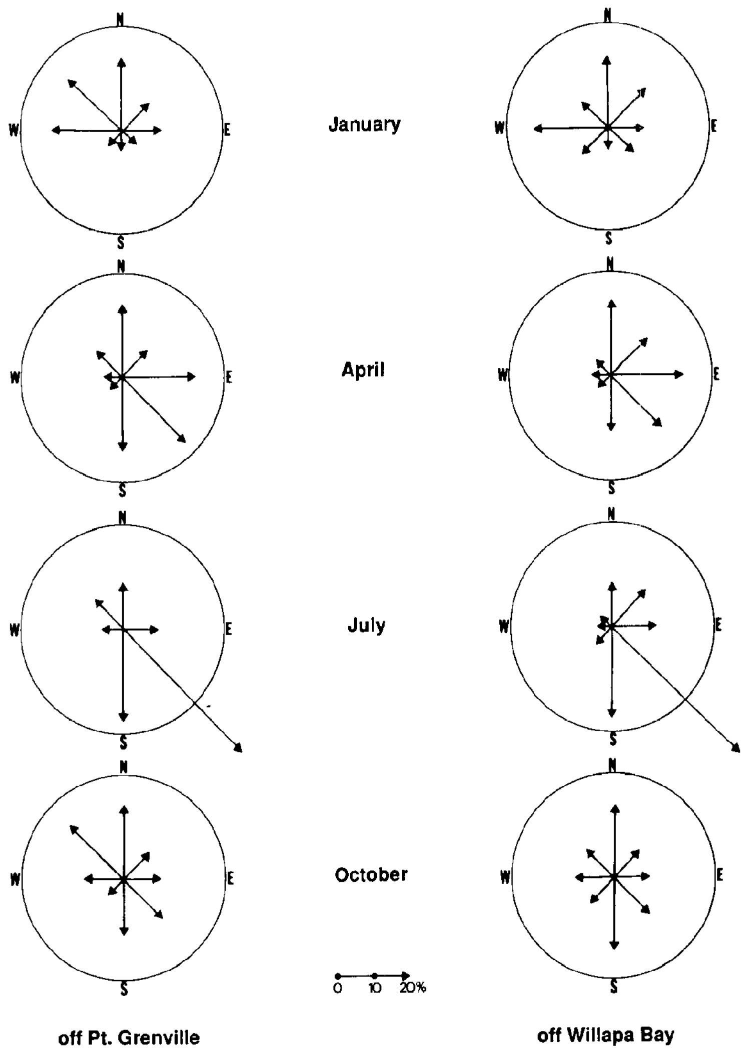


Figure 3.8 Patterns of mean frequency of wind direction (% of total observations) off Point Grenville and Willapa Bay in coastal Washington for January, April, July, and October. Winds are highly variable, but are more commonly from northern quarters in summer and southern quarters in winter. (Source: Naval Weather Service Detachment 1974, averages for available data from 1850-1974).

National Data Buoy Center climatic summaries[119] also include the following data: means, maxima, and minima for air and sea temperatures, air-sea temperature differences, sea level pressure, wave heights, peak wind gusts, and surface wind speeds; also, percent frequencies of wind speed vs. wind direction, wind speed vs. wave height, and wave height vs. wave period. Large amounts of data such as daylight-darkness, precipitation types, high wave recurrence intervals, and wind speeds are also available.[120]

PHYSICAL OCEANOGRAPHY

Physical oceanography is the study of water movements in the ocean and the factors controlling them. These factors include the temperature, salinity, and resulting density distributions within the ocean over distances from a few centimeters to thousands of kilometers; forcing functions such as wind, heating and cooling, and precipitation and evaporation; and modifying factors such as the effects of the earth's rotation and the configuration of shorelines and

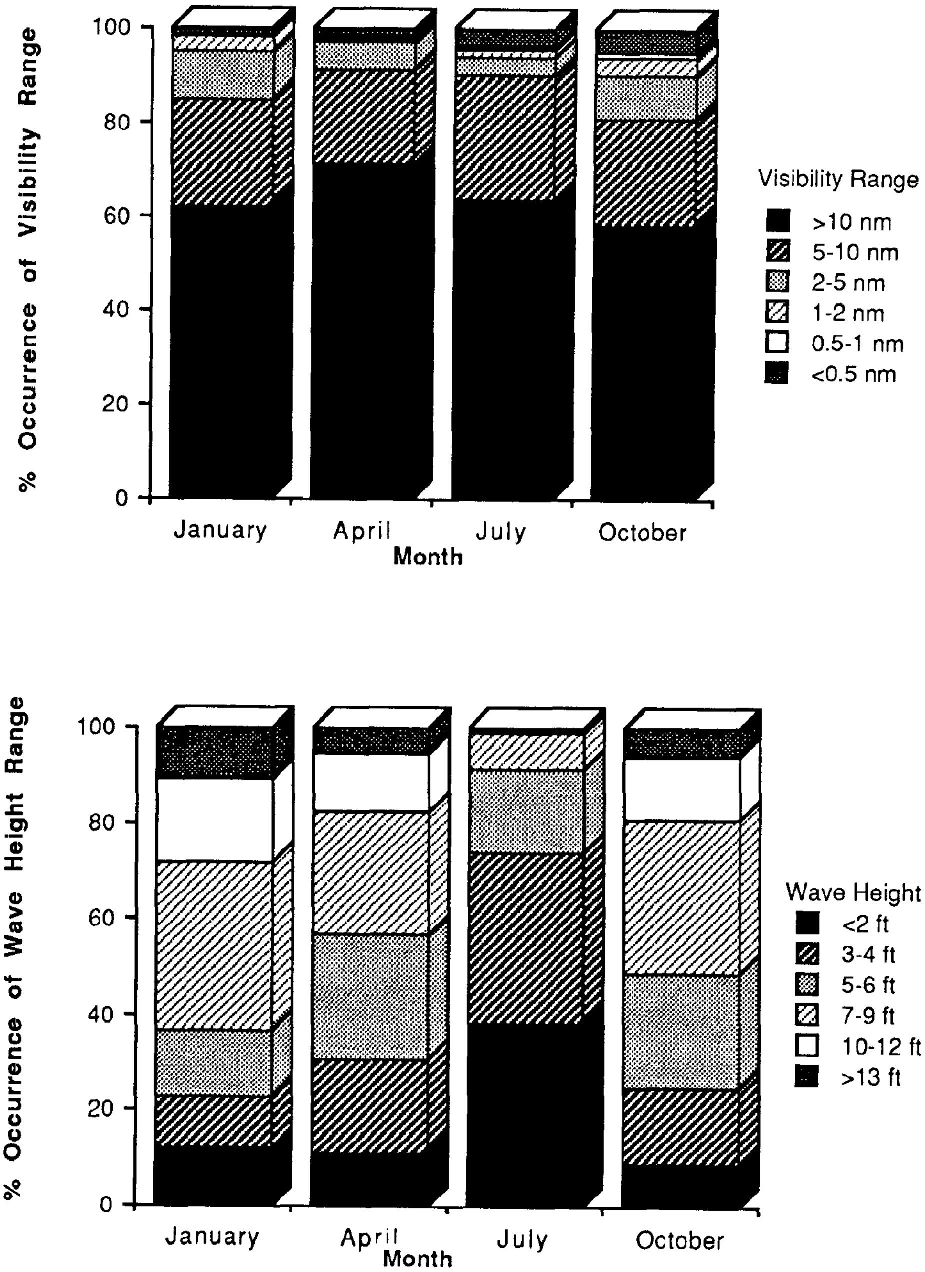


Figure 3.9 Mean percent frequency of visibility ranges (nautical miles) and wave heights (feet) off the Washington coast for January, April, July, and October (Source: Naval Weather Service Detachment 1974, averages for available data from 1850-1974).

the ocean bottom. Physical oceanography is important because, together with weather, it creates the conditions faced by structures and vessels in the ocean and governs the transport of spilled oil and material disposed of or lost at sea.

The physical oceanography of the Washington coast has been reviewed recently [68,91] and in the more distant past.[11] The following discussion is drawn from these sources where not otherwise indicated. The major features to be discussed are:

- wave conditions, including "tidal waves" or tsunamis;
- turbulence and vertical mixing;

- mean surface and deep-water currents over large and small spatial scales;
- variability of these currents patterns on various spatial and temporal scales;
- tidal and inertial currents;
- planetary waves;
- sea level variations;
- fronts, meanders, eddies, squirts, and jets;
- interactions with submarine canyons;
- interactions with the Columbia River and other estuaries.

Wave Conditions

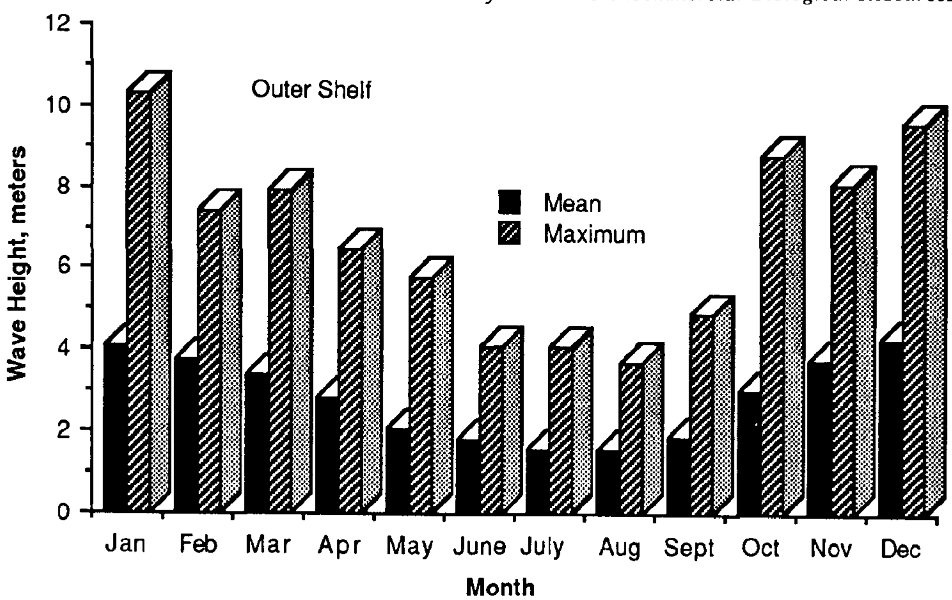
The Washington coast and the North Pacific are known for heavy waves, comparable to those of the North Sea, that can affect marine operations.[126,127] Extremes of wave height ranging from 15 to 29 m have been recorded on and beyond the shelf off Washington and Oregon. Statistical forecasts indicate the potential for 100-year storms generating winds reaching 176 km/hr (95 knots), significant wave heights of 20 m, and extreme wave heights of 36 m off Washington.[127] Data on mean waves heights and directions along the Washington coast are available from a number of sources.

Kachel and Smith [82] review wave estimates from three sources: three years of "hindcasts" derived from weather charts and known relationships of waves to weather; eight months of data from a meter on Cobb Seamount 400 km offshore; and three years of data from a buoy on the shelf off Grays Harbor. These results showed that the most severe waves are generated by winter storms generated near Japan that strike the Northwest coast. Winds from the south accompanying warm fronts generate waves with significant heights (average height of the highest one-third of the waves) up to 6-7 m, and those from the west-southwest to northwest accompanying cold fronts can generate waves with 8-10 m significant heights. Local waves are milder, mainly low (<3 m) swell, when storms strike the coast to the north or south of the state. Swell comes from remote storms and usually has different height, period, and direction from local seas.[127]

Wave buoy results are collected by the Coastal Data Information Program, are presented in annual reports,[148] and are available as on-line computer data from Scripps Institution of Oceanography. Additional hindcast data are also available from the Army Corps of Engineers.[32] MMS is sponsoring collection of west coast wave data into a statistical database.[41] Summary examples of Army Corps hindcast data on wave height and direction are presented in Figures 3.10 and 3.11. Wave heights are generally lower on the shelf due to friction with the bottom. Waves also refract (bend) when striking the shelf. A theoretical analysis of wave refraction performed for possible siting of an offshore monobuoy oil transshipment terminal [102,126] determined that zones of higher and lower wave energy should occur on the shelf. One potential "shadow zone" of reduced wave energy, about two miles long by five miles wide, was identified about six miles west-southwest of Point Grenville. This report concluded, however, that during winter—even in a wave "shadow zone"—with then-current technology, tankers would be unable to moor offshore about 65 percent of the time, and for continuous periods as long as 20-30 days.

All harbor mouths along the Washington and Oregon coast can be very hazardous to shipping because of steep or breaking waves caused by shoaling and by strong river currents flowing against incoming waves.[97] The Columbia River entrance has long been recognized as one of the most dangerous coastal inlets in the world due to the exceptionally strong wave-current interactions that occur there.[61] According to U.S. Coast Guard statistics, in an average year approximately 850 search and rescue missions are conducted, about 1,850 persons are assisted and 30 lives are saved, but about 10 lives are tragically lost in spite of these efforts.[59] At times, primarily during the winter season, bar conditions are so dangerous that the entrance must be closed. From 1971-1979 the bar was closed an average of 23 days per year (range 9 to 41 days).[193]

Tsunamis are long-period sea waves produced by a submarine earthquake or volcanic eruption. They may travel unnoticed across the ocean for thousands of miles from their point of origin, but build up to great heights over shallow water. The Alaskan earthquake of 1964, for example, generated a tsunami that struck the Washington coast and caused some damage. At Seaview, Washington, the 1964 tsunami reached a maximum height of 12.5 feet; at Neah Bay the maximum height was 4.7 feet.[198] The greatest damage occurred to a concrete bridge north of Grays Harbor, presumably from battering by log debris. The magnitude of tsunami waves over the



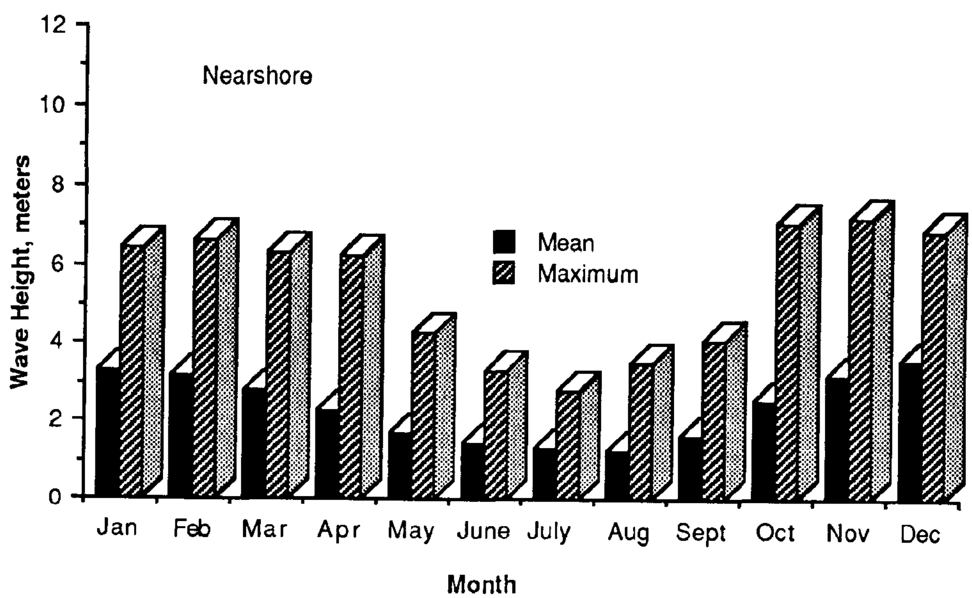


Figure 3.10 Monthly mean and maximum hindcast wave heights at nearshore and outer shelf stations off Grays Harbor (data from Corson et al. 1987 and Army Corps of Engineers 1988a).

shelf depends on the strength of the generating force and their orientation to the coast.[127] Theoretical probability calculations place the Washington coast in levels two and three for possible tsunami hazards.[169] Level two risk denotes a 90 percent probability that tsunami heights (combined with astronomical tides) will not exceed 5-15 feet over a period of 50 years; level three

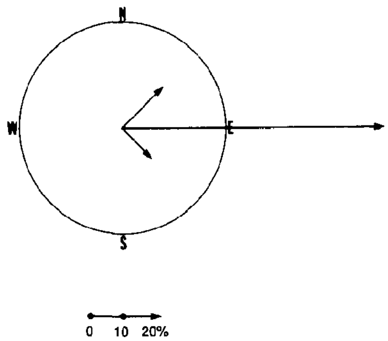


Figure 3.11 Percent frequency of wave direction (hindcast annual mean) at a deep-water station off Grays Harbor (data of Corson et al. 1987).

denotes a 90 percent level of 15-30 feet. Detailed maps of levels of tsunami risk are available from the U.S. Army Corps of Engineers Waterways Experiment Station in Vicksburg, Mississippi.

Vertical Stratification and Mixing

The patterns of water motion in the ocean are influenced by driving forces such as winds, and by the vertical distribution of water density. The water column (a hypothetical vertical segment of water) is typically *stratified* into layers which may respond differently to the forces that generate currents, as momentum is transferred from one layer to another. On the Washington coast, less dense, warmer, less saline water generally forms a buoyant, stable surface layer overlying denser, colder, saltier water (Figure 3.12). The density change boundary between these layers is called a *pycnocline*.

One consequence of stable stratification is a resistance to vertical mixing of the water column. The greater the vertical density gradient in the water column, the more force required to mix the layers of water together across a pycnocline. In general, outer Washington shelf waters are thermally stratified near the surface in summer and vertically mixed in winter, when surface water is cooled and wind and wave action are strong. During winter the surface mixed layer extends to depths of 40-60 m on the outer shelf. The stratification found in summer is due to surface heating

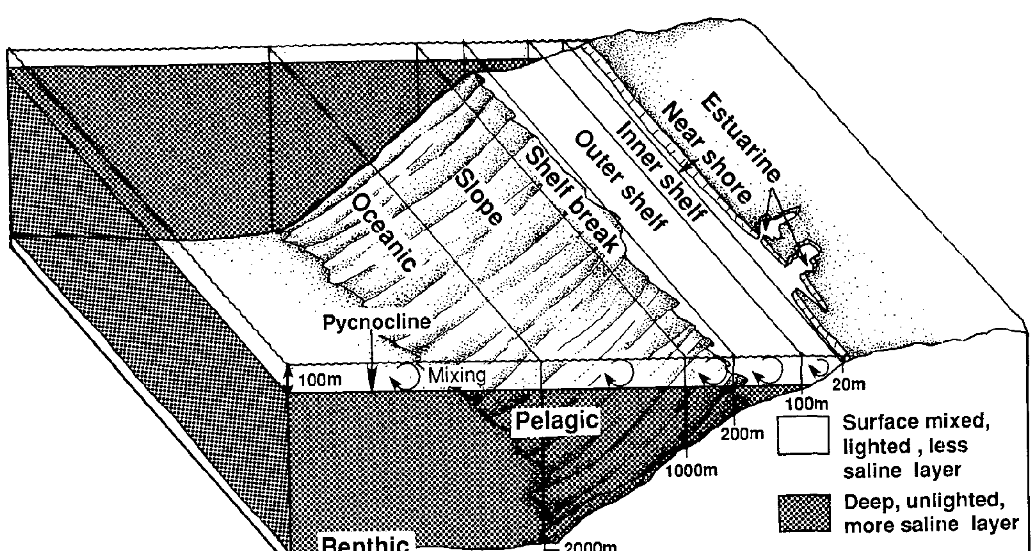


Figure 3.12 Schematic diagram of offshore domains in Washington coastal, shelf, and oceanic waters. Curved arrows indicate vertical mixing, which extends to the depth of the pycnocline, a barrier of increased water density (modified from Wahl 1984).

and decreased storm activity. The surface mixed-layer depths in summer are only 10-20 m. Nearer shore on the inner Washington shelf, however, runoff from the Columbia and other rivers reduces the depth of the mixed layer to 10 m or less in winter, and produces a strong pycnocline beneath the dilute river water mixture. In summer, the outflow from Columbia River moves offshore and to the south, creating strong stratification as a large pool of dilute water, the plume, overlies a sharp pycnocline. Along the northern Washington coast in summer, coastal upwelling reduces the magnitude of stratification.

The dissolution and dispersal of contaminants introduced into the sea surface strongly depend on mixing caused by forces that generate turbulence, such as winds and waves; factors that affect convective processes such as heating and cooling; and evaporation and precipitation, river input, and interactions among currents of varying speed and direction. The intensity of mixing in the horizontal direction is generally about a thousand times greater than that in the vertical direction, because the turbulence that causes horizontal mixing does not have to overcome the resistance to mixing offered by stable stratification. Water currents on the shelf vary in strength and direction both horizontally and vertically. The interaction between these variable flows promotes both horizontal and vertical turbulence and mixing.

Mean Currents

Currents are the major mode of transport of water and the substances it contains. The pattern of water currents strongly affects the potential transport of spilled oil or other contaminants that enter the ocean from petroleum-related activities. The mean currents off the Washington coast are relatively simple compared with those in some areas of the ocean, but the actual day-to-day pattern of water motions off the state's coast is quite complex and variable. As frequently is true in nature, this variability is generally more important to understanding the dynamics of water motion than are average conditions.

Oceanic currents. Throughout the year the broad (1,000 km wide) California Current flows southward in oceanic waters beyond the Washington shelf (Figure 3.13). This current is part of a large-scale clockwise circulation pattern in the central north Pacific, which includes the Kuroshio and Subarctic Pacific Currents bringing water from the western Pacific to the northwest coast. The magnitude and position of the California Current change seasonally. In winter the current is weaker and farther off the shelf, and in the summer it is stronger and closer to the shelf. Mean current speed is given in Table 3.1.

An opposing current, the Davidson Current, develops in winter inshore of the California Current, impinging onto the outer shelf. The Davidson Current flows northward over the slope and outer shelf during winter and early spring, but is absent during the summer. Mean current speed is given in Table 3.1. The presence and direction of the Davidson Current are consistent with the mean local wind patterns from the south and southwest during winter. However, larger-scale forces along the entire west coast are also implicated in the seasonal dynamics of the California and Davidson currents.

A narrow (20 kilometer) subsurface countercurrent (the California Undercurrent) flows northward along the upper continental slope, with its core at a depth of about 200 meters. It is stronger in summer and winter, and weaker in spring and fall. Mean current speed is given in Table 3.1. There is also evidence that a deeper (400 meters) southward current (the Washington Undercurrent) forms during the winter.

Shelf currents. Currents over the Washington shelf tend to follow the seasonal pattern of the oceanic currents, but also are strongly influenced by local winds, bottom and shoreline configuration, and freshwater input. These factors combine to produce a composite mean circulation pattern depicted in Figure 3.14. On the average, water flows southward in the upper 100 meters during summer, and northward below that depth. Water over the shelf flows generally northward at all depths during the winter; near shore under the Columbia River plume, southward flow may be found. Mean current speeds are given in Table 3.1.

The currents over the shelf are highly variable, so that calculations of mean current speeds must be interpreted carefully. Periods of reversals in current direction tend to cancel each other out when simple averages are calculated. Also, both the strength and the direction of the currents vary across the shelf. Maximum mean surface current speeds have been observed on the middle shelf (50-100 m isobaths) in the surface layer (20-30 meters depth) between April and June, and farther offshore later in the summer. Very few measurements have been made of current speeds closer to the surface or closer to shore, but some data suggest that currents speeds in the upper 5-10 m may

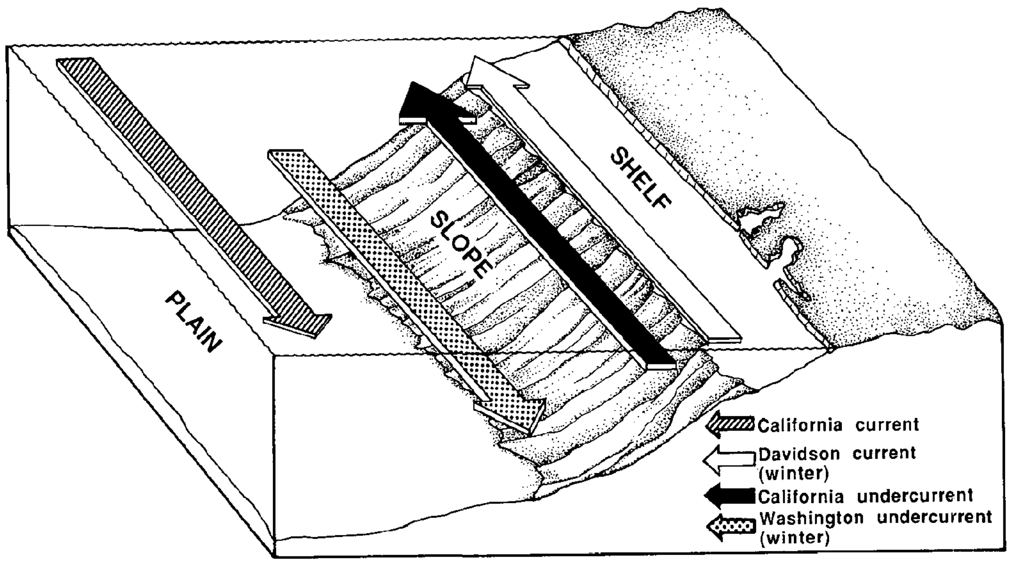


Figure 3.13 Oceanic and continental slope surface currents (California Current, and Davidson Current in winter) and undercurrents (California Undercurrent, and hypothesized Washington undercurrent in winter) off Washington (after Hickey in press).

be double those at 20-30 m, where they are typically measured. In addition, some data suggest onshore transport at depth during summer because of coastal upwelling.

These alongshore current components are accompanied by characteristic cross-shelf components. Because of the effect of the rotation of the earth (the Coriolis effect) on wind-driven surface currents, surface water tends to be transported to the right of the wind direction (in the northern hemisphere). Thus water is transported away from shore in summer by mean winds from the north. Between about May and August, mean offshore flow along the coast entrains subsurface water into the surface layer, a phenomenon called *coastal upwelling*. During this period upwelling occurs mainly within about 10-20 km of the coast, and strongest offshore flow is found mainly in the upper 10 m. During winter, mean winds from the southwest foster onshore transport of surface water and coastal downwelling. Onshore subsurface currents (mainly at middle depths) accompany upwelling, and offshore currents (mainly along the bottom) accompany downwelling. Long-term mean bottom currents have a shoreward component due to wave action in water depths less than 40 m.

The magnitude of the cross-shelf current components is small, but they nevertheless produce significant physical and biological effects. Upwelled water is rich in nutrients that support the growth of plankton and help sustain coastal fisheries. Downwelling can produce intrusions of offshore water into the surface waters of estuaries (for example, the Strait of Juan de Fuca),[53] opposing the mean offshore surface flow in those water bodies. Upwelling and downwelling also affect coastal sea levels.

Current Variability

Observed currents over the Washington shelf are highly variable in both space and time and may not resemble the mean patterns, so calculations of mean current speeds must be interpreted carefully. Spatial differences in currents occur across the width and length of the Washington shelf as a result of variations in such factors as the wind field along the entire west coast, freshwater input, and bottom topography. Both the strength and the direction of the currents vary across the shelf. Maximum mean surface current speeds have been observed on the middle shelf (50-100 m isobaths) in the surface layer (20-30 meters depth) between April and June, and farther offshore later in the summer. Very few measurements have been made of current speeds closer to the surface or closer to shore, but some data suggest that currents speeds in the upper 5-10 m may be double those at 20-30 m, where they are typically measured. In addition, some data suggest onshore transport very close to shore during summer.

Table 3.1 Current Speeds off the Washington Coast
(Sources: Hickey in press; Hermann et al. in press; Barnes et al. 1972)

Current	Mean Summer Speed (cm/sec)	Mean Winter Speed (cm/sec)
Oceanic Currents		
California Current (surface)	~10	<10
Davidson Current (surface)	-	20
California Undercurrent (200 m depth on slope)	>10	~10
Washington Undercurrent (400 m depth on slope)	?	?
Shelf Currents		
Middle Shelf (50-100 m isobaths)		
Surface layer (20-30 m depth)	17-20 southward, 2-4 offshore	~10 northward, ? onshore
Bottom layer	1-2 northward, ? onshore	1-2 northward, ? onshore

Temporal current fluctuations dictate that instantaneous currents on the Washington shelf depart from the mean patterns described above much as daily weather departs from the long-term climatic averages. Local currents over the shelf respond within hours or days to passing weather systems, and are also affected over time scales of weeks and months by larger-scale events in the Pacific such as temperature and salinity anomalies, planetary waves, and El Niño. These "event-scale" (multi-day), interannual (year-to-year), and "mesoscale" (weekly to monthly) fluctuations are generally of the same magnitude as the mean conditions, and therefore just as important in determining current patterns that affect oil and gas activities. Monthly mean patterns of surface current speed and direction for a sample year are shown in Figure 3.15.

Currents in the surface layer consistently show complete reversals over the course of a few days, especially during summer, when weather patterns abruptly shift. Shifts in currents deeper in the water column may lag behind the surface response to local wind shifts, but may also locally precede surface current changes if their driving forces are remote. In both cases the variations are closely correlated with wind shifts. Periods of reversals in current direction tend to cancel each other out when simple averages are calculated. Fewer data are available on spatial variability of currents, especially on the northern Washington coast, but data suggest persistent areas of northward current reversals in summer off the mouth of the Strait of Juan de Fuca and along the inner shelf. The possible origin of these reversals is discussed by Hickey.[68]

Tidal and Inertial Currents

Superimposed on the mean and weather-driven current patterns discussed above are regular and predictable current fluctuations driven by the tides. Predicted tidal currents are published by the National Oceanic and Atmospheric Administration (NOAA) for selected coastal locations. In this region with semidiurnal mixed tides, tidal currents reverse four times per day, so their speed varies from a maximum to near zero on the same cycle. In addition, tidal current strength varies over the fortnightly neap-spring tidal cycle. Tidal currents are stronger during spring tides associated with the full and new moons, and weaker during the neap tides around the quarter moons. Tidal currents are also strongest during the annual periods of greatest tidal amplitudes, especially during May through July and November through January, and weaker during the other months.

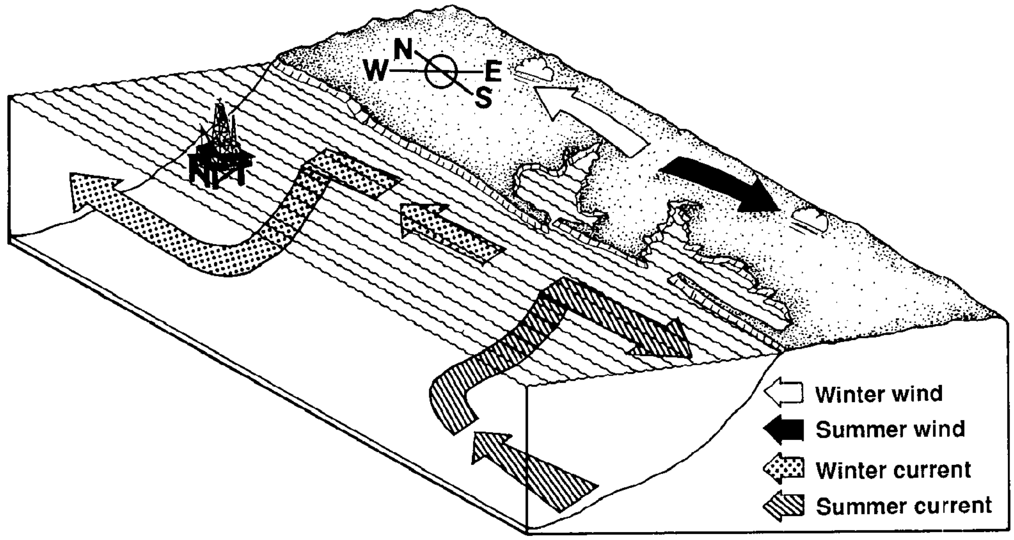


Figure 3.14 Simplified mean winter and summer current patterns on the Washington shelf. Mean flow along the bottom is northward in all seasons. Mean surface flow is southward in summer, accompanied by coastal upwelling of deeper water. Mean surface flow is northward in winter, accompanied by coastal downwelling of surface water.

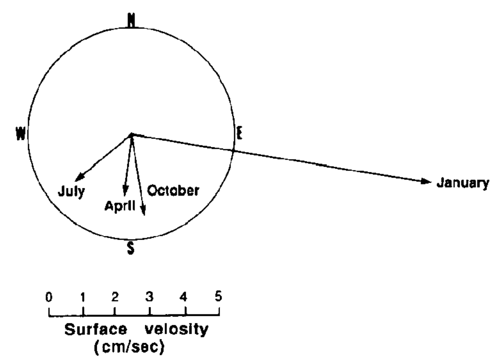


Figure 3.15 Monthly mean surface current velocities at a deep-water station off Grays Harbor in 1961 (modified from Barnes et al. 1972).

Tides are affected by coastal features and shelf bathymetry, so that published tidal current predictions for harbors and passages will differ from tidal currents on the shelf and offshore. An illustration derived from tidal currents measured over the shelf is presented in Figure 3.16. Tidal currents on the shelf tend to flow in an elliptical rotary pattern, northeastward on the flood and southwestward on the ebb. Floating objects follow such ellipses as they drift in the direction of the underlying wind-driven and other currents. Typical maximal tidal current speeds on the open shelf exceed 10 cm/sec, depending on the tidal phase. Near shore where tides are influenced by flow in and out of estuaries, tidal currents are much larger than the mean wind-driven currents. Tidal current speeds are added to wind-driven current speeds presented above in Table 3.1.

Inertial motions are unforced rotary motions in which centrifugal "force" (the tendency of moving matter to travel in a straight line) is in balance with Coriolis "force" (the tendency of moving matter to turn right in the northern hemisphere as a result of the earth's rotation). Inertial motion speeds are about 15 cm/sec over the shelf and 10-40 cm/sec in the upper 200-300 m over the slope. Inertial motions are coherent over scales of 50-100 km in winter and 10-20 km in summer.

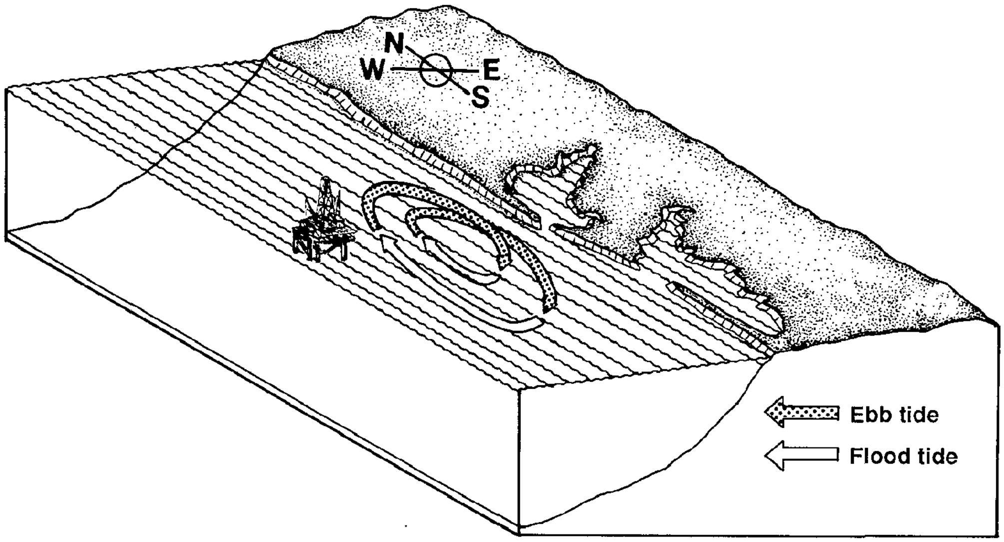


Figure 3.16 Generalized diagram of cyclic patterns of water transport by tidal currents on the Washington shelf off the Columbia River. Distance of transport on a tidal cycle is on the order of one kilometer (modified from Duxbury and Duxbury 1984).

Planetary Waves

Planetary waves are large-scale periodic water motions that travel along the surface or along density interfaces such as the pycnocline. They are caused by disturbances such as changes in winds over large areas such as along the coast between California and Washington, and have wavelengths of hundreds of kilometers. Their paths are constrained by bathymetry and by other dynamic factors such as the influence of Earth's rotation (Coriolis effect). Passing planetary waves can set water in motion. Some current fluctuations on the Washington shelf in summer are related to the passage of planetary waves generated by coast-wide wind distributions.

Planetary waves attracted a great deal of interest in Washington following the 1982-83 El Niño.[201] This phenomenon has been analyzed as a large-scale wave form that traveled from the western equatorial Pacific eastward along the equator and up the Pacific coast over the course of several months. When the warmer water traveling across the ocean accumulated in the eastern tropical Pacific, it spread north and south, bringing warmer sea temperatures, increased rainfall, higher sea levels, anomalous currents and reduced upwelling, and unusual fishes and other animals to the Washington coast. Niño events of varying intensity occur about every three to seven years (a mild Niño was observed in the equatorial Pacific in 1987).

Sea Level Fluctuations

Sea level at the coast and on the shelf fluctuates with the tides, but is also affected by currents, weather, and planetary waves. Coastal sea level is of interest for this report for two reasons: high sea level can aggravate coastal erosion problems that might affect onshore facilities; and sea level changes can serve as an indicator of other physical oceanographic processes and events taking place on the continental shelf. Sea level is higher during the winter due to lower density water in the coastal area and reduced atmospheric pressure, and lower in summer when atmospheric pressure and the average density of coastal water increase. Sea level rises during periods of low atmospheric pressure, and when the crest of a planetary wave contacts the coast. Sea level also can vary over periods of days, in phase with wind and current fluctuations.

Fronts, Meanders, Squirts, Jets, Eddies, and Interactions with Topography

Marine fronts, like weather fronts, are zones of abrupt transition in water currents and characteristics. They are formed by converging small-scale water motions. Fronts are commonly visible at the sea surface because of changes in sea-surface texture or accumulations of debris into windrows. Fronts are believed to be areas of higher biological productivity, which could be affected if these same sites accumulate debris and contaminants. Some fronts may be temporary and others may form at persistent locations associated with such factors as bathymetric features or river outflow. In winter, the seaward edge of the Columbia River plume forms a distinct front parallel to the Washington coast, with a strong horizontal salinity gradient. In summer, upwelling brings subsurface water to the surface at the inshore boundary of the plume to form a density front, thought to be about 20-30 km offshore.[91] Close to the river mouth, this boundary may be as close to shore as the end of the south jetty. The offshore boundary of the plume lies where the plume contacts open ocean surface water.

Meanders are prominent 80-200-km-long curvatures or "kinks" in otherwise straight or smoothly curving currents. Eddies are whirlpool-shaped current patterns 20-100 km across. Squirts and jets are narrow, distinct areas of offshore-directed currents. All these features can be formed by interactions of currents with bottom or shoreline configurations, with temperature and salinity structures (including river plumes), or with opposing currents. Eddies commonly are generated when planetary waves and oceanic currents contact the edge of the continental shelf. These eddies can be carried over the shelf, affecting current patterns and transporting water parcels with anomalous properties and organisms. Both meanders and eddies may remain stationary over locations favorable to their formation, such as submarine canyons. Eddies can have the effect of trapping water and anything contained in that water in a confined area.

There are few documented instances of meanders, eddies, squirts, and jets on the Washington shelf. Persistent eddies are thought to exist north of the Columbia River mouth and below the surface off the mouth of the Strait of Juan de Fuca in summer. Transient eddies have been well documented off Vancouver Island, and may be transported over the Washington shelf by currents.

When currents intersect submarine canyons their direction is altered. Subsurface upwelling occurs especially where currents along the shelf and slope cross the downstream edges of canyons. The water upwelled in this fashion may spread inshore or offshore and possibly reach the surface. In addition, current directions may be altered by the presence of canyons, creating persistent current meanders or eddies within the canyon, at least in subsurface waters. In a large canyon such as the Quinault Canyon, the meander or eddy may reach into the surface layer.

Nearshore currents are altered by the presence of headlands, although this process may be a minor one in Washington, which has a relatively straight coastline. These interactions can produce localized meanders, eddies, squirts, jets, and patches of upwelling, all of which may be visible on satellite photos of surface temperature and pigment concentrations.[134] An area of persistent upwelling into the surface layer is thought to exist around the Juan de Fuca canyon.

Interactions with Columbia River and Other Estuaries

The Columbia is the largest river on the West Coast and has significant effects on Washington coastal waters. The Columbia contributes 60 percent (winter) to 90 percent (late summer) of the freshwater entering the Pacific between San Francisco and Canada. The maximum flow occurs in June and the minimum in September. A low-salinity surface plume is evident throughout the year, with its extent and orientation changing seasonally with fluctuations in outflow and currents (Figure 3.17). The plume is directed northward and hugs the shore in winter, and is directed southward and disperses offshore in summer, in accord with alongshore and cross-shelf currents during those seasons. This low-salinity layer acts to increase vertical stability and decrease vertical mixing, to reduce upwelling, and to direct currents around the plume. Also, a southward undercurrent is thought to be present at times beneath the coastal Columbia River plume in winter.

Estuaries are areas where fresh water enters salt water. They may be simple river mouths, such as found in the Columbia, Hoh, Quinault, and other rivers that enter the sea directly; or the rivers may enter enclosed bays such as Grays Harbor and Willapa Bay. The Strait of Juan de Fuca also may be considered an estuary in a broad sense, since it carries the outflow of numerous rivers entering Puget Sound and the Strait of Georgia, but its outflow travels north and it not thought to affect the Washington shelf.

Estuaries typically have a basic circulation pattern, depicted schematically in Figure 3.18. On the average, fresher water flows outward at the surface, and more saline ocean water enters the estuary along the bottom. A sloping pycnocline or "salt-wedge," a zone of reduced flow and intermixing of fresh and salt waters, can reside between these two opposing flows. The horizontal location of this boundary between inflow and outflow fluctuates with the tides and river runoff.

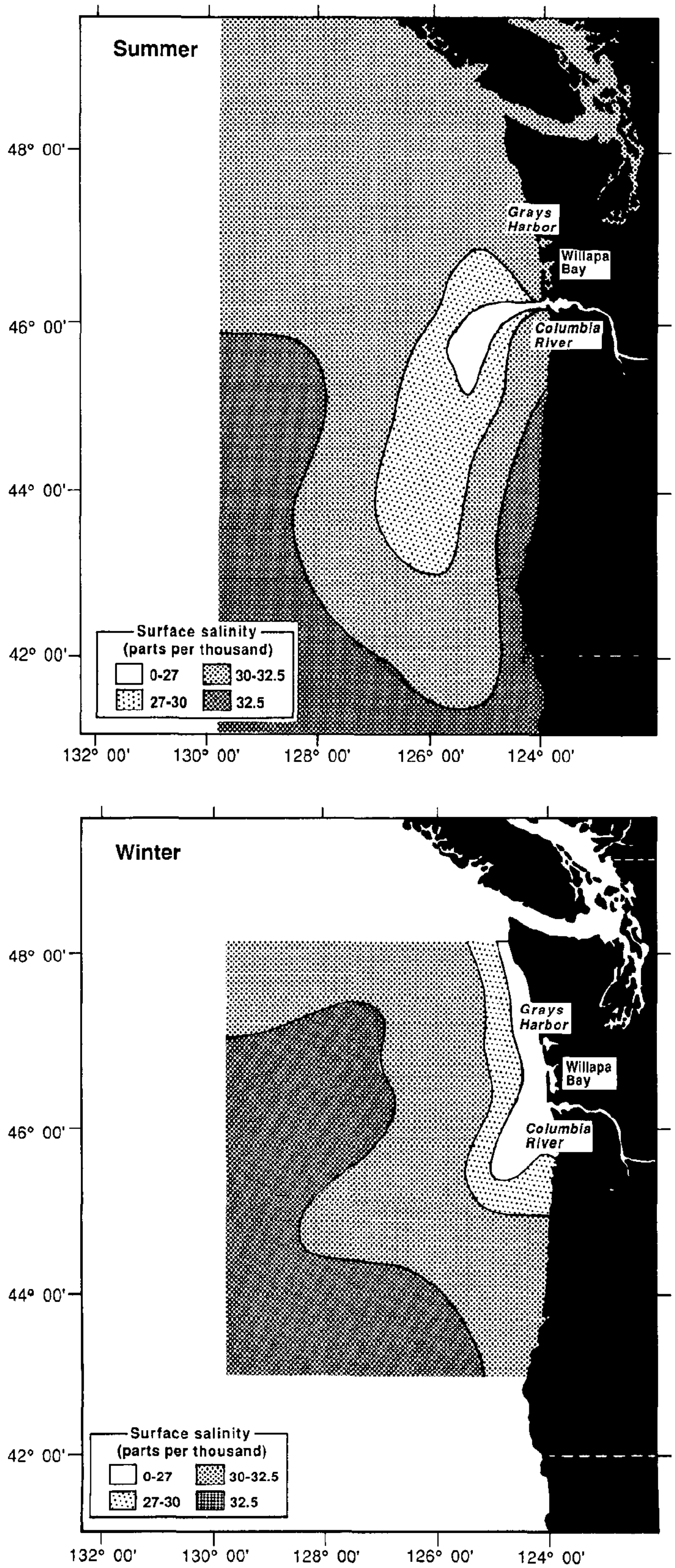


Figure 3.17 Generalized position and extent of Columbia River freshwater plume in winter and summer (modified from Barnes et al. 1972).

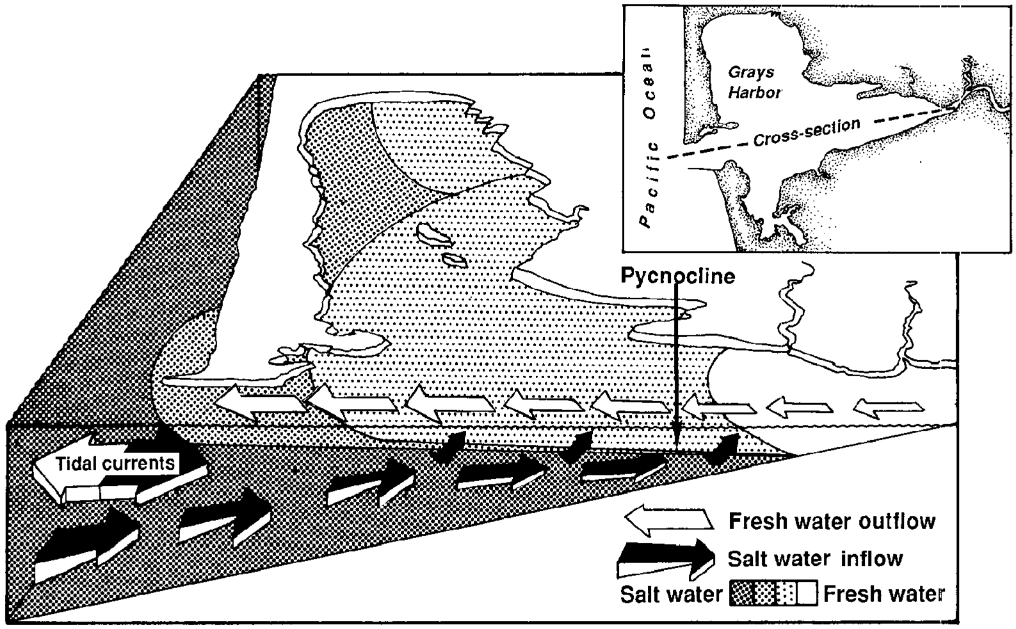


Figure 3.18 Simplified schematic diagram of water circulation pattern in estuaries, using Grays Harbor, Washington, as an example. Tidal currents dominate the water exchange between the estuary and shelf waters; superimposed on these currents is a small net outflow of fresher, less-dense water (driven by river input) at the surface and inflow of more saline, denser offshore water along the bottom. The pycnocline is a narrow boundary zone between these two layers.

This pattern is important because it provides a pathway by which contaminants that might be generated by offshore activities can enter estuaries despite their predominant outward direction of water flow. In the Columbia, salt water penetrates along the bottom up to 23 miles upstream under low runoff conditions;[121] in Grays Harbor the salt wedge resides at the head of the estuary between Hoquiam and Cosmopolis.[6]

The rate at which water turns over within an estuary as a result of fresh and salt water exchange is called the flushing rate. The flushing rate affects both how quickly tides and net circulation could transport contaminated seawater into the estuary, and how quickly tides and river runoff would cleanse it after a contamination incident. Runoff alone is ineffective at flushing Willapa Bay (only 0.4 percent flushing per day) compared with the tides, which exchange roughly 45 percent of the bay volume per tidal cycle.[127] However, much of this water is refluxed in and out of the estuary over several tidal cycles, so the actual rate of water replacement, especially at the head of the bay, much be must less than this. Complete flushing has been estimated to require at least 20 days under some conditions. Tidal and freshwater flushing combined are stronger in Grays Harbor, but good estimates of flushing rates for the estuary as a whole are not available.

INTERACTIONS OF MARINE METEOROLOGY AND PHYSICAL OCEANOGRAPHY WITH OFFSHORE OIL AND GAS DEVELOPMENT

Washington is noted for harsh offshore weather and wave conditions, and for the number of ships that have been wrecked along its shores. However, given the state of oil industry technology, these conditions are not likely to be the primary cause of a spill, whether it be from a platform blowout, a tanker or barge accident, or a pipeline break; rather, they would aggravate the consequences of an accident that occurred for other reasons. Accidents are more likely to arise from operator error or mechanical failure, with weather conditions (such as fog or rough seas) as a contributing factor. Perhaps the highest risks would accompany docking of tankers or barges at single point moorings, which may not be feasible at all times of year along the Washington coast.[126] In such cases, furthermore, winter storms or other inclement conditions could make spill containment and cleanup difficult or impossible.

Meteorology

Insufficient data have been assembled for this report to evaluate air-quality impacts of offshore oil and gas development. In general these impacts would appear to be low because of the small expected scale of development, the scarcity of other major sources of air pollution on the Washington coast, and the general strong wind mixing from relatively pristine Pacific Ocean air. Thermal inversions that lead to degraded air quality are infrequent along the Washington coast compared with locations such as southern California. The largest potential impacts anticipated in the MMS environmental impact analysis [113] would arise from increased tanker operations in Puget Sound, where air quality is lower, or from onshore facilities.

A formal analysis of effects of emissions from the platform, from vessel and aircraft traffic associated with it, and from onshore facilities on the atmospheric receiving environment will be required to address this issue more conclusively for the Washington coast region. One element that would come into play in such an analysis is the proximity of Olympic National Park, a Class I air quality zone where deterioration of visibility is prohibited. Some insight on the coastal air quality situation might be gained by adapting the air quality analysis conducted for the proposed Northern Tier Pipeline terminal at Port Angeles.

Oil spills would inject volatile hydrocarbons into the atmosphere. Under strong winds these vapors would disperse.[126] Under stagnant inversion conditions, a large spill close to shore near populated areas could adversely affect air quality. Oil spills that caught fire would cause additional problems with soot and smoke. Under some conditions these pollutants could affect air quality over populated areas of the Puget Sound basin for a prolonged period—as, for example, when smoke from a slash burn hung over the Sound area for several days in early October, 1988.

Physical Oceanography

Physical oceanography is of primary interest to oil development because it governs the dispersal and transport of spilled oil and of other materials lost or disposed of from a ship or platform. The rates at which materials are dispersed outward and downward in the water column depend on the extent of turbulent mixing and the density of the spilled material. These materials are also carried by currents as they float or sink.

The dissolution and dispersal of contaminants introduced into the sea surface are important in dissipating the toxic components of oil spills, and of muds, cuttings, and incidental releases of other contaminants from ships and platforms. Strong mixing is a positive factor in diluting these potentially harmful substances (although the wave action and currents that may accompany strong mixing hinder efforts to collect and clean up oil spills before they can be dispersed). Washington coastal waters are generally strongly mixed, especially in winter. The exceptions to this generalization are found during long periods of fair weather in the summer, in the southern nearshore areas affected by the Columbia River plume in winter, and especially in the Grays Harbor and Willapa Bay estuaries.

Because crude oil may contain several different chemical fractions, each having a different fate in the water column, the transport of these fractions of spilled oil will be affected by current conditions at different depths. In general, the oil remaining in the ocean would separate into three fractions: a floating fraction, a dissolved fraction, and a sinking fraction. After some period of time these fractions would separate and travel in different directions.

Dissolved oil would tend to be transported according to known mean surface layer current patterns: northward and onshore under mean winter conditions, and southward and offshore under mean summer conditions. These mean trends are illustrated by the generalized seasonal positions of the Columbia River plume (Figure 3.17). The trajectories of components of spilled oil that sank, or of negatively buoyant muds and cuttings, would be governed by subsurface or bottom currents. Over the shelf this transport would tend to be northwestward, following the trend illustrated by the distribution of Columbia River sediments (Figure 3.5).

The most critical aspect of physical oceanography for consideration of oil and gas development on the Washington continental shelf is the understanding of possible oil slick trajectories. In particular, the question is under what circumstances oil would be transported toward shore, where it would be most damaging. In the absence of rigorous modeling scenarios, the answer appears to be: under most circumstances. The exact path of a slick would be determined by the numerous additional factors such as tidal currents, planetary waves, and eddies, but its predominant direction would be dictated by local winds and surface currents.

The transport of floating oil would be closely linked to the wind, traveling at about three to four percent of wind speed and, in theory, at some angle to the right of the wind direction.[118] However, this transport can also be affected by waves, which tend to travel more shoreward on the Washington coast (Figure 3.11). Thus, in general, floating oil would have a significant probability of being transported toward shore at all times of year, with a higher probability of shoreward transport in winter than in summer.

If oil is spilled, it will not be transported according to mean conditions, but according to actual conditions. In summer especially, actual conditions frequently are the opposite of mean conditions. Thus, it is not possible to predict where a spill will travel on a given date; it is only possible to predict where it will travel under a given set of conditions, and to estimate probabilites for that set of conditions occurring on a given day.

The shoreline area where spilled oil would make landfall would of course depend on the site of the spill as well as the immediate conditions. The predominant shoreward winds are accompanied by a mean northward component in winter and a southward component in summer. Thus, coastal areas north of any potential spill site would appear to be more susceptible to receiving spilled oil, because of the predominant annual mean northeastward winds. However, at all times of year there is also a significant probability of southward transport, and even offshore transport, of spilled oil. The exact point of landfall would be influenced by contemporaneous conditions of local winds and nearshore current patterns.

Several additional factors influence spill trajectories besides winds and currents. Tidal currents are predictable and could be entered directly into a model of the possible trajectory of a spill at a given time and location. The Columbia River plume is persistent and reasonably predictable in size, orientation, and influence on circulation patterns. Planetary waves are highly random, however, and fronts, meanders, and eddies have some elements of both predictability—for example, meanders and eddies generated by submarine canyons—and unpredictability. Sample data on the speed and direction of water motions associated with meanders and eddies could be entered into a spill trajectory model to illustrate their possible effects if those factors happened to be present at the time and place of a spill in question. However, few data on these processes are now available.

An important question is whether, under what circumstances, and how much spilled oil might enter the major estuaries. There is no clear answer to this question, except that if oil were transported to the estuary mouth, where there is extensive vertical mixing, some undoubtedly would reach the inner waters. Heavier oil components lying near the bottom might be more likely to enter than the lighter surface components, because of the estuarine circulation pattern (Figure 3.18). However, since large tidal volumes enter and exit these estuaries, flood tides could carry a large volume of oil-contaminated coastal water into the estuaries. Further studies, especially including detailed studies of the circulation at the estuary mouths, would be needed to resolve this question. Knowledge of internal circulation and flushing rates also is inadequate to project the fate of oil entering the estuaries. The fine sediments and the extensive intertidal habitat in Grays Harbor and Willapa Bay make these estuaries highly susceptible to contamination. Trapping of oil in the sediments, together with low flushing rates, would permit only very slow cleansing of the estuaries if oiled.

A final question is the possible trapping or accumulation of spilled surface oil in eddies or along fronts. Such accumulation could be significant because these areas are thought to be sites of high biological productivity where large numbers of organisms aggregate and could be susceptible to contamination.

Recent symposia have been conducted to evaluate the state of knowledge of meteorology and physical oceanography along the Washington/Oregon coast.[14,149] These symposia produced detailed lists of data gaps and research needs. There is a general lack of meteorological data collected along and off the coast at a level of detail that could be used for predicting oil spill trajectories. There are also few data on ambient air quality conditions along the coast, or on the meteorological processes that govern them, for projecting potential air quality impacts of offshore production and onshore processing facilities.

Among the most critical of the physical oceanographic data needs identified were general information on interannual variability and transport in the cross-shelf direction, and specific current data in the upper 20 meters of the water column and shoreward of the 50 m isobath, particularly near estuary mouths. These are the most critical areas for determining where spilled oil will travel and whether it will strike land or enter estuaries. Also of interest is the documentation of the existence and locations of potential offshore fronts where both organisms and spilled oil may concentrate. Because of variability, it may be necessary to conduct research over several years, incorporating data rich in spatial and temporal variability on many scales, before data are adequate to construct a realistic model of possible oil spill trajectories.

Some of these information needs have been addressed by the Minerals Management Service Offshore Environmental Studies Program.[115] One of the above studies [149] was an MMS contract to survey existing knowledge of physical oceanography off Washington/Oregon, which produced an inventory of existing data that can now be analyzed numerically. A meteorological data buoy has been deployed off Cape Elizabeth by the National Data Buoy Center with MMS support since June, 1987. A baseline air quality monitoring study for the Washington/Oregon coast and studies of nearshore and estuarine currents are being considered by MMS for support in FY 1990.

BIOLOGICAL ENVIRONMENT OF THE WASHINGTON COAST

All organisms depend on physical and biological aspects of their environment that can be affected by oil and gas development. Impacts from oil and gas development can affect these organisms indirectly, through alterations in environment, as well as directly. Part of that habitat includes other organisms that have no major economic or political value of their own (are not directly used as a human resource) but are important as parts of the ecological whole that supports the valued species. In this section we examine some of these species and how they might be affected by oil and gas activities. Additional discussions of the species and ecology of the Washington coast and shelf are available elsewhere.[28,47,87] The resources of the Columbia River estuary, which is not considered in detail in this report, have been reviewed elsewhere.[51]

TYPES OF ENVIRONMENTS

Several types of environments are found along the coastal strip of Washington, each with different physical and biological properties that affect both the communities of organisms that reside there and the ways that those communities might be affected by oil and gas development. These environments are classified by their depth, their proximity to the bottom, the nature of the material making up the bottom, and the biota. The major environmental zones on the Washington coast are depicted schematically in Figures 3.12 and 3.19.

For discussion purposes Washington coastal waters can be divided into the nearshore zone (0-20 m depth), the inner shelf (20-100 m), the outer shelf (100-200 m), the shelf edge (200-1000 m), the continental slope (1,000-2,000 m), and oceanic waters (>2,000 m) (Figure 3.12). The open water environment away from the bottom and the shoreline is called the *pelagic* zone, inhabited by free-floating plants (*phytoplankton*) and animals (*zooplankton*) and by larger swimming animals (*nekton*). The uppermost few millimeters of water, affected by surface tension, is called the surface *microlayer*. It is a unique habitat occupied by a specialized community of plankton called the *neuston*, which includes eggs and larvae of some commercial fish species such as sole. On the bottom is the *benthic* region, divided into the *intertidal* zone subject to alternating exposure and inundation by the tides, and the *subtidal* zone never exposed by the tides. The *supratidal* zone is just above the high tide line and is affected by water conditions such as surf spray.

Benthic environments are classified by the type of material, or *substrate*, on the bottom. Both intertidal and subtidal areas may be rocky, gravely, sandy, muddy, or a mixture of more than one substrate. This division of environments is somewhat arbitrary, since all types (or mixtures of them) may occur in close proximity, but these ideal types serve for illustration. Rock-, gravel-, and sand-bottom areas are high-energy environments characterized by strong wave and current activity that keeps finer substrate particles from sedimenting. Mud-bottom environments (deeper bottom and more sheltered nearshore and estuarine areas) are areas of weaker water motions. The types and adaptations of organisms that live in these various habitats, and impacts of oil development, are dictated by the nature of the substrate and the related water motions.

These various environments are not independent of each other but are closely linked in several ways, so that impacts affecting one habitat directly are transmitted indirectly to the other habitats to varying degrees. The intermigration of animals between estuaries and open shelf waters during their life cycle is one example of ecological connections and interactions among habitats.

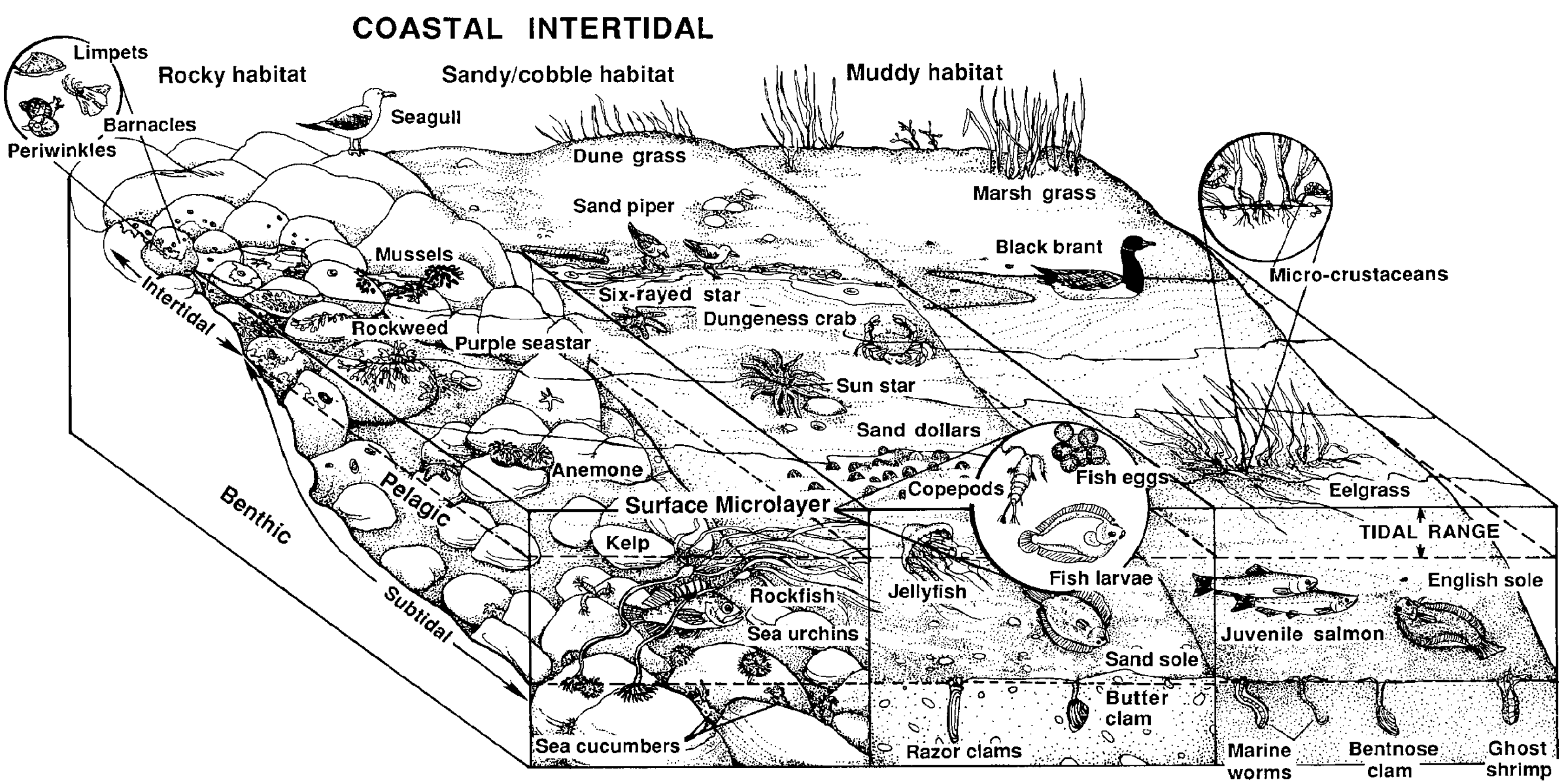


Figure 3.19 Schematic juxtaposition of the rocky, sandy, and muddy-bottom (estuarine) habitats and associated organisms in the pelagic, surface microlayer, benthic intertidal, and benthic subtidal zones in coastal Washington (after Carefoot 1977 and Kozloff 1983).

Pelagic and benthic environments are closely linked by transfers of matter, energy, and organisms. Plankton is a major direct food supply for many intertidal and subtidal organisms. Also, the waste and detritus that sink from pelagic organisms, along with material exported from shallow benthic habitats, are the major food sources for the deeper subtidal benthic habitat. In turn, larval stages of benthic or nektonic animals such as crabs, clams, and finfish (called *meroplankton*) are an important component of the plankton under some conditions. These sorts of relationships demonstrate that impacts to one type of habitat would be felt by the other habitats as well.

The Washington coastal zone north of Point Grenville are varying segments of rock, gravel, and sandy beach. The habitats in these areas have not been mapped in detail. The coast is primarily sandy south of Point Grenville. Also along the southern coast are the three major estuaries, as well as major stretches of coastal sand dunes. Estuaries are particularly rich environments because of the broad expanse of sheltered shallow water, and because of high productivity. Estuaries illustrate the fact that the physical environment has another important function in addition to supplying food. Many marine animals find essential shelter in various habitats. Several important fish and shellfish species use estuaries as nursery grounds during some portion of their life cycle. Estuaries are also important wintering grounds for some species of waterfowl. In addition, some smaller fish species and early life stages of larger fish species use kelp or eelgrass beds as shelter from predation by larger fishes.

PLANT RESOURCES

In general, continental shelves are the most productive areas of offshore waters, and the shelf off Washington is ranked high among shelf areas in the United States for its biological productivity. The upwelling circulation pattern enhances productivity of the shelf waters by bringing dissolved nutrients into the lighted surface layer to support plant production. The major plant resource for the food web of the shelf is *phytoplankton* (single-celled free-floating microscopic algae). In many shallow nearshore waters, the plant community is dominated by benthic algae, from microscopic algal coatings on rocks and in sediments to macroalgae. A third major plant resource is seagrasses, which form dense "beds" in some areas of estuaries.

Phytoplankton

Phytoplankton production on the Washington shelf has been recently reviewed.[4,37,65,134] Phytoplankton species fall into three general groups. The dominant organisms in terms of food production are believed to be *diatoms*, but other taxa such as *dinoflagellates* and assorted *microflagellates* are increasingly seen as having importance. Phytoplankton cells reproduce very rapidly, as often as once a day or more. One of the major driving forces for primary productivity in Washington shelf waters is coastal upwelling.[65] Productivity is highest in the spring and summer, less in the fall, and low in winter. Production is generally greatest on the inner shelf and decreases offshore. However, production is also believed to be lower in the core of the Columbia River plume due to high stability, turbidity, and lack of nutrients. In addition, production is highly "patchy" in space and time, driven by the variability in currents and upwelling that regulates the supply of nutrients and distribution of phytoplankton in the surface layer. On the outer shelf, especially later in the summer, phytoplankton production and biomass are maximal at the depth of the pycnocline (termed the *deep chlorophyll maximum*), well below the water surface, due to nutrient depletion in the upper layer.

A unique group of phytoplankton species inhabits the surf zone of temperate oceanic sandy beaches around the world.[96] In Washington the diatom species *Chaetoceros armatum* and *Asterionella socialis* dominate this assemblage, with *C. armatum* being the principal food of the razor clam. Productivity and biomass of this species are very high, and production is sustained through the winter. *C. armatum* has two unusual habits: it attaches clay particles in an adhesive outer coat, and it regulates its vertical distribution in the surf, floating at the surface in the daytime and sinking to the bottom at night.

The Washington shelf has been ranked in the highest productivity category of U.S. continental shelves (along with California, the Bering Sea and Gulf of Alaska, and mid- and North Atlantic) based on older data. MMS [114] places the Washington/Oregon planning area (including shelf, slope, and oceanic waters) in the productivity range of 200-500 grams carbon/m^2/year. These values now appear to be underestimates. Recent estimates of mean annual productivity are 646 grams carbon/m^2/year over the shelf, 294 over the slope, and 229 in oceanic waters,[134] compared with the earlier estimate of more than 300 grams carbon/m^2/year over the shelf and more than 125 in the Columbia plume and oceanic areas.[4] The higher productivity values in recent years are based in part on improved methodology which is applicable nationwide, however, so that Washington's ranking relative to other areas might not change. Primary productivity off Washington shows considerable spatial and temporal variation, which is not well studied.[134]

Benthic Algae

Nearshore plant assemblages on the outer coast are dominated by benthic microalgae and macroalgae. The microalgae are mostly *benthic diatoms*, which resemble planktonic species (also classed as microalgae) but form thin coatings on rocks and other surfaces (such as the brown scum that forms on aquarium glass) or occur freely among sediment grains. These species are food sources for many intertidal and subtidal animals. The macroalgae are seaweeds or kelps of varying size, from thin crusts on rock to giant kelp. Seaweeds have no roots like those of higher plants, and with few exceptions must attach to rock. Both types of plants are limited to shallow waters down to the depth to which light penetrates, i.e., down to depths of 50 meters, but mainly less than 10-20 meters.

Macroalgae are some of the most productive plants on earth. The intertidal assemblage on Tatoosh Island has been estimated to produce as much as 14.6 kg dry matter/m^2/yr, depending on species.[95] This figure is as much as ten times the estimated mean productivity of phytoplankton on the Washington shelf. The most productive values are limited to the rock areas with greatest wave exposure, but these still represent a significant contribution to overall local productivity. The Pacific Northwest coast supports the highest diversity of kelps in the world.[36] Productivity of subtidal kelp beds is difficult to measure but has been estimated (in southern California) at 350-1500 grams carbon/m^2/yr, with most values well under 1000.[36] These estimates equal or exceed the productivity of phytoplankton on the Washington shelf.

Macroalgae have important roles in addition to being direct food sources for animals. Familiar species such as *Ulva* (sea lettuce) and *Porphyra* (eaten as *nori* in Japan and elsewhere) are eaten by intertidal and subtidal animals, but many other species have defenses against animals and may be poorly digestible. Macroalgae, however, are a major source of *detritus* (dead material that accumulates on the bottom), which is broken down by bacteria to become a dominant food source for many benthic animals. Seaweeds also are a major agent of physical habitat structure and shelter for numerous animals such as fishes and crabs. Giant kelp habitats are essential to certain valued nearshore animals such as fishes and sea otters, as well as to other components of nearshore communities.[55]

Seaweeds have regular seasonal growth and reproductive patterns. Many species have complex life cycle patterns involving alternating sexual and asexual generations of very different size and configuration (e.g., kelp and nori, Figure 3.20). The life cycles and seasonal patterns of production and reproduction are well studied for only a few species.[185] Seaweeds generally grow most quickly in the spring and fall due to nutrient availability.

Seagrasses

Two types of higher (vascular) plants, which have roots and flowers, occur in the intertidal and shallow subtidal zone on the Washington coast.[136] Present in small populations on rocks in the intertidal areas along the outer coast are three species of surfgrass (*Phyllospadix*). More important ecologically are two species of eelgrass (*Zostera*), which are abundant in certain shallow intertidal and subtidal areas of estuaries, where water is sheltered from surf. Eelgrass grows on soft sandy/muddy bottom from roots, which draw nutrients from the sediment, and rhizomes, which can propagate vegetatively, the dominant reproductive mode in the subtidal zone. Usually perennial, it flowers in the spring and releases its seeds in the fall. Recruitment and recolonization, however, appear to occur before seed dispersal. The rhizome and root structure of eelgrass helps stabilize sediments and minimize erosion.

Approximately 15,500 acres (20 percent) of Willapa Bay and 11,000 acres (45 percent) of Grays Harbor intertidal and subtidal areas have eelgrass cover. Estimates of its productivity (leaves only) are in the range of 500 grams carbon/m^2/year,[136] comparable to that of phytoplankton on the open shelf. Eelgrass also supports a community of microalgae and small seaweeds living on its leaves and sharing the sediment, which increase the productivity of the community. These

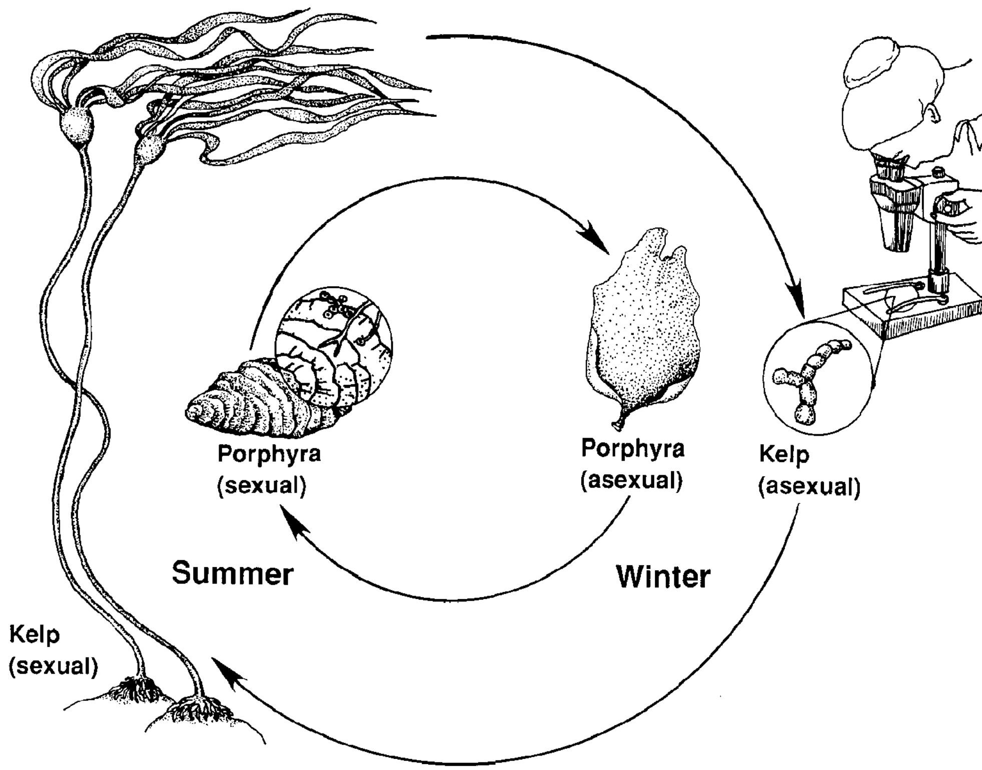


Figure 3.20 Schematic diagram of life cycles of kelp (*Nereocystis* sp.) and nori (*Porphyra* sp.). Both seaweeds undergo alternation of sexual and asexual generations; however, they differ in whether these life cycle stages are macroscopic- or microscopic-size, and in which seasons each stage grows. Kelp undergoes its large-scale sexual stage during summer, and its microscopic asexual stage in winter. The large asexual stage of nori grows in winter, and the microscopic sexual stage grows inside shells of oysters and other mollusks in summer. These differences illustrate how oil could have differing effects on various seaweed species, depending on the season of spillage (after Carefoot 1977 and Waaland 1977).

accompanying plants may equal or exceed the productivity of the eelgrass they depend on. In addition, dying eelgrass releases large quantities of dissolved nutrients that support growth of other plants and microorganisms. *Z. japonica*, a small species that grows in the high intertidal zone, is an important food for black brant geese, and other duck species also feed directly on eelgrass or associated vegetation. Like seaweeds, however, eelgrass is important less as a direct food source than as a source of detritus and as a habitat and shelter for invertebrate and vertebrate species.

There are few local studies of the relative importance of these different plant components to animal communities in various habitats on the Washington coast as a whole. The best-studied plant-animal food webs are those in estuaries.[51,149,150] Some relative differences are clear: eelgrass is important only in estuaries, and seaweeds are important on rocky shores and mudflats; thus, phytoplankton dominates by default on sandy shores, where wave action also prevents significant colonization of sand grains by benthic diatoms. Macroalgae and eelgrass beds are extremely productive under ideal conditions.[95,136] On a shelf-wide basis, nevertheless, phytoplankton is the dominant plant community because of the much larger area over which these organisms grow.

ANIMALS

The animal assemblages of the Washington coast and shelf vary with the type of physical environment. The major environmental division is between the pelagic and benthic realms. The types of animals that live in benthic environments are strongly influenced by the depth, the substrate (rock, sand, or mud), and the food sources (plants, animals, and detritus). It is important to understand the substrate and feeding relationships of animals, because they influence how animals are affected by oil and gas development.

Animals are divided into groups that consume predominantly plants (*herbivores*), other animals (*carnivores*), and detritus (*detritivores*), and those that have a varied diet (*omnivores*). They are also divided by mode of feeding into:

- *filter-feeders*, which sieve their food from large quantities of water;
- *scraper-grazers*, which skim the surface of rock;
- *deposit feeders*, which ingest sediment whole;
- *predators*, which attack or capture their prey individually; and
- *scavengers*, which forage for detritus.

Within the pelagic domain, animals are mobile: either floaters (zooplankton) or swimmers (nekton). They are exclusively filterers or predators, meaning they have adaptations either for straining food from large volumes of water or for capturing single prey, respectively. Pelagic food flows principally from phytoplankton to zooplankton to fishes, birds, and mammals. This food web supports many of the most important and familiar species in Washington coastal waters, including salmon and other pelagic fish, seabirds, seals, sea lions, porpoises, and many whales.

Zooplankton of the Washington coast and shelf may be divided into several groups. Numerically dominant are the microzooplankton, mostly single-celled microscopic animals whose life cycles and roles in the food web have not been well studied off Washington. Microzooplankton consume bacteria and small phytoplankton, and are prey for carnivorous zooplankton and juvenile and small adult fishes.

The dominant zooplankton group in terms of biomass and consumption of primary productivity is the filter-feeding crustaceans, including copepods and euphausiids (krill). These animals are present as eggs, larvae, juveniles, and adults in the plankton. It appears that very little of the primary production on the Washington shelf goes unconsumed by zooplankton, based on both the estimated feeding capacity of the zooplankton and the chemical composition of the sediments.[138] An area of consistently high copepod abundance appears to exist 10-30 km off the coast of Washington, possibly due to higher primary production in this region.[90] Many species in this group undergo daily and seasonal vertical migrations, spending daylight hours and the entire winter at depths below 100 meters. The species of copepods and krill present over the shelf vary with location and season, and are also affected by variations in currents, distribution of fronts, and position of the Columbia River plume. Copepods and krill are the predominant prey of adult pelagic fishes over the shelf. Recent research on continental shelves elsewhere [60,199] indicates that zooplankton can congregate in submarine canyons and around fronts, making these locales potentially more sensitive to impacts from oil.

All feeding types are found in the benthic domain, although herbivores are found only in shallow depths where plants can grow. The nature of the benthic food web is dictated primarily by the depth and the substrate.

Phytoplankton is a major food source in rocky, sandy, and muddy environments, and all these habitats have a significant presence of filter-feeding herbivore species. These species are attached to the outer rock surface in rocky habitats (e.g., mussels), and resting on or burrowed within the sediment in soft-bottom habitats (e.g., oysters, razor clams).

Benthic algae also are a major food source for herbivores in all three environments. In rocky habitats, scraper/grazers feed on benthic diatoms and small seaweeds attached to rock, and some larger omnivores such as sea urchins consume pieces of larger seaweeds. Detritus from macroalgae and seagrasses supports a detritivore community comprising such animals as crabs and sea urchins. In sandy and muddy habitats, diatoms in sediments are extracted by two classes of herbivores: small scraping/grazing animals living on or between sediment and detritus particles (mainly crustaceans and annelid worms); and larger deposit-feeding animals that ingest sediment whole either on or below the sediment surface (mainly lug worms and clams, with a few crustaceans). The same categories of herbivores and deposit feeders also consume detritus along with the associated microorganisms such as bacteria and protozoa. Eelgrass is a direct source of food for several species of waterfowl, notably black brant geese, as well as other goose and duck species. In addition, an assemblage of scraper/grazers (including some birds) feed on the diatoms and small seaweeds growing on eelgrass fronds. Lists of species associated with soft-bottom habitats have been compiled.[81,136]

The smaller herbivores and detritivores in these habitats are fed on by mainly vertebrate predators, especially fish and birds. These carnivores are themselves preyed on by larger fish, birds, and mammals. A major fraction or a majority of the food reaching these higher animals passes through the detrital pathway. Some notable invertebrate predators also are found in particular habitats; for example, starfish are major predators in rocky habitats.

POTENTIAL IMPACTS OF OFFSHORE OIL AND GAS ON THE BIOLOGICAL ENVIRONMENT

Pelagic Environment

The impacts of oil development are probably lowest in the pelagic habitat, where water motions are strongest and the potential for dispersal is greatest. Impacts are smallest for muds and cuttings, which sink to or are discharged near the bottom, and for produced water (especially if treated), which is rapidly dispersed in open waters along with contaminants it might contain. This dispersal and warmer surface water temperatures also facilitate biochemical breakdown of the oil. The positively buoyant fractions of spilled oil float at the surface to form a slick which directly impacts the surface microlayer and any organisms in it. The soluble components of oil dissolve in the surface layer at a rate and to a depth determined by wave action and the possible use of dispersants. Oil droplets are also emulsified into suspension in the surface layer. Through current action and turbulent dispersion these dissolved and suspended components decrease in concentration with distance from the source of oil until they drop below toxicity thresholds for organisms.

Filter-feeding zooplankton have been documented to consume suspended oil droplets in the vicinity of a spill and incorporate them into fecal pellets which sink rapidly to the bottom.[118] This process has been cited as a major pathway of removal of oil from the surface layer to the bottom. There also has been speculation that oil contamination could alter the species composition of the plankton in a way that would be less productive of pelagic fishes, but this research is not well substantiated.

Benthic Environments

The impacts of oil development on benthic habitats depend to a great extent on water motions and the associated bottom substrate.[119] In subtidal habitats there is a localized impact from deposition of muds and cuttings, both from burial and from contaminants in the deposits. These impacts extend only a small distance from the point of deposition and have been judged not to be of significant impact except in the immediate vicinity. On high-energy bottoms, these deposits are rapidly dispersed, whereas on low-energy bottoms they accumulate. However, impacts have been judged to be greatest on rocky bottoms because of the addition of foreign substrate material. The impacts of spilled oil will generally be least in the deep subtidal zone, originating from the negatively buoyant fraction of crude oil. These impacts will generally be more physical (e.g., suffocation) than biochemical, since heavy oil fractions generally are the least toxic, and will be difficult to observe. One documented phenomenon is asphalt "paving," in which heavy oil adheres to suspended sediment particles, which settle to the bottom and solidify to form a hard layer that cuts off the underlying sediment from water and forms a barrier to chemical and biological degradation.

Impacts of spilled oil on the intertidal and shallow subtidal zones are the most publicized and most significant of all oil spill effects. As above, the magnitude and duration of impacts per amount of oil depend on the energetics of water motion and the associated underlying substrate. Effects are of shortest duration in high-energy rocky environments, because oil penetrates the substrate to a minimal extent, so that water motions disperse and carry away the oil most rapidly. In contrast, oil tends to soak into and cling to sediments, depending on their size. The particles on sand and gravel beaches become coated with oil, but the shores generally experience strong wave action which resuspends the particles at least temporarily and can gradually wash them of their oil burden. This action also serves to aerate the sediment and promote biochemical breakdown of the oil. In some cases, an oil layer can become buried in a beach. This burial may effectively remove it from the habitat, or may simply sequester it until the next large storm releases it to recontaminate the beach. The shorelines most severely impacted by spilled oil are the muddy substrate found in estuaries. The fine sediments and the weak circulation and shelter from waves form a natural trap for spilled oil, and the low-oxygen (anoxic) conditions commonly found only a short depth in the sediment inhibit the biochemical breakdown of the oil.

The ecological connections between habitats make very likely the possibility that organisms in one habitat would suffer from impacts on others. For example, oiling of extensive areas of an estuary such as Grays Harbor at a sensitive time of year might heavily impact year-classes of several offshore benthic animals that depend on the estuary for breeding and juvenile rearing. Examples include Dungeness crab and English sole.

Phytoplankton

The physiological effects of petroleum on plankton have been reviewed elsewhere.[31,119,172] A muds and cuttings plume, if discharged at the surface, would have a localized effect on primary production by decreasing available light (muds) and possibly by introducing contaminants. Organisms contacted by spilled oil would experience lethal and sublethal effects, but phytoplankton at the fringes of a spill might experience some growth enhancement due to increases in nutrients. There is some evidence that oil can affect species composition of the phytoplankton assemblage, having a greater negative impact on the more productive and abundant diatoms. In areas where a deep chlorophyll maximum is present, water column production would be even less affected by surface spills. Spilled oil would not be expected to significantly affect total primary production on the open shelf as a whole due to rapid dispersal and high regenerative powers of phytoplankton. This conclusion is supported by studies of past spills.[172]

Oil would significantly affect plant production in localized nearshore areas in the vicinity of landfall of a spill. In general, reduced food supplies would be available to nearshore filter feeders as a result, but the significance of this impact may be less than the direct impacts of oil on the consumer species. The effects of oil on the surf diatom *C. armatum* have not been studied. If this species is affected as other diatom species are, and in view of the species' characteristic adherence of sediment particles, the localized impacts in the vicinity of oil landfall could be intense, and could prevent regrowth of the species so long as low concentrations of oil were present in nearshore waters due to sediment reservoirs. It is not clear what these levels might be relative to the levels at which razor clams would be physiologically affected or tainted for human consumption. It is possible that the overall production of *C. armatum* along the Washington coast as a whole would be significantly affected if a large area of the southern coast were oiled. Spills nevertheless would be unlikely to permanently prevent phytoplankton of any species from recolonizing nearshore waters once they were free of contamination.

Benthic Plants

Benthic diatoms would also be affected by landfall of an oil spill, and would be slower to recover because of their greater proximity to oil trapped in sediment. This greater impact would be most significant in muddy sediments where the most oil is trapped and where it remains the longest. The same impacts would affect seaweeds, which frequently are attached to small rock outcrops amidst softer sediments. There are few data on the effects of oil on seaweeds, especially on their reproductive cycles and alternate generations. Many macroalgae have a mucus layer that confers a natural resistance to oiling. Impacts on seaweeds could have significant additional effects on animals dependent on them for habitat and shelter, in addition to their importance to the food supply. Effects on different species of seaweeds could vary with the season, depending on the reproductive cycle of the species in question. The species most heavily impacted would be those in the intertidal and shallow subtidal zones, although giant kelps which have fronds floating at the surface would also be affected. Seaweeds are also affected by bottom disturbances such as excavation and burial, which interfere with the ability to attach to the substrate, and by water column turbidity, which obstructs light needed for photosynthesis. Such problems could arise locally from pipeline laying or construction of onshore facilities.

There are few data on biochemical impacts of oil on seaweed communities. As with other species, undoubtedly there are concentration thresholds delimiting sublethal and lethal effects. Presuming that intertidal seaweeds and some subtidal species such as giant kelp would be killed over an area that experienced landfall of a spill, the question becomes how the community recovers from the impact. This subject has received considerable study in the context of other disturbances such as storms, and while no general conclusion is apparent, two observations emerge.[36,95,131,132] First, disturbance is integral to outer coast environments, and many species' life strategies exploit disturbance. Therefore, disturbances must be quite severe to be detectable against the normal background level of perturbation and to be linked to long-term changes in the community. Second, the ecological outcome of disturbances is not easily predicted, and one disturbance may reverse the outcome of the previous. In general, rates of recovery from disturbances are rapid (one year), but some changes are stable. For example, if giant kelp is selectively depleted in a localized area by a disturbance, sea urchins may prevent its reestablishment in that area.

Eelgrass itself appears to be less sensitive to oil contamination than animals within the eelgrass community.[136] Oil spills temporarily damage *Phyllospadix* and *Zostera* leaves that are out of water, but do not appear to affect immersed leaves or rhizomes or roots. Few impacts on eelgrass were observed as result of the *Amoco Cadiz* spill in 1978. Oil spilled in the spring could disrupt flowering, and the dispersal and biodegradation of spilled oil would likely be retarded by its capture in mats of dead leaves, which are particularly abundant in fall. Impacts on eelgrass beds could have significant consequences for animal populations as well.

The most serious threats to eelgrass beds are dredging and other activities that disturb the sediment and increase water turbidity (such as shoreline and upstream construction and logging), and draining and filling of beds.[136] These threats would be posed by offshore oil development to the extent that increased ship traffic and onshore construction would cause such activities. In addition, after an oil spill in an estuary, cleanup activities may involve physical removal of both sediment and eelgrass. In such cases the magnitude of damage to the estuary from cleanup may be comparable to that from the oil.

Eelgrass beds in Willapa Bay are currently shrinking as a result of the spread of saltmarsh cordgrass (*Spartina alterniflora*) introduced in the 1940s and 1950s, causing a potential decrease in water bird habitat.[136] Black brant populations in Washington are also declining, having dropped 74 percent between the 1940s and 1981 as a result of habitat losses from human development. An example of the effects of a large-scale (90-100 percent) die-off of eelgrass occurred in the North Atlantic in 1931-33 for unknown reasons.[136] Scallop, fish, clam, and crab populations went into severe declines, and the brant geese population of Holland dropped from 10,000 to 100 by 1953. Erosion of sediments that followed the loss of eelgrass in some Danish lagoons caused irreversible changes in the bottom such that eelgrass could not be reestablished.

ANIMALS

The feeding types and habitats of marine animals have important effects on how those species are impacted by oil and gas development, and how they recover. Mobile vertebrate carnivores have some ability to avoid an oil spill, although the data are scarce for noncommercial species to indicate the degree of avoidance that actually takes place (clearly some birds do not avoid spills). Species at or closest to the surface and to the intertidal zone would be most susceptible to spilled oil. Scraper/grazers such as snails and limpets have been documented to play a major role in removing oil from rocks and creating a clean surface for colonization by plants and filter-feeders. The important role of detritus in food webs indicates a pathway by which oil impacts can be persistent. Especially in poorly flushed sheltered environments, oil is trapped in among fine-grained detrital particles and is dispersed and degraded very slowly. Thus, detritus can act as a reservoir for continued entry of spilled oil into the food web. In dense mats and in fine-grained sediments, oxygen can be excluded from detritus and associated oil, greatly retarding the rate of decomposition.

Eelgrass beds are a particularly vulnerable environment, and many animals that depend on them could be affected by an oil spill. The following have been suggested as the greatest potential impacts of oiling on an eelgrass bed:[136]

- contamination and tainting of food for water birds;
- narcotization and suffocation of bottomfish, and increased predation by crabs, which are highly resistant;
- tumors on the lower surfaces of flatfishes;
- loss of food supplies and increased predation on shoreline and open-water fishes forced to move out of the eelgrass beds;
- rapid and severe mortality of smaller crustaceans;

- paralysis and death of mollusks and annelid worms exposed to highly aromatic crudes and refined products.

The possibility is remote that a spill could be so extensive as to cause irreversible changes in the environment or seriously deplete the potential for recolonization of affected species to the coast. A similar community of species that would serve as a reservoir for recruitment occurs from northern California into British Columbia and southeastern Alaska. However, the distances over which recruitment takes place can be very small, so that recolonization might occur very slowly. Furthermore, even in the presence of potential recruits of all the impacted plant and animal species, the same community would not necessarily rebuild. The absence of certain species could affect the success of others at recolonizing. The classic example of this principle is the mutual benefit of the sea otter and kelp, each of which is more abundant in the presence of the other. The sea otter had to be reintroduced to Washington by human efforts after its local extinction, and might have to be again if a major oil spill struck its habitat.

MMS ENVIRONMENTAL SENSITIVITY RANKINGS

In preparing environmental impact assessments of OCS planning areas prior to lease sales, MMS is required to consider marine productivity and environmental sensitivity in determining the location and timing of oil and gas activities. As discussed above, the Washington/Oregon planning area ranks in the highest category of marine productivity, based on data that are probably underestimates. MMS also calculates composite indices of environmental sensitivity for planning areas based on the relative proportions of types of habitats and their sensitivities, and on the abundance and sensitivity of various types of organisms.[114] Washington/Oregon ranks ninth in sensitivity among 22 planning areas considered in the current Five-Year Plan, highest of any area outside of Alaska. (When subarea deferrals are considered, this area drops to tenth.)

A thorough analysis of these sensitivity rankings and the method used for preparing them is beyond the scope of this report, but several revealing facts are clear at first glance. The legal requirement to employ a logistically simple yet scientifically defensible sensitivity rating method is a challenging one. The rankings are intended as *relative* rather than absolute measures of sensitivity, to be used only for comparing planning areas. MMS [114] acknowledges shortcomings in and criticism of its method, and openly states that the minimum necessary information for calculating absolute sensitivity is not available.

MMS's ranking method reflects a blend of qualitative sensitivity judgments and quantitative abundance data that are all assigned quantitative values. The indices rate immediate damage to and long-term recovery times of environments and organisms contacted by spilled oil. The oil is assumed to be unweathered, and all potentially vulnerable organisms (e.g., migratory birds) are assumed to be present and impacted by a spill (that is, worst-case impacts are considered). Effects of muds and cuttings, produced waters, noise, habitat alteration, and air emissions are not considered. The calculations also do not include the probability of spills, nor the susceptibility of various regions and organisms resulting from potential spill locations or trajectories.

Given these constraints, the sensitivity rating applied to the Washington/Oregon planning area still has noticeable flaws. For example, the value used for length of estuarine and wetland shoreline is only 45 miles, or ten percent of the total Washington/Oregon coastal shoreline. This would appear to be a gross underestimate,[47] perhaps representing the widths of estuary mouths rather than their internal perimeters. Additional arguments can be made for extending the geographic scope of the analysis into the Strait of Juan de Fuca and Puget Sound.[47] Estuarine and wetland shorelines rate a fivefold higher sensitivity value than sandy beaches, so small changes in the calculated extent of this environmental type could have large effects on overall sensitivity rankings.

In addition, Washington/Oregon's adult fish and shellfish resources are rated as "low," as are, for example, those of central and northern California and the Chukchi and Beaufort Seas. (The north and south Atlantic, central Gulf of Mexico, Kodiak, Aleutian, St. George, and Navarin areas are among those rated "high.") These ratings may not reflect commercial fisheries; MMS[114] evaluates the economic value of commercial fish resources of various planning areas separately when considering social costs of oil development. Nevertheless, the ratings are open to question. Further study is required to determine the basis for these evaluations, whether similar questionable judgments were made in ranking of other planning areas, and whether these flaws would significantly affect this area's relative sensitivity ranking. These problems undermine confidence in the scientific validity of MMS's sensitivity evaluation method and suggest that both the results and the method itself require critical review.

MARINE BIRDS OF THE WASHINGTON COAST

The coastal marine habitats of Washington are occupied by a variety of birds, whose numbers and composition constantly change in annual cycles. Individuals of some species are present in Washington coastal waters only for a brief period of time to feed, as a stop on a larger migratory itinerary. Individuals of other species spend their entire lifetimes in local waters, breeding during the spring and summer months in isolated locations. Species vary in their preferences for marine habitats, some being very specific while others are found in a range of habitats. Some species that occur in Washington coastal marine habitats are classified as Endangered or Threatened, out of concern for their continued existence. Characteristics of there species are summarized in Table 3.2.

Table 3.2 Status of Threatened and Endangered Bird Species Occurring in Washington Coastal Marine Habitats
(Source: S. Speich)

Species	Status	Comments
Brown Pelican	Endangered	Late summer and fall migrant; a few hundred individuals present near shore and in bays, harbors, estuaries, and river mouths; dives or feeds from surface for fish.
Aleutian Canada Goose	Endangered	Small numbers present in Willapa Bay during migration; feeds in marshes and upland areas.
Bald Eagle	Threatened	Resident; small numbers nesting along coast, bays, and rivers; nests in trees; feeds on dead and live ducks, gulls, cormorants, alcids, etc.; often on beaches, tidal flats, marshes, islands, and rocks.
Peregrine Falcon	Endangered	Resident, with migrant influxes; feeds on storm-petrels, ducks, shorebirds, alcids, small land birds; often on beaches, tidal flats, marshes, islands and rocks; a few pairs nest on north coast.
Snowy Plover	Endangered	Summer resident; a few birds nest at Leadbetter Point, Willapa Bay, and at Damon Point, Grays Harbor; nests on ground, and forages in sandy beach areas.

The entire Washington coastline, with its associated estuaries and adjacent waters offshore, at various times of year provides critical habitat for an abundance of resident and migratory birds. Critical habitat is "usually limited in abundance and availability, without which some species cannot survive".[174] Critical habitat includes nesting, foraging, roosting, and wintering areas.[163]

Marine bird species may be divided into four groups, based loosely on their geographic distribution and feeding habits. The groups are:

- *seabirds*, such as gulls, which feed in open waters from the shoreline and estuaries to the open ocean;
- *shorebirds*, such as sandpipers, which feed mainly along the intertidal and nearshore marine environment;
- *water birds*, such as ducks and geese, found near shore on the open coast and in estuaries;
- *predators*, such as bald eagles, which breed and roost on land near water bodies and feed in and near the water.

Species characteristics of marine birds on Washington's outer coast are summarized by these categories in Table 3.3.

ABUNDANCE

The population numbers of marine birds usually vary between seasons. Although some species are only present in small numbers at any time, others may reach considerable numbers in season. A species' abundance is usually described as rare, uncommon, common, or abundant.[79,189] A species common in one season may be rare or absent in another. Species abundance also varies between habitats.

- *Rare*—occurs in small numbers and is seldom seen, even in preferred habitats. Examples from coastal Washington include yellow-billed loon, Laysan albatross, glaucous gull, and black tern.
- *Uncommon*—usually present in small numbers in preferred habitats, but not always seen. Examples include red-necked grebe, flesh-footed shearwater, black scoter, Sabine's gull, Arctic tern, and ancient murrelet.
- *Common*—usually present in preferred habitats, often in large numbers, and often seen. Examples include Western grebe, Northern fulmar, fork-tailed storm-petrel, scoters, and rhinoceros auklet.
- *Abundant*—almost always present in preferred habitats, often in large or very large numbers, and usually seen. Examples include sooty shearwater, surf and white-winged scoters, California gull, and common murre.

RESIDENCE STATUS

It is useful to consider the residency status of the marine birds that occur along the Washington coast. As with abundance, there is considerable variation in the status of birds between seasons.

- *Residents* are present throughout the year. Breeding residents nest in the coastal areas of Washington. Nonbreeding residents are represented by nonbreeding individuals during the spring and summer periods. The glaucous-winged gull is a resident species that nests in coastal Washington, and many individual birds live their entire life in the area. The surf scoter is a resident species that does not nest in the area, but nonbreeding young birds remain here during the spring and summer months, while adults go north to nest.[58]
- *Summer visitors* are present during the spring and/or summer and usually absent during the winter. Summer residents may or may not breed in the area. Summer resident species that nest in the area include Leach's storm-petrel, osprey, snowy plover, spotted sandpiper, and Caspian tern. Summer resident species that do not nest in the area include sooty shearwater and Heermann's gull.

• *Winter visitors* are present during the winter, and spring or fall, or both, and usually absent during the summer. Examples include the loons and grebes, swans, geese, brant, most ducks, scoters, most shorebirds, herring gull, Thayer's gull, and black-legged kittiwake. Many species that are classified as winter visitors could also be classified nonbreeding resident species, on the basis of small numbers of young nonbreeding individuals present during the summer period. Nonbreeding common loons, Pacific loons, Western grebes, surf scoters, white-winged scoters, and black scoters are present in Washington coastal waters during the summer.

• *Migrants* are generally only present during the spring or fall migration periods, or both. Examples include white-fronted geese, several shorebirds, phalaropes, pomarine and parasitic jaegers, California gulls, Sabine's gulls, and Arctic terns. Individual brown pelicans disperse up the Pacific coast from breeding colonies in Baja California, Mexico, and southern California, in late summer and fall, but by the end of the year nearly all birds have departed coastal Washington for southern waters. Heermann's gulls have an identical pattern, but it occurs earlier, in the summer and early fall periods.

HABITAT PREFERENCES

Perhaps the best way to look at the marine birds of coastal Washington is by their preferences and occurrence in marine habitats. Marine habitats are important to birds in several ways. Breeding marine birds are dependent on particular combinations of nesting, foraging, and roosting habitats for successful reproduction. Roosting sites are used for resting and preening, and especially for safety and shelter during winter storms and periods of high stress and energy consumption.

Feeding seabirds often concentrate in the area of fronts, especially on the inner shelf and shelf edge.[188] Near shore, the mouths of the Grays Harbor, Willapa Bay, and Columbia River estuaries are feeding habitats for a number of species that occur in nearshore waters and farther offshore, such as shearwaters. The locations of such fronts are not well described, and it is not clear whether any fronts are persistent in distinct areas. Fronts are consistently noted at the entrance to the Strait of Juan de Fuca. Fronts between the Columbia River plume and surrounding shelf waters would be expected to occur persistently along the south coast. Commercial fishing and the offal it produces are also important factors in concentrating birds from the outer shelf to the continental slope.

There are only a few studies of Washington coastal marine habitats and the occurrence of marine birds. Those by T.R. Wahl[188] are by far the most comprehensive, covering the nearshore and offshore waters of the southern coast in particular. Other reports cover oceanic waters;[147] the nearshore waters from Point Grenville to Destruction Island;[160] the species, numbers, and locations of marine bird breeding colonies on the coast of Washington;[163] the occurrence and abundance of shorebirds in coastal estuaries;[64,196] and the lower Columbia River.[63] The following discussion is compiled from these sources.

Generally Offshore Species

Five species of shearwaters are found in Washington offshore waters during late spring, summer, and fall months. The sooty shearwater is by far the most numerous and outnumbers all other species present when at peak numbers. Huge feeding flocks estimated to approach one million birds are observed at the entrance to the Strait of Juan de Fuca. Although shearwaters are found in oceanic waters, highest densities off Washington are found over the continental shelf and slope.

Both Leach's storm-petrels and fork-tailed storm-petrels breed in colonies on nearshore islands along the Washington coast and forage in offshore waters. Leach's storm-petrels are found farther offshore, while fork-tailed storm-petrels occur closer to shore in shelf waters. Storm-petrels are generally absent during the winter. Storm-petrels feed on small food items found at or just below the ocean surface. They also ingest small particles of oil.[15]

Two species of phalaropes migrate through the offshore waters of Washington. Red phalaropes are more abundant than red-necked phalaropes and occur closer to shore. Phalaropes feed on plankton near the surface and often flock along fronts where food is concentrated.

Table 3.3 Dominant Marine Birds of the Washington Coast

Species	Distribution	Seasonal Presence	Reproduction	Diet	Comments
Seabirds					
Order Procellariiformes					
Family Procellariidae (Fulmars and Shearwaters)					
Northern fulmar (*Fulmaris glacialis*)[7]	Outer shelf	Abundant Sept.-April, few in summer	Arctic	Surface feeders on jellyfish, other zooplankton, squid, detritus	Most abundant procellariids in winter
Sooty, pink-footed, flesh-footed, Buller's, short-tailed shearwaters (*Puffinus spp.*)[7,17,21]	Large flocks on outer shelf (esp. spring) to estuaries & Juan de Fuca Strait (esp. fall)	Visitors Apr.-Nov; also northward migrants May-June	Southern hemisphere Dec.-Mar.	Surface small fishes, e.g. anchovies; squid	"Sooties" most abundant (up to 75%) seabirds off Washington in summer
Family Hydrobatidae (Storm Petrels)					
Leach's, fork-tailed storm petrels (*Oceanodroma leucorhoa, O. furcata*)[1, 21]	Forages on outer shelf and oceanic waters	Absent in winter	Colonial nests in rocky crevices and burrows on islands	Surface zooplankton and detritus, small fish, squid, krill	Mate and feed chicks at night; in burrow or offshore during day
Order Charadriiformes					
Family Laridae (Gulls and Terns)					
Western (*Larus glaucescens*), glaucous-winged gulls (*L. occidentalis*)[1,17,20, 21]	Ubiquitous nearshore to offshore	Year-round resident; some winter visitors	Nest in colonies along coast, on islands, in estuaries	Fishes, krill, other zooplankton, detritus; eggs of alcids & other gulls	Interbreed: often counted together on south coast
California gull (*L. californicus*)[1,17,20, 21]	Nearshore to offshore	Moves to coast from inland waters in fall and south in winter	Varied nest sites on islands, piers, buildings, beaches, rocks, or inland	Omnivorous on fish, detritus, garbage, intertidal animals; alcid, gull, & oystercatcher eggs	Most abundant, widespread & adaptable gulls, populations increasing

Black-legged kittiwake (*Rissa tridactyla*)[7,17,21,22]	Shelf and offshore	Winter visitors	Arctic	Surface krill, other zooplankton, small fishes	Congregate near offshore fronts
Caspian tern (*Sterna caspia*)[1,9,13]	Estuaries and nearshore waters; Tunnel Island is northern limit of range	Depart in winter	Nest in colonies on low bare sand & gravel islands in estuaries	Nearshore fishes, e.g. perch, salmon, sculpin, anchovies	Washington nesting population is largest on west coast north of Mexico
Common (*S. hirundo*), Arctic (*S. paradisaea*) terns[7,20]	Common: nearshore and in estuaries Arctic: on outer shelf & slope	Common: winter visitor Arctic: migrant in May (northward) and Jul-Oct (southward)	Arctic nests in arctic in summer	Plunge-dive for small fish	Vulnerable to water turbidity that would hide prey
Family Stercorariidae (Jaegers)					
Pomarine, parasitic jaegers (*Stercorarius spp.*)[7,20]	Pomarine offshore, parasitic nearshore	Migrants in fall (southward to S. America) & spring (northward)	Arctic	Parasitize other seabirds, esp. gulls & terns	More common in fall than spring; can occur in large aggregations
Family Alcidae (Murres, Murrelets, Auklets, Puffins, Guillemots)					
Common murre (*Uria aalge*)[1,22]	Widespread over inner shelf	Year-round residents: winter distribution uncertain, joined by visitors from south in summer	Colonial nests on flat cliff and island tops	Deep divers for fish, crustaceans, squid	Shift some breeding colony and resting sites year-to-year; very vulnerable to disturbance & predation while nesting
Marbled murrelet (*Brachyramphus marmoratus*)[1,17]	Within 2-3 km of shore in pairs and flocks, near north coast, Grays Harbor, Willapa Bay	Year-round resident	Nests in old-growth forests	Dive for fish & crustaceans	Mostly in inland waters; little knowledge of numbers or breeding habits; may be undercounted
Ancient murrelet (*Synthliboramphus spp.*)[3,6,21]	Outer shelf north of Grays Harbor	Year-round residents and winter visitors	Nests in burrows, crevices, under rocks & logs on islands	Dive for small fish & zooplankton near tidal fronts & strong currents	1 nest site observed in Washington in 1924

Species	Distribution	Seasonal Presence	Reproduction	Diet	Comments
Cassin's auklet (*Ptychoramphus aleuticus*)[1]	Flocks over outer shelf and slope	Year-round resident	Nests in burrows in soil, crevices, other holes, under trees & bushes on islands	Dive for small fish & zooplankton	One of most abundant breeding seabirds; most abundant alcid
Rhinoceros auklet (*Cerorhinca monocerata*)[1,2,18,21]	Offshore, over reefs, estuaries, channels	Mainly summer resident; most believed to migrate to California in winter	Digs burrows on islands	Opportunistic divers for most abundant small fishes, e.g. anchovy, sand lance	Relatively rare; Destruction Island is southernmost large colony in North America & one of 10 largest in world
Tufted puffin (*Lunda cirrhata*)[1,2,21]	Offshore, and near large channels, fronts, and tidal rips	Breed Apr-Sept; depart in winter	Burrows on steep grassy slopes or cliff edges	Dive for small fish, squid, crustaceans	Eggs less vulnerable to gull predation; local populations decreasing
Pigeon guillemot (*Cephus columba*)[1,2,20,21]	Shallow rocky shoreline	Year-round resident; close to nests in summer, winter distribution uncertain	Solitary or small colonial nests in rock crevices, under boulders, in bluffs	Dive for small bottomfishes	Most widespread nesting seabird in Washington, but low numbers
Family Phalaropodidae (Phalaropes)					
Red-necked, red phalaropes (*Phalaropus spp.*)[7,17,20]	Feed offshore; migrate nearshore	Visitors Apr-Nov.; also northward migrants May	Arctic	Surface zooplankton	Widespread in oceanic North & South Pacific in winter
Order Pelecaniformes					
Family Pelecanidae (Pelicans)					
Brown pelican (*Pelecanus occidentalis*)[6, 9]	Roosts on rocks, islands, jetties; feeds in nearshore waters, estuarine channels	Late May-Nov., peaks in September	Breeds in S. California & Mexico	Small fishes	Federal endangered species, but recovering, may be reduced to threatened status

Family Phalacrocoracidae (Cormorants)					
Brandt's (*Phalacrcorax penicillatus*) double-crested (*P. auritus*), pelagic (*P. pelagicus*) cormorants[1,21]	Near shore, bays, estuaries, rivers, lakes, in channels	Year-round resident; some winter visitors and residents	Colonial nests on islands, on mainland cliffs and bluffs, sand islands, jetties, pilings, navigation aids	Dives 70-140m for fish, shrimp; often feeds in large flocks in channels with strong currents	Conspicuous but not numerous; must dry wings after diving
Order Gaviiformes					
Family Gaviidae (Loons)					
Pacific (arctic), red-throated, common loons (*Gavia spp.*)[6,7,8,21]	Pacific: offshore; red-throated & common: near shore & estuaries	Winter visitors and fall & spring (Apr-Jun) migrants	Breed in Canada, Alaska, Arctic	Dives for small fishes and crustaceans	Little known about fall migration
Family Podicipedidae (Grebes)					
Western grebe (*Aechmophorus occidentalis*)[3,6,20]	Near shore outside surf line in protected waters	Highest populations in fall, low in summer	Nest on inland lakes during summer	Zooplankton, small fish	
Shorebirds: Shallow-Probers and Surface-Searchers					
Order Charadriiformes					
Family Haematopodidae (Oystercatchers)					
Black oystercatcher (*Haematopus bachmani*)[1,2]	Near shore on outer coast	Year-round resident; migration unknown	Solitary nests on offshore rocks & islands, headlands	Mussels, limpets, chitons, barnacles	Eggs vulnerable to storms, predation by crows & gulls
Family Charadriidae (Plovers)					
Western snowy plover (*Charadrius alexandrinus nivosus*)[9,12]	Nearshore waters, Baja-Washington; also alkaline/saline inland lakes	Year-round resident; may migrate north or south in winter, or inland in spring and summer	Nest on sand flats in estuaries March-Sept. (peak June-July)	Invertebrates and small fishes	State endangered, federal sensitive species; nests very sensitive to disturbance; population in decline
Semipalmated (*C. semipalmatus*), black-bellied (*Pluvialis squatarola*) plover [20]	?	Residents & summer visitors	?	Feed on invertebrates in tideflats	?

Species	Distribution	Seasonal Presence	Reproduction	Diet	Comments
Family Scolopacidae (Dowitchers, Sandpipers, Dunlins, Sanderlings)					
Short-billed, long-billed dowitchers (*Limnodromus spp.*)[3, 20]	Beaches and estuarine tide flats	Migrants present during summer (Mar-Nov)	?	Feed on invertebrates in tideflats	-
Sanderling, dunlin, western sandpiper (*Calidris spp.*)[17,3,20]	Beaches and estuarine tide flats	Migrants present during spring & fall migrations and winter	?	Molluscs, crustaceans, algae, eelgrass	Bowerman Basin a crucial feeding area during spring migration
Shorebirds: Waders					
Greater yellowlegs (*Tringa melanoleuca*)[3, 20]	Beaches and estuarine tide flats	Migrants present during summer (Apr-Nov)		Feed on invertebrates in tideflats	-
Family Ardeidae (Herons)					
Great blue heron (*Ardea herodias*)[3, 9,13,14]	Beaches and estuarine tide flats	Resident	Breed late February-April, wetlands & upland areas	Feed on small fishes & invertebrates in tideflats	-
Water Birds					
Family Anatidae (Geese, Swans, and Ducks)					
Black brant (*Branta bernicla*)[9,14,16,17]	Willapa Bay is one of several migration stops in Washington	Visitors Oct-May	Nest in Arctic in summer	Eelgrass	Washington population is lower than historical levels
Canada goose (*B. canadensis*)[9,14,16, 20]	Entire west coast	Year-round residents and winter visitors	Nest in spring in Alaska & Canada, also in Columbia R. (Aleutian, dusky, cackling races nest only in Alaska)	Eelgress; terrestrial grasses during day	Some sensitive & endangered races (Aleutian, dusky, cackling), others healthy & increasing
Trumpeter (*Cygnus buccinator*) and tundra swans[15,20]	?	Visitors Nov.-Feb.	Nest in Alaska in summer	?	Declining use of Willapa/Columbia

Sea ducks: scoters (*Melanitta spp.*), mergansers (*Mergus spp.*), oldsquaw (*Clangula hyemalis*), goldeneyes (*Bucephala spp.*), scaups (*Aythya spp.*)[3,6,7,17,20]	Near shore outside surf line, in estuaries	Residents (scoters, mergansers) most abundant late summer - fall; also winter visitors, and migrants north Mar-Apr	Breed mostly in Canada & Alaska	Molluscs, crustaceans, zooplankton, small fish, algae, eelgrass	Scoters most numerous; large numbers of flightless scoters present off coast in late summer
Ducks: mallard, pintail (*Anas spp.*)[20]	Estuaries, rivers, ponds	Year-round residents	Nest near coast	Terrestrial & aquatic vegetation	Estuaries are a major stop on fall migration
Ducks: wigeon, gadwall, teals (*Anas spp.*)[2,20]	Estuaries, rivers, ponds	Year-round residents and winter visitors	Nest near coast	Mollusks, crustaceans	Estuaries are a major stop on fall migration
Predators and Aerial Searchers					
Order Falconiformes *Family Accipitridae (Eagles and Ospreys)*					
Bald eagle (*Haliaetus leucocephalus*)[6]	Shoreline	At nesting sites fall through mid-summer; may be absent in late summer	Tops of large snags on islands & mainland	Nesting gulls, murres, puffins, cormorants, ducks, geese; fishes; bird eggs	Federal and state threatened species
Family Falconidae (Falcons)					
Peregrine falcon (*Falco peregrinus*)[6,9,10,11]	Shoreline	Migratory visits spring & fall; some wintering birds.	Nests on islands & cliffs	Shorebirds, storm petrels, alcids	Federal and state endangered species
Order Passeriformes *Family Corvidae (Crows)*					
Crows and ravens (*Corvus spp.*)[8,21]	Near shore	Year-round resident	Nests along coastline	Carrion, eggs & young of sea birds	Populations increasing

[1]Speich and Wahl 1986, [2]USFWS 1985, [3]Simenstad and Armstrong (in press), [4]USFWS 1988b, [5]Atkinson 1988, [6]Speich et al. 1987, [7]Wahl 1984, [8]Yates 1988, [9]Atkinson 1988, personal communication, [10]K. McAllister, WDW, personal communication, [11]Army Corps of Engineers 1988b, [12]Oregon Department of Fish & Wildlife 1986, [13]USFWS, [14]Hidy 1988, [15]USFWS 1986a, [16]McKnight & Knoder 1975, [17]Vermeer & Vermeer 1975 (British Columbia), [18]Wilson & Manuwal 1986, [20]Simenstad & Armstrong (in press), [21]Ainley et al. 1980, [22]Wahl 1984

Pomarine and parasitic jaegers are common migrants in nearshore and offshore water along the Washington coast. The first is generally found in deeper water habitats, while the parasitic jaeger is found in nearshore habitats, often close to shore.

Seven species of gulls are found off coastal Washington. The glaucous-winged and Western gulls nest in colonies along the coast, Grays Harbor, Willapa Bay, and the Columbia River estuary. They forage over nearshore and offshore waters. The numbers of glaucous-winged gulls increase during the winter when large numbers move south from northern colonies. In the late summer and fall, California gulls move from colonies in interior North America to Pacific Coast waters. Later in the fall California gulls migrate south out of Washington waters. Black-legged kittiwakes winter in oceanic and shelf waters off the Washington coast.

Eight species of alcids are found in Washington coastal waters. Most are found in shallower nearshore waters, especially during the summer period when birds are closely tied to their nesting sites. Tufted puffins are often found in oceanic waters, far from land, during the winter. Foraging areas of tufted puffins that nest in colonies along the Washington coast are unknown but are probably over the continental slope. Rhinoceros auklets, which also breed at a few sites along the coast of Washington, are found foraging in both nearshore and outer shelf and slope waters. Cassin's auklets, like the above two species, nest in colonies along the coast and forage over the continental slope.

Overall, offshore seabirds are most abundant during the fall, followed by spring, winter, and summer (Figure 3.21).[188] Fall and spring are the peak seasons because of the numbers of migratory birds passing through, and fall populations are more abundant than spring because of the presence of young-of-the year. Also, fall migration is longer, and thus birds are present for a longer period of time than during the spring migration, when species may pass through Washington in a few weeks.

Generally Nearshore Species

Three species of loons are commonly seen feeding in shallow water, but during migration loons are also found out to the shelf edge. Pacific and red-throated loons are seen migrating along the coast, often as a constant flow of thousands of birds heading up or down the coast, depending upon the season. Loons also winter in nearshore waters.

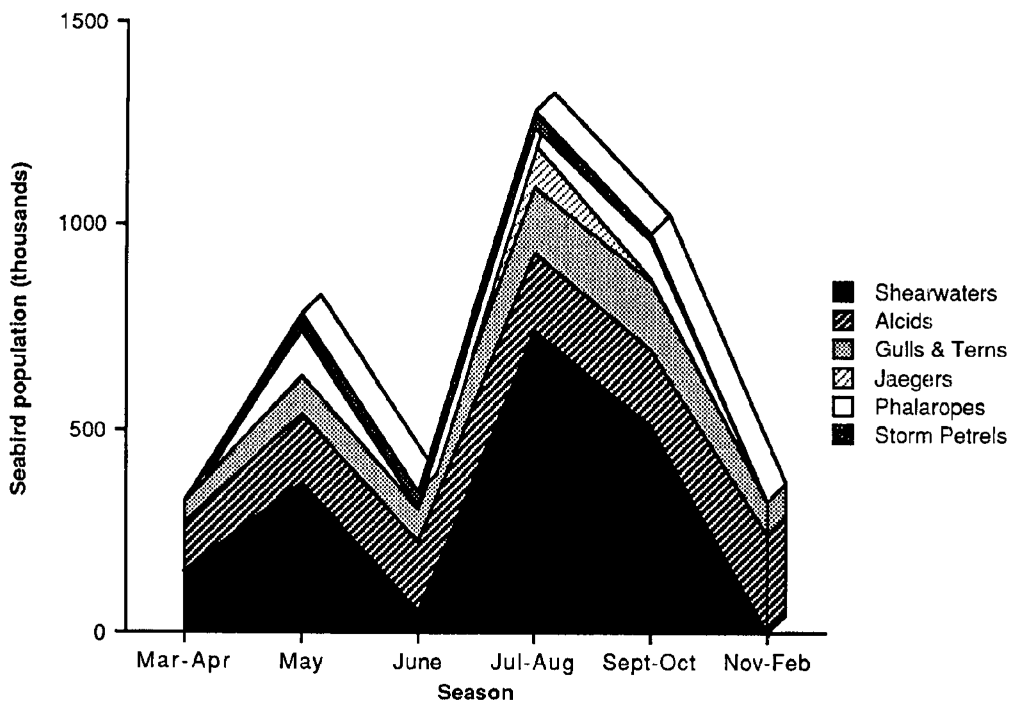


Figure 3.21 Estimates of seasonal offshore use of Washington coastal waters by feeding seabirds (data from Wahl 1984).

Western grebes winter close to shore. Numbers are likely highest during migration periods. Western grebes are often found in flocks, sometimes numbering several hundred birds. Numbers and flock sizes along the coast do not appear to reach the numbers found in northern Puget Sound.[199]

Sooty shearwaters also occur in large numbers in nearshore waters during the summer months. Flocks numbering in the hundreds of thousands are observed roosting on the water just off southern beaches, from Point Grenville to the Columbia River, and in the channels to Grays Harbor, Willapa Bay, and the Columbia River. Tens of thousands of birds are often seen streaming past observation points on the coast in a short period of time, moving from one area to another during migration.

Brown pelicans, a federal endangered species, are found as migrants and fall residents in nearshore waters. About 600-700 birds roost on coastal rocks and islands and forage in nearshore waters and in the channels of Grays Harbor and Willapa Bay and in the Columbia River. Red-necked phalaropes are found in nearshore waters during migration. Small flocks are often encountered during this period. Several species of gulls also are found in nearshore waters. Species commonly seen, in season, are glaucous-winged and Western gulls (which nest on coastal islands), Heermann's gulls (late summer migrants from Baja California and the Gulf of California, Mexico), and California gulls (migrants from the interior of the continent). These species typically forage from the coast to the continental slope.

Three species of cormorants nest on nearshore islands. Double-crested cormorants also nest in Grays Harbor and the mouth of the Columbia River. Cormorants generally stay close to shore and roost on nearshore rocks and islands, headlands, jetties, and navigation aids in harbors. During the winter, there is an influx of Brandt's cormorants from southern coastal colonies, probably from Oregon, California, and Baja California Norte, Mexico. Caspian terns nest in colonies in Grays Harbor, Willapa Bay, and the Columbia River. During the summer birds are regularly seen foraging nearshore along the coast.

Several species of water birds occur in nearshore waters, but most are migrants roosting and feeding for short periods. Scoters are by far the most numerous species of sea ducks in nearshore waters. Relatively small numbers of sub-adult birds are found in the area during the summer, soon joined by large numbers of adults from in northern continental nesting areas. The sub-adult birds pass through a flightless period when they molt their feathers. At this time flocks numbering tens of thousands are found scattered along the coast. At least 100,000, and possibly up to 300,000 birds molt in the area between Point Grenville and Destruction Island. After molting is completed, many birds may disperse down the Pacific Coast, but scoters are found in coastal waters throughout the winter.

Many species of shorebirds migrate through the coastal region of Washington. Many of these species forage on sandy beaches or mudflats. However, several species prefer to forage on rock substrate, and are consistently found on rocks and islands in season. These include ruddy and black turnstones, wandering tattler, surfbird, and rock sandpiper. They pass through the area on migration, and smaller numbers of three species winter here.

The nearshore waters of Washington are used by several alcid species for foraging. Large colonies of tufted puffins, rhinoceros auklets, Cassin's auklets, and common murres are present on islands in nearshore waters. Except for Cassin's auklets, birds are often seen roosting and gathering about the colonies. Foraging areas differ somewhat for each species. Cassin's auklets and tufted puffins are believed to forage over the shelf break and in deeper waters. Rhinoceros auklets may forage in these areas but also regularly forage in closer nearshore waters, and even in Grays Harbor. Common murres, like rhinoceros auklets, fly considerable distances to foraging areas up and down the coast, and are also seen from Grays Harbor south to the Columbia River.

During summer common murres from nesting colonies in Oregon migrate north after breeding. Adult males accompany their newly fledged chicks to sea, staying with them and feeding them for several weeks. The chicks fledge when small, and are unable to fend for themselves. While migrating, the adult murres also undergo a complete molt that renders them flightless. Thus, during the summer there is a stream of common murres swimming, and in part flying, north through Washington nearshore waters. Many of these birds enter the Strait of Juan de Fuca when they reach Cape Flattery. Speich and Wahl [163] estimate that about 300,000 murres may enter northern Puget Sound in some years.

One of the most interesting alcids, the marbled murrelet, nests along the coast of Washington. Although it forages like other murrelets, it flies up to 50 km inland to nest, apparently exclusively on the moss-covered limbs of old-growth conifer trees. Research is now under way to determine whether this hypothesis is entirely correct. There is concern that the species' numbers have declined through the elimination of nesting habitat by the cutting of old-growth forests, and the U.S. Fish and Wildlife Service is now reviewing a petition to list the marbled murrelet as threatened in California, Oregon, and Washington. Censuses suggest that there are between 1,000 and 2,000 marbled murrelets nesting in the nearshore waters of Washington.[165]

Nesting Sites on Coastal Rocks and Islands

There are many nearshore rocks and islands along the Washington coast, most within a kilometer of shore, but some farther off shore. Many of these islands are bare rock, but others are covered with soil, grasses, and other vegetation, and are important as nesting sites to many species of marine birds (Figure 3.22).[162] Coastal rocks and islands are also important as roosting sites for many species. Almost all the coastal rocks and islands are in public ownership, and closed to the public. Most of the sites are contained in three National Wildlife Refuges established in 1907: Flattery Rocks, Quillayute Needles, and Copalis Rocks. The area was designated the Washington Islands Wilderness in 1970. The protected status of these islands has recently been reviewed.[161] The area is offshore the coastal strip of Olympic National Park and several Indian reservations, and was designated as a federal Marine Sanctuary in 1988.[47]

The seabird colonies of Washington's outer coast are the largest in population in the continental United States.[35] Estimates of the nesting seabird population along the Washington coast range from 108,530 breeding pairs [174] to 240,000 individuals.[162,188] Of the individual counts, about 170,000 are alcids, and about half of those Cassin's auklets. Other prominent groups include 40,000 storm-petrels, 30,000 common murres, 17,000 gulls, 7,900 Caspian terns, and 5,400 cormorants (Figure 3.22).

There is considerable uncertainty about these seabird population counts. There are many sources of error in seabird counts, including poor visibility, incompleteness of area surveyed, and duplicate counting.[162,168] Counts of nests are probably most reliable, and counts in offshore feeding areas least reliable. Actual populations also are believed to vary considerably between years.

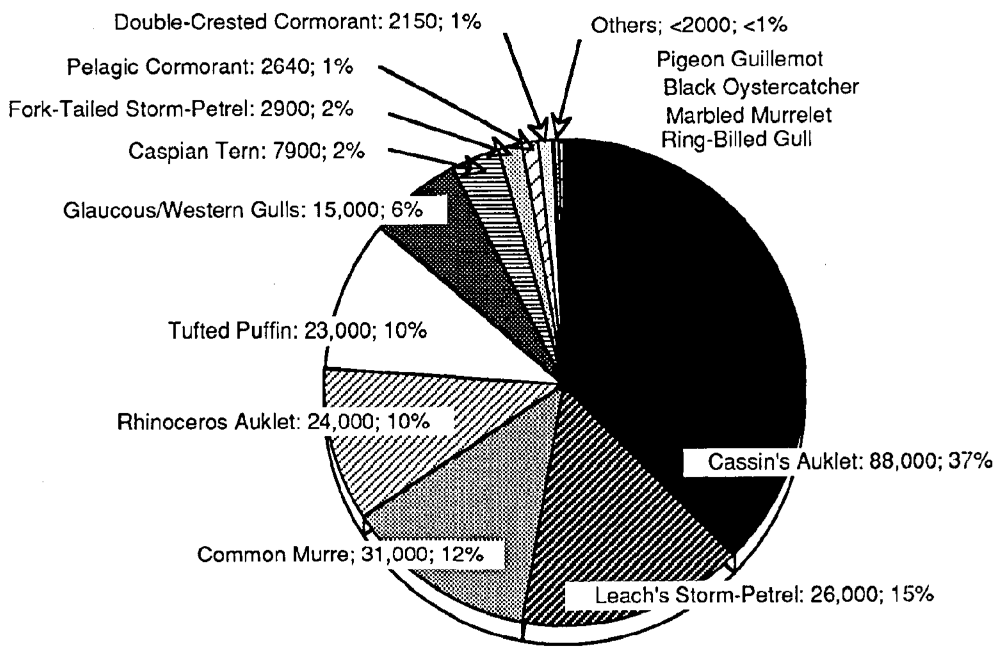


Figure 3.22 Estimated breeding populations of seabirds (numbers of individuals) by species for coastal Washington as a whole (data from Speich and Wahl in press).

Figure 3.23 shows the most recent estimates (1982) of distributions of nesting seabird abundance along the coast. Almost 75 percent of the estimated breeding seabird population in the state is found between Point Grenville and Neah Bay. The stretch of coast between Point Grenville and Tunnel Island is a particularly rich seabird habitat. An estimated mean population of 52,000 seabirds, or 17 percent of all known seabirds nesting in Washington, are found in this segment of coast.[160]

The dominant group in Figures 3.22 and 3.23 is clearly the alcids, which altogether compose 86 percent of the nesting seabird populations.[66] The dominant species in this group are Cassin's auklets, common murres, rhinoceros auklets, and tufted puffins. Destruction Island hosts one of the seven major colonies (18,000 pairs) of rhinoceros auklets in the world; another is at Protection Island in the eastern Strait of Juan de Fuca.[175] The Copalis Rocks Refuge is particularly rich in certain aspects: it contains 82 percent of the Brandt's cormorants, 77 percent of the common murres, and 39 percent of the rhinoceros auklets breeding in the state of Washington.[161]

Fork-tailed storm-petrels and Leach's storm-petrels nest on many of the coastal islands. They nest in burrows in sod and soil, and in various passages in the soil, rocks, and roots of vegetation. The colonies often number several thousand birds, though there are several smaller colonies. To date a detailed census of all possible nesting sites on the coast has not been completed, and the total numbers nesting are likely somewhat higher. Storm-petrels are seldom seen near colonies during the day, and they are present, flying about, in colonies only by night. Incubating birds remain in their nest chambers throughout the day.

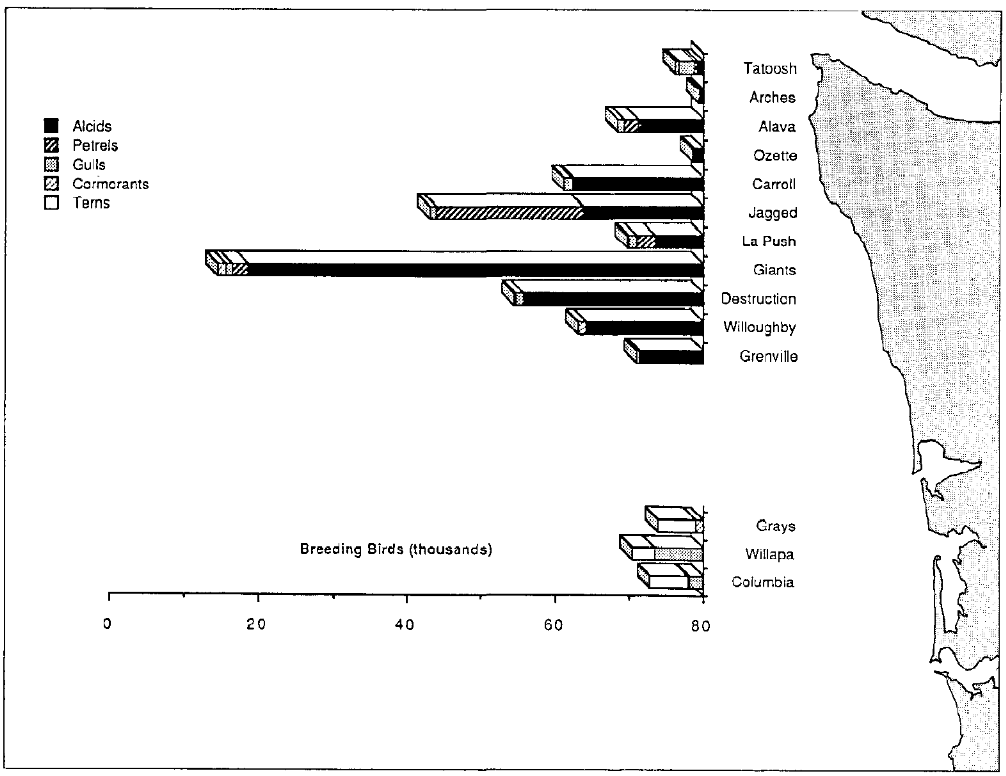


Figure 3.23 Estimated breeding populations (numbers of individuals) of seabird families (alcids, storm-petrels, gulls, cormorants, and terns) by region along coastal Washington (data from Speich and Wahl in press).

Double-crested, Brandt's, and pelagic cormorants nest on coastal rocks and islands, and inaccessible headlands, where they construct characteristic nests on cliff ledges (pelagic cormorants), and on various broad and flat areas. The first species also builds nests in trees and shrubs. These sites are generally free from predators and disturbance. The coastal rocks and islands also serve as roosting sites: cormorants must get out of the water at regular intervals to dry their plumage, which unlike that of other marine birds becomes wet while they are in the water.

Peregrine falcons, a federal endangered species, nest on only a few islands and mainland cliffs. There are only a half dozen nesting pairs on the coast,[107] their locations kept confidential to minimize disturbance. Peregrine falcons are most abundant locally during the spring and fall migrations of shorebirds, which are a primary prey. There are three subspecies of peregrine falcons that occur in Washington: a local breeding population and two visitors that nest to the north and are present in fall through spring.[161] All are managed as endangered species. Not only do peregrine falcons nest on coastal islands, but some of their principal prey are marine birds that nest on the islands, such as storm-petrels and Cassin's auklets. Much attention is given this species, as numbers in North America declined dramatically through the effects of the metabolites of the pesticide DDT causing thin-shelled eggs and nesting failure.

Bald eagles, a federal threatened species, nest on islands and the mainland along the Washington coast.[107,108] Bald eagles regularly roost on coastal islands and rocks. During the summer they prey upon nesting marine birds, particularly pelagic cormorants, glaucous-winged gulls, and common murres. They also take the eggs and young of cormorants, gulls, and murres. Near Point Grenville, eagles make regular visits to nesting colonies each day. About 302 known pairs of bald eagles nest in western Washington,[108] about 30 on the outer coast adjacent to the Islands Wilderness.

The black oystercatcher is a large shorebird that nests on the ground on islands rocks, and headlands along the outer coast and throughout northern Puget Sound. Only a few hundred oystercatchers nest in Washington. This species forages mainly on exposed rocks at low tide, eating attached organisms such as barnacles.

Glaucous-winged gulls nest and roost on several coastal islands and rocks from the southern Washington coast to Alaska. Western gulls nest on the same sites and hybridize with the glaucous-winged gulls. Western gulls nest from Baja California Norte, Mexico, to the southern Washington coast. Most of the gulls that winter in the area or pass through it use the coastal islands, rocks, and beaches for roosting. The sites are important as places to rest undisturbed and to escape from unfavorable weather. The numbers of these species increase during the winter as birds from northern and southern colonies move into the area. California gulls nest in the interior of North America, for example in eastern Washington, and they appear on the coast in the summer after breeding. They are found foraging in all coastal marine habitats during the late summer and fall, and leave the area during the winter.

Common murres nest on several coastal islands and rocks. The Washington population is nearly 30,000 birds, and probably fluctuates through time. Nest site availability (ledges and flat areas) probably is not limiting the numbers of common murres nesting in Washington. However, little is known of the murre's food habitats in Washington, and food availability does affect the reproductive performance of all marine birds. Murres generally do not roost on islands. Murres, like scoters, grebes, and loons, usually remain on the water through winter storms.

Pigeon guillemots nest throughout the marine waters of Washington. Small numbers are found nesting at many sites along the outer coast. Nests are usually in holes in cliff, banks, and rock slides. It is thought that few pigeon guillemots winter in nearshore waters. When present, pigeon guillemots are usually found in shallow nearshore waters.

The ancient murrelet is at the southern end of its breeding distribution in Washington coastal waters. It is not certain, but probable, that it now nests in the area, as birds in breeding plumage are observed during the summer in the area. The only recorded nest is one found on Carroll Island in 1924.[71] Ancient murrelets from northern colonies move into Washington coastal waters in winter.

Cassin's auklet is one of the most abundant breeding birds in Washington coastal waters. It nests on several islands, in earthen burrows, where its numbers reach several thousand birds. It is nocturnal about the colonies, and during the day is seldom seen. Specific information of feeding areas is lacking, but they are recorded over outer shelf and slope waters. Like all the alcids, Cassin's auklets dive to catch food.

The rhinoceros auklet nests at only a few sites in Washington marine waters. Most birds nest on Protection Island, in the Strait of Juan de Fuca, and on Destruction Island, in coastal waters. This alcid's world population is not as large as those of most of the other alcids that breed in colonies. The two large colonies found in Washington are among the largest in the world. Only small numbers nest south of Washington. During the summer, especially, rhinoceros auklets are commonly seen from nearshore to the shelf edge. Most rhinoceros auklets leave Washington waters during the winter.

The tufted puffin nests at many sites from central California to Alaska. Colonies in Washington are generally smaller than many of those in northern areas, numbering from several hundred to a few thousand birds. During the winter almost all puffins depart Washington waters. Young puffins spend perhaps two or three years on deep Pacific Ocean waters before they return to nesting colonies for the first time. During the summer puffins are often found in nearshore waters, especially near colonies, but little is known of their foraging areas.

Coastal Beaches

There are a variety of beaches along the Washington coast. To the north are smaller sandy beaches, interdispersed between rocky headlands and shorelines. These areas give way to longer stretches of beaches in the central coast area. North of the Columbia River stretch many miles of mostly uninterrupted beaches. Many species use these beaches for roosting and feeding.

Gulls are the most conspicuous residents of coastal beaches. Large roosting groups are often found scattered along beaches, especially during migrations and during storms. They obtain most of their food in nearshore waters, channels, and bays and estuaries. Peregrine falcons are often found along coastal beaches during migration and winter. There they feed on shorebirds, hunting among flocks. They also hunt in the coastal bays and estuaries.

Although a variety of shorebirds are found seasonally on coastal beaches, especially during spring and fall migration, the numbers of most species are low. Species commonly seen roosting and foraging during migration, and numbering thousands of birds, include Western sandpipers, sanderlings, and dunlin. Others found are semi-palmated plover and black-bellied plover. Sandpipers, sanderlings, dunlin, and the black-bellied plover are also present during the winter. Several thousand sanderlings probably winter on coastal beaches.

Coastal Bays and Estuaries

The southern Washington coast contains three important estuaries: Grays Harbor, Willapa Bay, and the Columbia River. These areas are discussed here because data are available. Additional data on Columbia River bird populations are available.[51] There are few data on smaller estuaries farther north, which are also potentially important areas. Estuaries are rich in bird life, particularly during migration seasons and winter, because of the rich waters, intertidal areas, and small islands present. The estuaries are roosting and foraging areas for a number of nearshore species discussed above, including sooty shearwaters, brown pelicans, and gulls.

Several species also nest in the estuaries. Double-crested cormorants nest on sand islands in Grays Harbor and on pilings in the Columbia River near the Astoria Bridge. In total, several hundred birds nest in these areas. After nesting, many individuals apparently stay in the region for the winter. The great blue heron is a resident species in coastal bays and estuaries. Nesting colonies are located in trees near the Columbia River, Willapa Bay, and Grays Harbor. Herons forage in exposed tidal areas, in shallow water, and at the edge of deeper water areas, often by wading. Small colonies of ring-billed gulls are located in Grays Harbor and Willapa Bay, numbering just a few hundred individuals. There is little information on the foraging areas of ring-billed gulls.

Terns are commonly observed in the coastal bays and the Columbia River. They dive from the air to capture prey, usually fish, at or just below the water surface. Caspian terns nest on sand islands in all three areas, and forage in the bays and rivers and along the outer coast. As far north as Tunnel Island. Caspian terns depart Washington waters during the winter months. In addition to Caspian terns, common terns are often observed during migration feeding in coastal bays and estuaries and in nearshore waters.

Except for a small number of pigeon guillemots, alcids do not breed in these areas. However, during the breeding period rhinoceros auklets and common murres are regularly observed feeding in entrance channels and into the interior of the bays. A small number of marbled murrelets forage in Willapa Bay and probably nest there, on Long Island.[8]

Grays Harbor and Willapa Bay are important migration stopping points and wintering areas for water birds on the Washington and Pacific coasts. The 22,748-acre Willapa Bay National Wildlife Refuge was created in 1937 primarily to protect the overwintering habitat of the Pacific variety of black brant geese (*Branta bernicla nigricans*). Brant nest in the arctic in summer, and migrate south as far as Mexico for the winter. Brant pass through the area during migration, and a few thousand birds, variably, winter in the bay. Willapa Bay is the most important brant wintering area on the Washington coast, and is one of the most important in the Pacific Northwest.

Estimates of brant abundance in the refuge are reviewed annually.[7] Populations of this species in traditional coastal habitat along the Pacific flyway in the U.S. and Canada have declined 85 percent in the last 20 years,[178] partly because of a shift to habitat in Mexico. The total West coast population is estimated at about 120,000 compared to a historical maximum population of 500,000 to 1 million.[8] This decline is associated with habitat reduction caused by human development. Hunting of brant in the Willapa Refuge has not been allowed since 1983.

A number of Canada geese, 2,000 to 3,000, winter in Willapa Bay, and others stop for periods during migration. About 10,000 Canada geese winter on the Columbia estuary, and about 2,000 residents have been observed in the summer, with 125 nests counted.[179] The Willapa area also is visited by federal sensitive races of geese having low populations, including the Aleutian, cackling, lesser, and dusky Canada geese, and white-fronted and snow geese.[7,178] The major period of use is November-March. Cackling geese are observed during the spring (April-May) migration in several groups of 50 to 250 birds. A small (550-700) population of dusky Canada geese is resident in the bay. Trumpeter swans (a federal sensitive species) and a few tundra swans frequent Willapa Bay and the Columbia River estuary during the fall migration. Peak population count in 1987 was about 70.[181,182] These numbers reflect a continuing decline in swan use of the area due to poor vegetation conditions.[178]

Many ducks also use the coastal bays and estuaries. During the fall migration, tens of thousands of ducks feed and rest in the bays (Figure 3.24). Several thousand ducks winter in the area. Spring and summer populations are lower. During the fall migration (September through

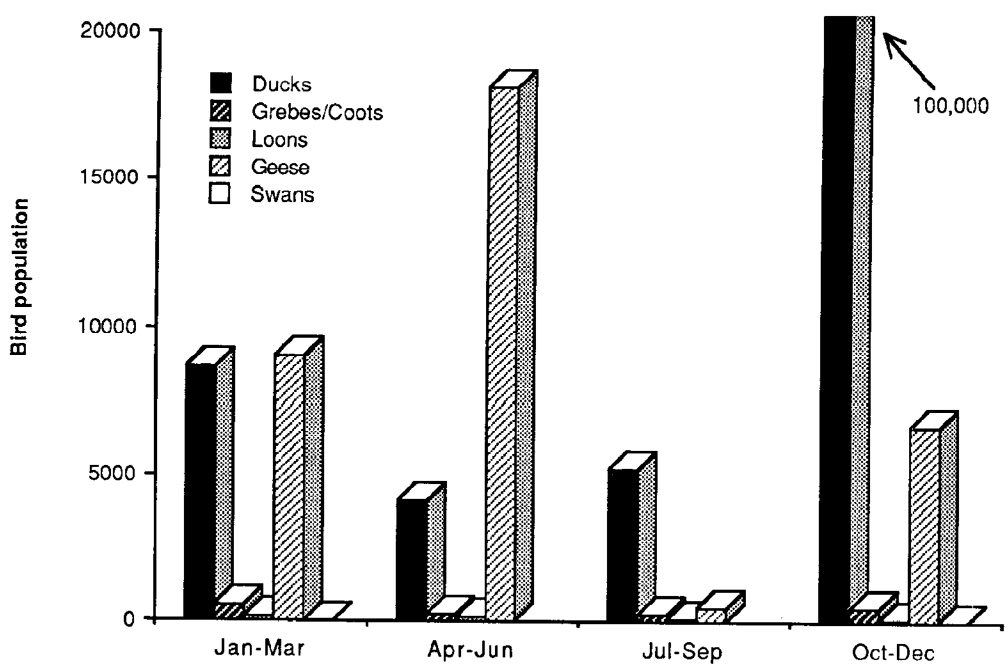


Figure 3.24 Estimates of seasonal peak populations of water birds in Willapa Bay National Wildlife Refuge in 1987 (USFWS unpublished data).

November) about 50,000 to 80,000 ducks (wigeon, pintail, mallard, teal, canvasback, bufflehead, merganser) feed and rest in the bay.[69,178,181,182]

Grays Harbor, in particular, hosts large numbers of shorebirds in season. During the spring migration period birds appear on mudflats and sandy areas of the harbor. One part of the harbor, Bowerman's Basin, is identified as a site containing exceptionally large numbers of birds. The newly created National Wildlife Refuge in Bowerman Basin is believed to be the last significant feeding site for millions of shorebirds migrating along the Pacific Flyway northward to Alaska's Copper River delta.[174] Grays Harbor qualifies on scientific criteria as an "estuary of international importance," supporting more than 1 percent of the flyway population of any species of shorebird.

Western sandpipers are the most abundant shorebird species in this area, and far outnumber the next most abundant species, dunlin. At the peak of migration in late April, 500,000 to 600,000 birds are found in Bowerman's Basin, and the total shorebird population of Grays Harbor is probably close to 1,000,000 birds.[151] Since individual birds only spend a short time in the harbor before flying north, the total number of shorebirds that use Grays Harbor during the spring migration is possibly near a few million birds. The fall migration is spread out over several months, and total numbers present on any given day do not reach the peak numbers observed during the spring. The high diversity of species and numbers present makes Grays Harbor in particular a very important feeding and stopover area for migrating shorebirds. Fewer species are present during the winter, and total numbers, although in the thousands of birds, are considerably lower than the numbers present during migration. The numbers of shorebirds in Willapa Bay, although less, generally vary in a similar way (Figure 3.25).

More than 50 species of shorebirds (killdeer, snipe, yellowlegs, whimbrel, dowitcher, willet, plover, dunlin, sandpipers) are found in Willapa Bay, primarily during the spring and fall migrations.[177] Their peak numbers are estimated to exceed 100,000,[69] and total population using the bay is thought to exceed 1 million.[182] About 2,000 Caspian terns typically nest on the sand islands near the bay entrance; however, none were observed in 1987. Others are in the Columbia estuary.[52,69,182] Recent estimates of the seasonal abundance of shorebirds in Willapa Bay are shown in Figure 3.25.

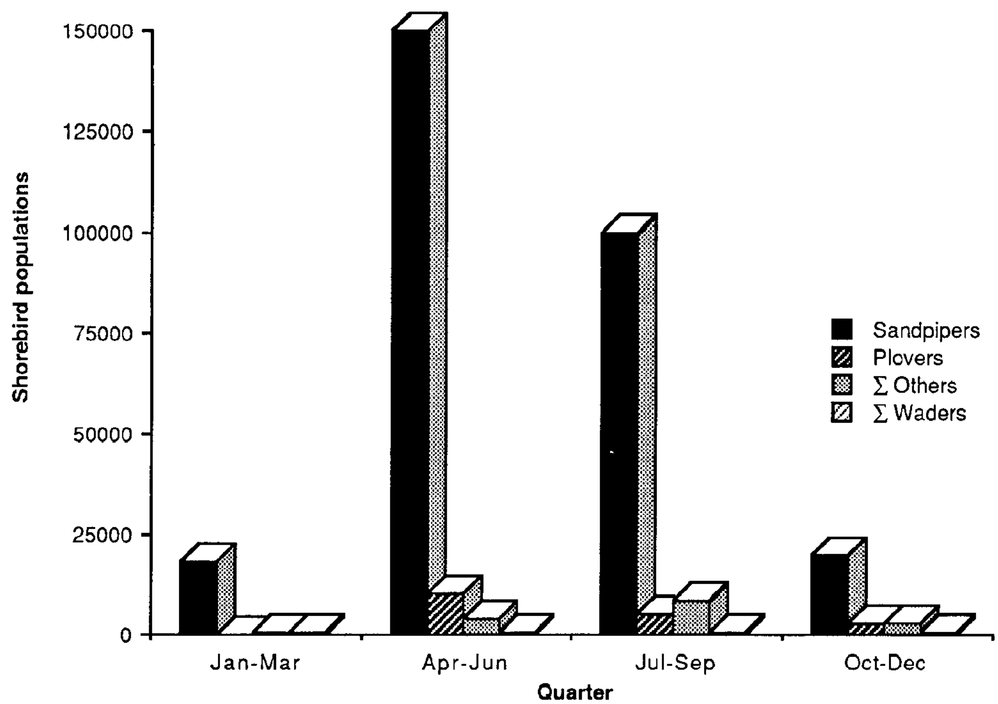


Figure 3.25 Estimates of seasonal peak populations of shorebirds in Willapa Bay National Wildlife Refuge in 1987 (USFWS unpublished data).

The Columbia White-tailed Deer Refuge and the Lewis and Clark National Wildlife Refuge are located in the Columbia River Estuary and managed as satellites of the Willapa Refuge. The Lewis and Clark Refuge, located on a string of islands in the river for about 30 miles upstream of Astoria, hosts breeding colonies of Caspian terns, blue herons, gulls, double-crested cormorants, and Canada geese.[52,179] The numbers of these nests are uncertain but exceed 5,000 for Caspian terns and 300 for herons.[52] Peak annual populations of water birds in these two units over the last several years have varied in the range of 2,000-3,000 geese, about 50,000 ducks, and about 800 swans.[178,179]

A small breeding colony for the Western snowy plover is present on coastal beach areas of the Willapa Refuge.[8,178] Snowy plover, at the northern limit of its breeding range here, is a state endangered species and a federal sensitive species, with a low and declining population on the entire West Coast due to predation and habitat loss and disturbance.[128] A maximum of 24 plovers (and only 8 individuals in 1988) nest on sand flats at Leadbetter Point during summer.

There are an estimated five bald eagle nests around Willapa Bay,[69] where eggs are laid prior to April and young fledge by June-July.[8] Bald eagles, a federal threatened species, forage on the shoreline and are water-dependent, consuming fishes and waterfowl. An additional 26 sites are observed in the Columbia estuary,[179] with apparently increasing production.

Between 6 and 12 peregrine falcons, a federal endangered species, are believed to be present in Willapa Bay at times when their migratory shorebird prey are present.[70] Peregrine falcons are not known to nest in the bay, but individuals that nest between Alaska and Oregon are present during migrations in October-November, and again in March-April. Some individuals that probably nest along the Washington or British Columbia coast overwinter in Willapa Bay.[178]

POTENTIAL IMPACTS OF OFFSHORE OIL AND GAS DEVELOPMENT ON MARINE BIRDS

Potential sources of adverse impacts for birds resulting from oil and gas exploration, development, and production include large and small oil spills, discharge of drilling muds and produced waters, dredging and filling onshore and dumping offshore, and disturbance by seismic activities, flaring of gas, and aircraft and vessel traffic.[111] Degradation of habitat from non-petroleum industrialization is also a factor.

It has been known for many decades that oil in the marine environment can impact marine birds, often causing mortality.[17,184] However, only relatively recently have the effects of oil pollution on marine life, including marine birds, become widely appreciated, mainly as the result of tanker accidents, such as the *Torrey Canyon*,[18,20,154] *Hamilton Trader*,[74] San Francisco,[152] *Palva*,[157] *Arrow* and *Irving Whale*,[26] *Amoco Cadiz*,[30] *Esso Bernicia*,[67] and *Argo Merchant*.[138]

Although oil spills resulting from tanker accidents are often reported, there are other paths by which oil may reach the environment in quantities potentially harmful to marine birds.[16,39,118,122] These include leaks or blowouts at platforms,[73] pipeline ruptures or leaks, spills during transfer of oil to shore by barge or vessel, spills at shore terminals or offshore platforms, and spills at shore holding and refinery facilities. Another path for the introduction of oil into the environment is from vessel ballast and bilge pumping.

Although there are many pollution events each year along the Pacific Coast of North America and in its bays, harbors, rivers, and estuaries, only a few are large enough to gain public attention and impact marine birds. Examples of such large spills include San Francisco Bay[2,116] and then again later off San Francisco,[152] coastal Washington,[144] Santa Barbara Channel,[27] Whidbey Island,[160] Columbia River [83,160] Gulf of the Farallones off San Francisco,[137] central California coast, [129] and Port Angeles.[86,166,191]

Physiological Effects of Oil on Birds

There is a large and growing literature of the effects of oil and refined petroleum products on marine birds.[39,54,76,118,123,124,184] Marine birds can contact oil in the environment in several ways. Birds often have specific feeding areas and oceanographic conditions, where they feed. Oil slicks in these areas can result in oiling as birds swim, rise after diving to feed, or settle onto the water after flight. When birds are on the water at night, they may be more susceptible to oiling. Birds that feed in shallow waters or exposed intertidal areas along shorelines or in bays and estuaries also can become oiled while feeding there. The responses of birds to oil vary with species and circumstances.

There are other situations where birds can be oiled. Several species, such as scoters and murres, go through flightless periods when they molt. At times these birds aggregate in large flocks, in specific areas in preparation to entering breeding sites or to begin migration. They are more susceptible to oiling during these periods. Birds such as storm-petrels ingest oil directly from the water surface, mistakenly as food or incidentally to taking food items.[15] The amounts of oil, or fractions of oil, contained in ingested food are unknown.

The most obvious effect of encounters with oil is the oiling of the plumage. This often leads to clogging of the fine structure of feathers and loss of buoyancy, resulting in sinking and drowning. The extent of this is unknown, as birds that sink are probably not found. The oiling of plumage also leads to the loss of thermal insulation, requiring the affected bird to increase metabolism to maintain body temperature by utilizing fat and muscular energy reserves. In cold climates birds succumb faster, and during storms birds use greater amounts of energy than normally required. In cold climates the oiling of even a small portion of the plumage may prove fatal.

The ingestion of oil can damage internal organs (lungs, adrenals, kidneys, liver, nasal salt glands, gastrointestional tract) and lower the white cell count. Hydrocarbons have been found to contaminate liver, kidney, and muscle tissues. The role of stress is also important, and may be responsible for the degradation of tissues. Mortality may be due to hypothermia and drowning and not changes in organs. But ingestion of oil does change the physiology of birds, and birds that have ingested oil are more likely to be affected by stress and less able to tolerate low temperatures.

The ingestion of small amounts oil by female birds can result in the temporary depression of egg laying, reduced hatching success of eggs laid, reduced eggshell thickness, and changes in reproductive organs. In addition, the retention of mates is lowered, which in following years results in reduced reproductive success.

There are numerous studies showing that the application of small amounts of oil to eggs, especially in early stages of development, causes mortality. In fact, the placement of oil on eggs has been used to control gull colonies. Oiling of adult plumage also can cause subsequent egg mortality. When female marine birds ingest oil there can be changes in the physiology of subsequently hatched chicks, such as reduced rates of weight gain and chick survival. Chicks that successfully leave the colony but at reduced weight are less likely to survive to first reproduction than birds that fledge at full weight. Thus, exposure of the female to oil may not be fully expressed for several months, in the case of chicks, and even longer in terms of mate choice.

Because many seabird species require three to four years to mature and may produce only one to two young per year, recovery times for their populations can be great. Common murres may require more than 50 years to double their numbers under stressful conditions.[185]

The results of studies on oil toxicity are not always in agreement. This is in part due to the use of different oils (often with different toxicities) different study species, and applications at different times of the reproductive cycle in the case of adults, and at different times of development in eggs. Most studies are in laboratory settings and more need to be performed in the field, especially with species that do come into contact with oil. However, external oiling or ingestion of oil often does lead to mortality.

Species Vulnerability to Oil

Only recently have attempts been made to quantify the vulnerability of marine birds to oil spills[85,165,199] and the importance of local populations to species' total populations.[165,199] These models take into account only short-term mortality from exposure to oil and not possible long-term sublethal effects. Thus, when oil is present, either birds are oiled and soon die, or they survive.

The results of a model that attempts to account for the complexity of factors involved in determining species vulnerability to oil are presented in Figure 3.26. This Bird Oil Index rates a variety of marine birds from the Strait of Juan de Fuca.[199]

The components of the Bird Oil Index developed for application to Washington marine waters combine species' susceptibility to oil and significance of local populations. The first component relates to the susceptibility of species as determined by habits of individual birds. A highly susceptible species is one that nearly always roosts on water, dives from danger, forms large flocks on the water, forms large breeding colonies, and is highly specialized in feeding.

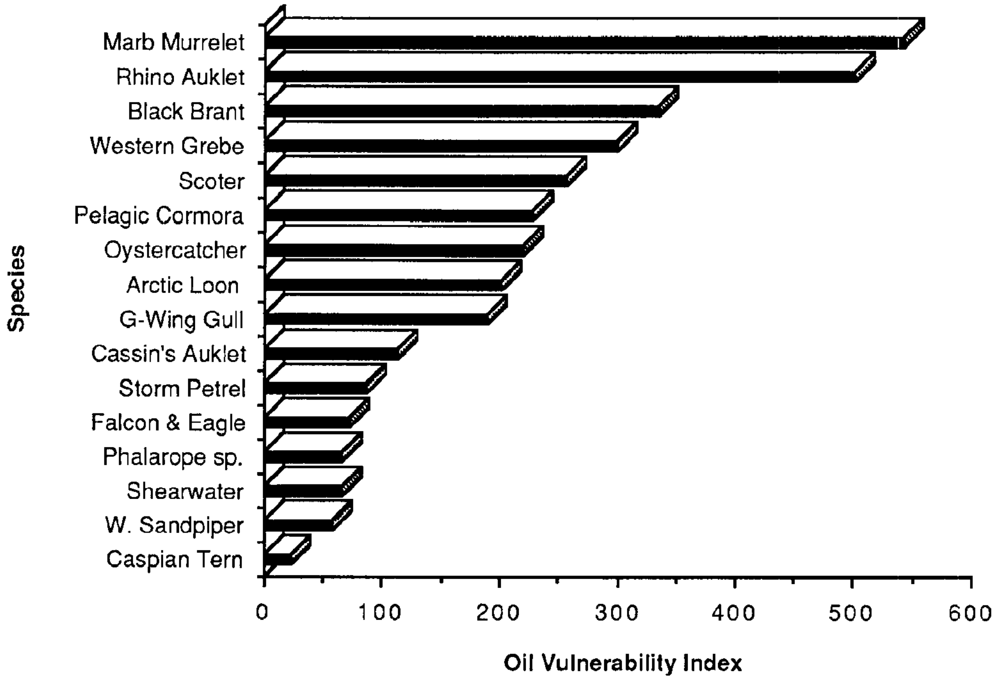


Figure 3.26 Graphical representation of relative values of Bird Oil Index for different marine bird families, derived for the Strait of Juan de Fuca. Higher number indicates greater vulnerability (data from Wahl et al. 1981).

Examples would be auklets, puffins, and murres, all of which are found along the Washington coast in breeding colonies.[163] The second component considers the sensitivity of species as determined by total population characteristics. A highly sensitive species would be one that has a small population of limited numbers, low reproductive capacity, localized breeding distribution, is concentrated during the winter, and spends all year in marine habitats. Examples in Washington coastal waters would be pelagic and Brandt's cormorant, yellow-billed loon, trumpeter swan, brant, several shorebirds, Heerman's gull, marbled murrelet and rhinoceros auklet. The third component rates the importance of the marine waters of Washington to each species' whole population.

Using this technique, there are several species of marine birds that occur on the outer coast of Washington that are particularly vulnerable to oil when present, and whose numbers in Washington are a significant part of the species' population during part of the year. Notable among these are alcids, brant, grebes, scoters, and cormorants (Figure 3.26). The threatened bald eagle and the endangered peregrine falcon are susceptible to oil mainly through secondary contamination by ingestion of oiled prey.

In contrast, other species present in coastal Washington waters may be highly susceptible to oiling, but they represent only a small portion of the species' world population, and the elimination of all their numbers in Washington may be insignificant to the larger population. Even if a significant portion of a population were lost, in time it is likely that the species would recover its numbers and distribution. However, this assumes that oil related mortality does not become regular, and that other factors do not start to reduce numbers. Populations of ducks in the Baltic Sea were reduced by frequent oiling, for example, as were penguin colonies in South Africa, and seabird colonies on the coast of Brittany,[76] but perhaps only the populations of the ducks and penguins were reduced to levels that became cause for concern.

The data available on recent spills in Washington do not indicate large-scale impact on marine birds. The *Mobiloil* spill in the Columbia River in 1984 took place about 45 miles upstream of the wildlife refuges during March when relatively few birds (mostly grebes) were observed to suffer oiling.[69,70] However, the effects of the spill on birds were not systematically studied. Following the *Arco Anchorage* spill at Port Angeles in 1985, an estimated 4,000 water birds died and $12,000 was spent on rehabilitation.[86] Nesting birds appeared to be unaffected, however, and water bird populations appear to have recovered over the course of three years.[159]

In the North Sea, despite the large-scale presence of offshore oil operations, transport of oil to shore, general shipping and shipment of oil through the area, and the continued chronic appearance of oiled birds on beaches, local breeding populations of marine birds are increasing.[38,39] However, if other environmental factors should start to increase mortality rates, then the annual losses to chronic oiling could become of concern.

It is evident that both the outer coastal islands off the northern Washington coast and the major estuaries of the southern coast support large marine bird populations that are vulnerable to impacts of oil spills. In the absence of a more in-depth analysis, these two areas would appear to be about equally vulnerable and therefore equally deserving of concern and protective measures to reduce potential oil spill impacts.

Determining Mortality

One method used to quantify the mortality from oil spills is to count the numbers of dead and incapacitated birds found oiled on beaches. This method has been used in Europe for many years and has given insight into the impacts on water birds from major pollution events[75,154,172] and from chronic oil pollution.[19,38,39,145] However, it is difficult to relate the numbers of birds found on beaches to the actual numbers that are oiled and killed, because 40 to 90 percent probably sink at sea and do not reach shore.[13,33,38,74] Observed stranding rates are greatly and variably influenced by tides, currents, wind, distance to shore, time in the water, size of the bird, bird behavior after oiling, and the nature of the oil.

A few studies from the west coast of North America document the rates at which dead birds are found on beaches and the proportions that are oiled: southern California,[23] California,[130] Oregon [101,162] southern coastal Washington beaches,[100,162] and northern Puget Sound.[162,199] The rates at which oiled dead and incapacitated birds were found on beaches in Washington after the Columbia River, Whidbey Island, and Port Angeles oil spills were clearly much higher than the established background rates.[160,162,166] Even so, it was still not possible to give a definitive determination of the numbers actually killed in the spills, other than those recovered from beaches.

The second method used to determine the numbers of birds lost in pollution events is to compare the number of birds present in affected areas before and after the event. However, this method presumes that there are baseline data of sufficient quality available for comparisons. Counting marine birds on large bodies of water and the ocean is not an exact science, and there is much variability in the data obtained.[24,25,199] Unless a high proportion of the birds present are lost, it is doubtful that reductions in numbers can be demonstrated statistically. In addition, even if reductions from baseline levels are demonstrated, other factors, such as changes in prey availability, weather, and currents could be responsible. Thus, the methods utilized to determine losses to bird populations on the water must be evaluated in each spill situation.

Colonial nesting marine birds are concentrated at a relatively small number of nesting sites along the outer coast of Washington.[163] Colony census data from several years are available,[163] but most are of single censuses in any given year, and at many sites only a few censuses are available over several years. Often the censuses, especially of birds nesting in large numbers, are imprecise. Unless an oil spill caused mortality to a large proportion of the population, a decrease in numbers would be difficult to detect.[39,76,146] Even where several years of data exist, decreases in numbers might be hard to detect and would take considerable effort to demonstrate. Not only are there difficulties in obtaining accurate counts because of daily and seasonal variations in numbers at particular sites,[38,62,76,146] but even if changes are detected, they could be due to shifts in regional populations to or from the subject sites. Declines in numbers also could result from other factors such as prey availability, winter storm mortality, disease, etc.[38,39,76] There are few cases in which oil-related declines in seabird populations have been clearly demonstrated. Monitoring of colonies should continue, and the methods and effort to detect changes after oil spills must be evaluated in each case.

Recently, efforts to model the effects of oil spills on marine bird populations have advanced.[48,49,50] The development of models has led to the identification of data needed to evaluate the effects of oil spills on marine bird populations at sea and at colonies.[76,195] Recent spills in California have allowed the testing of models,[49] and will help refine the models and data requirements. Models may help us better understand the dynamics and effects of oil spills.

There is also considerable uncertainty about the success and advisability of attempts to rehabilitate oiled birds following a spill. The numbers saved may be insignificant to the population, and there are few data indicating that rehabilitated birds ever successfully breed again.[166]

Other Associated Effects

Routine activities associated with the exploration for and production of oil potentially can have detrimental effects on marine birds. The concern is that disturbance from aircraft and boat traffic can affect species' use of particular areas for feeding and roosting, and cause mortality and nest/young desertion in breeding colonies.

A growing body of evidence shows that breeding colonies of marine birds are susceptible to aircraft disturbance.[76,158,161] Although the responses to close approaches of aircraft are variable, aircraft near colonies often cause temporary desertion of nests with eggs or young, and can lead to mortality from exposure or predation. Common murres, which nest in colonies, incubate by holding the egg on their feet, and when frightened often cause their eggs or young to fall from nesting cliffs.

The intrusion of humans into breeding colonies also can have disastrous effects on reproduction.[29,76,158,161] The close approach of boats to colonies can cause similar reactions by nesting birds. Even researchers, trained to work in breeding colonies, must use extreme care to not induce unwanted mortality. Even the apparently tolerated presence of intruders in colonies can have subtle effects that may be felt in the future.

There is also concern about disturbing birds in roosting and foraging areas. Black brant in Willapa Bay are easily flushed from roosting and feeding areas by boat, aircraft, and humans that approach too close.[8,159] Other birds found in estuaries, ducks and shorebirds, may also be affected.

Apparently no studies are available on the effects of vessel disturbance on birds in the ocean or in large bodies of water. The passage of any vessel will momentarily displace birds, but they appear to move back into areas afterwards. Indeed, vessel traffic through the Grays Harbor channel, the mouth of the Columbia River, and many parts of Puget Sound seem to have no lasting effects on bird usage of the areas.[159,192] However, subtle effects are not to be ruled out, and heavy traffic in confined areas may well have lasting impacts.

There is a need for careful studies of the effects of vessel and aircraft traffic on birds,[76] because effects may be subtle and are not immediately apparent. Studies of disturbance effects of birds on the open water also are needed. Apparently, industrial activities can coexist with marine bird breeding colonies and feeding and roosting areas, provided that minimal separation distances are maintained,[159] but there is concern for accumulated effects of chronic disturbance, an area that needs careful investigation.

Marine Mammals of the Washington Coast

Washington's coastal waters are inhabited or visited by 29 species of marine mammals and one common terrestrial mammal.[106,161] Of these, two species of otter, four species of pinnipeds (seals and sea lions), and two species of cetaceans (whales and porpoises) have been listed as numerically dominant year-round breeding residents or regular seasonal migrants. Table 3.4 provides a summary of key data on these major species. This table indicates typical and not odd observations—for example, gray whales, sea lions, harbor seals, and harbor porpoises occasionally enter estuaries and the lower reaches of rivers.[12,117]

In addition, one pinniped and 21 cetacean species occur less frequently, either as low or depleted populations or as visitors from other areas (Table 3.5). Several of these less common species are important because they are classified as threatened or endangered by the state and/or federal governments. Such species also may have the potential to return to former areas of residence and levels of abundance as population levels increase, if they are sheltered from stresses.[103] For example, the humpback whale was considered common along the Washington coast before being severely impacted worldwide by whaling in the 1960s.[161]

Table 3.4 Dominant Marine Mammal Species on the Washington Coast

Species	Diet	Seasonal presence	Distribution	Breeding	Abundance
Order Carnivora					
River Otter (*Lutra canadensis*)	Small crabs, shrimp, fishes, seabirds	Year-round resident	Shoreline of fresh and salt waters		Common; population unknown
Sea Otter (*Enhydra lutris*)	Clams, crabs, chitons, sea cucumbers, octopi, sea urchins	Year-round resident	Kelp beds Destruction Is. to Point of Arches	Early spring, possibly winter, near Cape Alava	136 animals in 1987[1]; state and federal endangered species
Order Pinnipedia					
Harbor seal (*Phoca vitulina*)	Fish, squid, octopus	Year-round resident	Columbia River and outer coast in winter; estuaries and western Strait of Juan de Fuca in summer[2]	Pupping in spring and summer in estuaries[2]	Total state population more than 18,000 and increasing[3]
Northern sea lion (*Eumetopias jubatus*)	Fish, squid, octopus	Seasonal migrant: adult males in winter, smaller numbers of all sexes & ages in summer	7 known coastal haul-out sites	No known breeding in Washington	Stable at about 600 in winter, less than 100 in summer[4] for entire state
California sea lion (*Zalophus californianus*)	Fish & squid	Seasonal migrant: winter in Washington, summer in California	7 known coastal haul-out sites	None in Washington	More than 1000 for entire state and increasing
Northern fur seal (*Callorhinus ursinus*)	Fish, squid	Seasonal migrant: November-May	Common over slope, occasional over shelf	None in Washington	Uncertain
Order Cetacea					
Harbor porpoise (*Phocoena phocoena*)	Fish, squid	More common in late summer, less in winter	In small pods near shore; locations uncertain	Probable; mothers with neonates observed[5]	Common but numbers uncertain
California gray whale (*Eschrichtius robustus*)	Benthic invertebrates & small fishes	Migrate north February-March, south in October - December; small year-round resident population	Over shallow shelf	None known in Washington	Total population 17,000+;[5] resident population size is small; federal endangered species

1 Bowlby et al. 1988
2 Everitt and Jeffries 1979; Everitt et al. 1980
3 Jeffries personal communication; Beach et al. 1985
4 Everitt 1980
5 Jeffries personal communication

Table 3.5 Other Significant Marine Mammal Species on the Washington Coast (Sources: Speich et al. 1987; NMML 1979; Jeffries personal communication; Felleman 1988)

Species	Distribution	Abundance
Order Pinnipedia		
Northern elephant seal (*Mirounga angustirostris*)	Coastal & offshore	Annual migrant, increasing sighting records
Order Cetacea		
Right whale (*Balaena glacialis*)	Coastal & offshore	Rare, federal endangered species
Minke whale (*Balaenoptera acutorostrata*)	Coastal & offshore; probably breed in Puget Sound	Regular sightings
Fin whale (*B. physalus*)	Offshore	Rare, federal endangered species
Sei whale (*B. borealis*)	Offshore	Rare, federal endangered species
Blue whale (*B. musculus*)	Offshore	Rare, federal endangered species
Humpback whale (*Megaptera novaeangliae*)	Coastal & offshore, Puget Sound	Rare, federal endangered species
Sperm Whale (*Physeter macrocephalus*)	Offshore	Rare, federal endangered species
Dall's porpoise (*Phocoenoides dalli*)	Coastal & offshore, Puget Sound	Regular sightings
Pacific white-sided dolphin (*Lagenorhynchus obliquidens*)	Coastal & offshore	Regular sightings
Killer whale (*Orcinus orca*)	Breeding resident, Puget Sound, Strait of Juan de Fuca	Regular sightings

Rare = Species that are depleted from their original numbers and may once have been abundant on the Washington OCS.
Coastal = Estuaries and continental shelf
Offshore = Continental slope and seaward

OTTERS

Washington coastal waters are inhabited by river otters and sea otters. River otters are terrestrial mammals that live near and forage in shallow fresh and salt waters. There are no good data on their population numbers or distribution on the Washington coast or other marine waters of the state, but they are not considered threatened. Sea otters were native to the outer coast of Washington but were eliminated here by hunting before about 1910.[21] Total North Pacific population numbers are recovering from hunting pressure and are currently estimated at 132,000.[161] The small but expanding population now inhabiting the Washington coast, estimated at 136 and currently classified as endangered in the state, is descended from two transplants of individuals from Alaska made near Point Grenville in 1969 and near La Push in 1970.

The Washington sea otter population currently ranges along 70 kilometers of coast, from Destruction Island north to Point of the Arches (Figure 3.27). Potentially they may occur offshore to depths of 40 meters.[78] Sea otters are closely associated with kelp bed habitats, in which they feed on benthic invertebrates. Few data are available on their foraging habits. Recent benthic surveys suggest that there has been a substantial reduction in total prey biomass within the sea otter range, but the changes in community composition are uncertain.[89] Although there is no indication that Washington sea otter populations are currently limited by food supplies, the prey availability outside their current range suggests there may be opportunity for the population to expand its range in the future.

Seasonal shifts in sea otter populations occur along the Washington coast. Cape Alava is used year-round, with the majority of the population residing there in winter and early spring because of its sheltered waters and abundant *Macrocystis* kelp beds. A total of 20 pups were observed in the spring pupping season of 1987, but otherwise there are few data on their reproductive, survival, or mortality rates on the Washington coast.[21] By late spring and early summer, the animals distribute southward to the Cape Johnson area north of the Quillayute River. Males (especially nonbreeding males) are more mobile than females with pups, and may produce most of the summer shift in distribution. By September the majority of animals are found near Cape Alava again. Their distribution in depths greater than 10 fathoms, and during the night and the winter, is poorly known.

PINNIPEDS

The most abundant pinniped in Washington, and the only species that breeds in the state, is the harbor seal. This species ranges along the Pacific coast from Baja California into the Bering Sea. Washington harbor seals belong to the eastern Pacific race, one of five subspecies. The most abundant marine mammal in Washington, it is a year-round resident of coastal and inland waters. Haulout sites for resting, birthing, and nursing are found on nearshore rocks and reefs along the Olympic coast as well as on low sand bars in the coastal estuaries (Figure 3.27). Additional haulout sites in the Columbia estuary are noted elsewhere.[51] Harbor seals are widely foraging predators in benthic and estuarine habitats. The most important prey are fishes such as eulachon, herring, smelt, anchovy, tomcod, sole, and flounder in the Grays Harbor, Willapa Bay, and Columbia estuaries.[12]

The current harbor seal population in Washington probably exceeds 18,000 animals, with highest coastal densities found in the Columbia River, Willapa Bay, and Grays Harbor estuaries.[12] About 1,000-1,500 harbor seals in February and 300-500 at other times are observed in the Columbia estuary.[12,179] Populations have been increasing in recent years at rates exceeding 14 percent per year in coastal estuaries.[12,78] About 2,000-2,200 seals are observed on the outer coast from Point Grenville to Cape Flattery.[78,161]

Harbor seals have been observed to migrate seasonally in conjunction with their breeding cycle and prey abundance. Seals enter the Columbia River estuary in spring following migratory eulachon.[150] Pregnant females move from the Columbia River into nursery areas in Willapa Bay and Grays Harbor to give birth and to nurse their young during the spring and summer.[43,161] To a lesser extent, migrations are also observed from the outer coast and eastern Strait of Juan de Fuca into the western Strait.[44] Seasonal migrations are also attributed to dispersion from breeding grounds during winter to forage for seasonally spawning prey species such as eulachon.[12]

Harbor seals give birth in May and females stay close to nursing pups until weaning in July. From July through September the animals undergo molting, during which they spend greater amounts of time hauled out.[161]

The other seals regularly observed in Washington are regular migrants, the Northern fur seal and the Northern elephant seal. Northern fur seals principally inhabit the Pribilof Islands in the Bering Sea, with individuals commonly found migrating along the continental shelf and seaward off Washington between November and May.[117] Their populations in Alaskan waters, some of which may migrate through Washington waters, are being studied for designation as depleted by the National Marine Fisheries Service.[72] Northern elephant seals breed between January and March on islands from Baja California to central California. The young of the year,

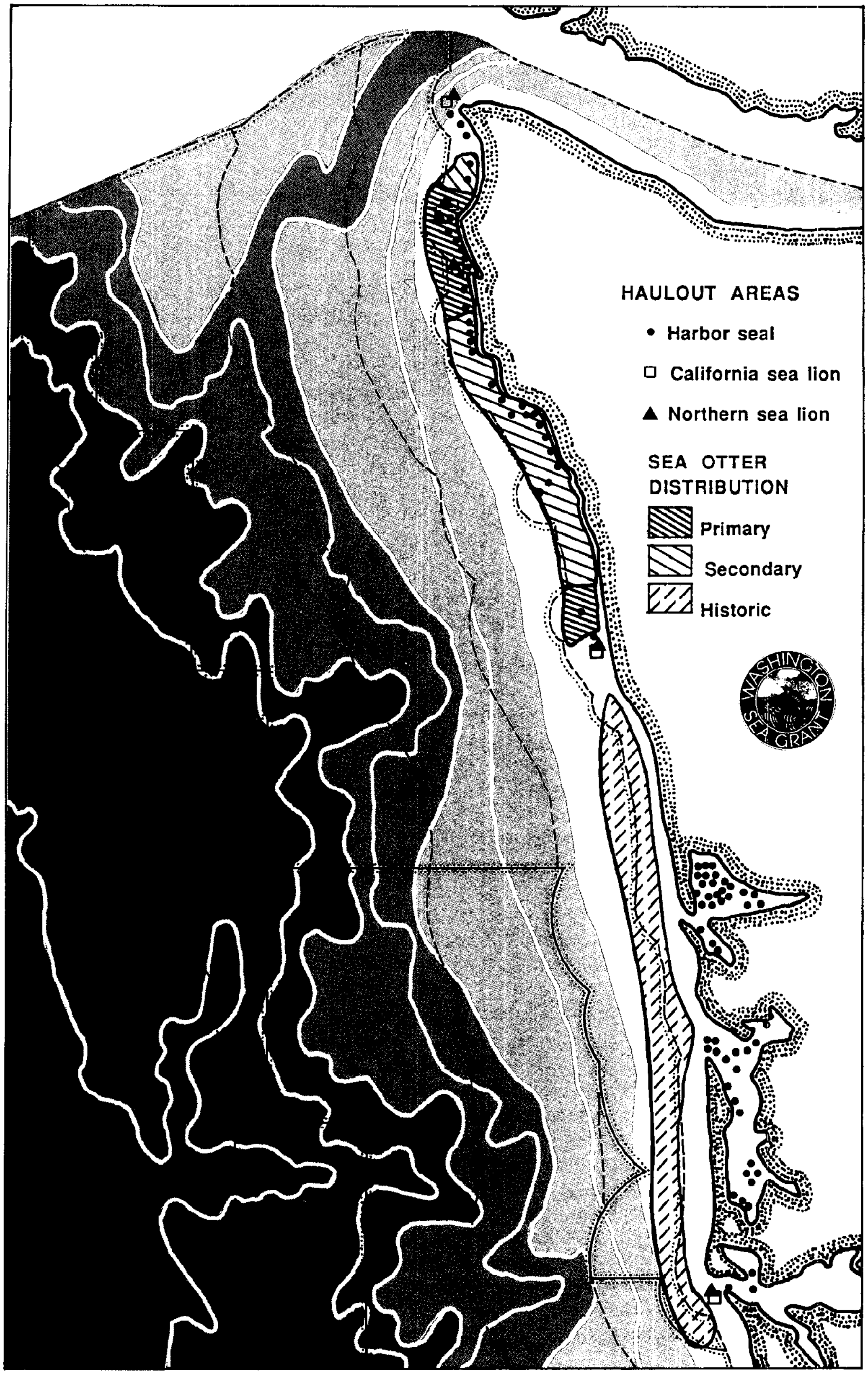


Figure 3.27 Distribution of sea otter ranges and harbor seal and sea lion haulout sites along the Washington coast (Source: S. Jeffries, WDW).

subadults, and adults migrate as far north as Alaska after the breeding season. They are increasingly visiting the Washington coast associated with rapidly growing populations, sometimes seen in the water (but not hauled out) in estuaries.[78,127,150]

Two sea lion species are regular migrants to Washington. Both species are found throughout coastal and inland waters, with seven haulout sites along the outer coast (Figure 3.27). Their diet consists mostly of fish and squid.

The Northern, or Steller, sea lion ranges from the Aleutian Islands to California, with the majority of the population found in Alaska. It breeds on coastal islands during summer throughout its range, but no rookeries are known in Washington. This species is present around Washington coastal haulout sites all year, but population numbers peak in October and November.[42,78,161] These sea lions commonly are observed in coastal estuaries during spring when prey are abundant.[150] Northern sea lion populations in Washington were estimated during the 1970s at about 450 in winter and about 600 in summer.[150] Northern sea lion populations are rapidly declining in parts of the Aleutian Islands, but appear to be stable in British Columbia, Washington, Oregon, and California at about 11,000 animals total.[112] However, the National Marine Fisheries Service is studying the possible threatened or endangered status of this species in the North Pacific.[72]

The population and breeding center of the California sea lion is in the California Channel Islands and Baja California, where the entire population resides in summer.[78] In late summer after the breeding season, male California sea lions migrate as far north as Washington and reach maximum abundance there in winter. Populations have been expanding throughout their range, with 5,000 to 6,000 animals migrating into Washington and British Columbia waters annually out of a total North Pacific population of about 177,000.[79,161]

CETACEANS

Cetaceans are present off Washington all year, but there is considerable variation in species composition and population numbers. In early spring, cetaceans are most abundant nearshore during gray whale migration. During late spring, the highest cetacean populations are found on the outer shelf and shelf edge, and include a number of species. In fall, populations are highest on the outer shelf and slope habitats, composed mainly of southbound gray whales, as well as Dall's porpoises and Pacific-white sided dolphins. Of the important marine mammals off the Washington coast (Tables 3.4 and 3.5), all the large cetaceans are endangered.[22]

The most abundant cetaceans in Washington are the harbor porpoise and the California gray whale. Characteristics of the harbor porpoise have been reviewed recently.[10,161] It is the smallest cetacean in the northeast Pacific, and probably the most abundant in nearshore waters. An estimated 50,000 harbor porpoises inhabit the coastal waters of Washington, Oregon, and California. Harbor porpoises are observed in small groups within 40 km of the coast feeding on herring and anchovy, with an extremely patchy distribution. The species is believed to avoid vessels and is very sensitive to disturbance. Because of this sensitivity, it is hard to gather accurate population data. Observed populations in Washington are highest in September, and very few are observed in January, but it is not known whether this difference is caused by migration. Harbor porpoises are believed to breed in Washington because females are observed with celfs.

Approximately 17,000 California gray whales live in the northeast Pacific.[80] They annually migrate north to feeding areas in Alaska between March and June, and south again to Baja calving and breeding grounds from October to December. They migrate in relatively shallow water, with most animals observed within a few kilometers of shore in depths less than 50 meters.[161] Their peak period of abundance off Washington coincides with the northern migration in February and March and with the southern migration in November and December. There is recent evidence of 10 to 15 summer residents thought to be attracted by adequate food resources along the Washington coast at locations such as Kalaloch, Cape Alava, and Cape Flattery.[161] Juveniles are sometimes observed in Puget Sound.[78] Unlike most other cetaceans, gray whales feed on bottom animals; in Northwest waters these prey include amphipod and mysid crustaceans near kelp beds.[80] The gray whale was severely depleted by hunting, and though now recovering to near-historic levels, it is still classified as a federal endangered species.

CONFLICTS BETWEEN MARINE MAMMALS AND OFFSHORE OIL DEVELOPMENT

Oil and gas exploration, development, and production activities—including seismic surveying, drilling, air and ship support, construction and operation of on- and offshore facilities—can cause behavioral and physiological impacts on marine mammals through physical or acoustic disturbance, or direct contact, inhalation, or ingestion of oil. In general, the ability to project potential impacts of petroleum activities on marine mammals in Washington is limited by lack of knowledge about the mammal species, rather than by lack of generic studies of oil impacts on mammals.[78] For many local marine mammal species, there is little information on the patterns of seasonal and interannual distribution and abundance, feeding and prey selection, critical habitats, reproductive habits and rates (for species breeding locally), and effects of existing anthropogenic disturbances. Even on the assumption that generic studies of oil impacts on marine mammals can be applied to species and conditions in Washington, local data are required to determine how many animals may be at risk, at what times and under what conditions, and what the significance of this exposure may be for populations as a whole.

The following discussion of generic impacts is derived principally from several recent reviews.[34,46,56,57,61,176]

Space-Use Conflicts

Conflicts of offshore oil and gas activities with marine mammals can arise when these activities, from seismic exploration to exploratory and production drilling and transshipment, take place in a location that the animals are accustomed or obligated to use. The resulting impact would depend in part on whether the displacement is temporary or prolonged. Such locations include migratory corridors, breeding and nursery grounds, and feeding grounds. In particular, the concept of critical feeding areas is widely discussed, but there are few hard data verifying their locations or nature, and likewise few studies of the extent to which marine mammal species can utilize alternate feeding grounds in the event of space-use conflicts. Areas near breeding grounds could be considered critical feeding areas as well. Displacement of mammals from accustomed habitats could increase stress and competition for resources among animals in remaining habitats. Collisions between mammals and vessels can be minimized but not eliminated.

Space-use conflicts between oil and gas development and marine mammals are plausible but largely hypothetical; recent reviews do not document any instances—indeed, any studies—of potential disruption of mammal habitat or migration by petroleum activities. Many mammal species present off Washington also occur in areas of California that have petroleum activities, and few impacts on cetaceans from these developments have been documented. However, in the absence of detailed studies, the potential significance of space-use conflicts on marine mammals in Washington must be considered largely unknown.

Noise and Other Disturbance

Many marine mammals have very sensitive hearing and depend on underwater sounds for communication, location of food, spatial orientation, and predator avoidance. Acoustic disturbances may produce a variety of behavioral and physiological effects on marine mammals, depending on the species studied, the stimuli, transmission medium, season, ambient noise, previous exposure of the animal, and physiological or reproductive state of the individual. There are few studies of noise disturbance on marine mammals, except for those directed at certain species such as the gray whale.

Air guns, now preferred over explosives for seismic surveys, do not physically injure marine mammals, as explosives can at close range. One set of studies noted that gray whales slowed their swimming and altered their course to remain about five kilometers away from signals emitted by an air-gun array, and exhibited a dramatic "startle response" within one kilometer.[105] There was no evidence, however, that large-scale migration patterns or population abundance of gray whales are currently affected by the level of seismic exploration occurring in the study area (Monterey, California). The National Marine Fisheries Service has recommended, and seismic surveyors are reported to be adopting, a policy of conducting surveys only when no gray whales are within two kilometers of the vessel.[45] There also was no evidence in the Monterey study that local southern sea otters were affected by air-gun signals 900 to 1,600 meters offshore.

Aircraft and vessel noise can cause extreme disturbance in pinniped rookeries. Mass dispersement from these sites can lead to separation of mother-pup pairs, and the accidental injuring and death of pups. Repeated disturbance may cause eventual abandonment of these habitats. As the only pinnipeds known to breed in Washington, harbor seals are the most susceptible, especially during the spring-summer pupping season. However, there is no evidence that aircraft and vessel disturbance are affecting pinniped population abundances in Washington under current conditions.

Cetaceans may respond to sudden noise impulses in a variety of ways including sounding, aggregating, and dispersing followed by regrouping. Some species, such as dolphins, may be attracted to boat noise. Vessel activity and other activities near shore are a potential source of disruption to harbor porpoise populations, which are poorly studied but believed to be very sensitive. Other species living in close proximity to human activities, such as gray whales, may become habituated to low levels of disturbance. Tests of gray whale and sea otter responses to underwater playback of recorded sounds of drilling, production, and helicopter overflights in some cases showed avoidance by gray whales similar to that induced by single air-gun signals; only the loudest sounds, such as those from drillships, produced responses at distances greater than 100 meters.

Oil Contamination

Oil can affect mammals directly through external contamination, or through internal contamination by ingestion or inhalation. Mammals can also be indirectly affected by mortality or tainting of prey organisms and can experience long-term effects from chronic low-level exposure to contaminated water, food, or sediment in addition to short-term effects from a spill.

External oil contamination from spills reduces the insulative capacity of fur in otters, seals, and sea lions. The animal can respond by increasing its metabolic rate to produce more body heat, but if unable to compensate for the loss of body heat the animal may die. This problem is more acute for sea otters, which have no blubber layer, and for harbor seal pups than for adult seals and sea lions. Eye and skin irritations and possible infections may also be caused by contact with oil, and the sense of smell may be disrupted by the vapors.

The effects of oil consumed through contaminated prey, grooming of fur, or nursing depend on the amount ingested, the physiological condition of the animal, and whether the ingested oil is regurgitated or inhaled. Large amounts of ingested oil can be tolerated if passed rapidly through the intestinal tract. Hydrocarbons may be rapidly excreted, metabolized, and stored in the liver and other tissues and/or excreted through the kidneys. Cetaceans should be able to detoxify ingested oil. If the amount of oil consumed exceeds the body's ability to filter and remove toxins, the result may be kidney failure and eventual death.

Inhalation of just a few milliliters of liquid oil, which can follow regurgitation, can be fatal. Inhalation of oil vapors also can have toxic effects. In most cases, it is unlikely that marine mammals would inhale significant quantities of vapor, because of the rapid dispersion of gases in open waters. Fur-bearing species that are externally contaminated would be exposed for longer periods of time, however.

Oil has lethal and sublethal effects on food organisms. Benthic, nektonic, and planktonic prey species in the immediate vicinity of a spill would be killed, and growth and reproduction of prey could be retarded at a greater distance from the spill site. Species with narrow spatial and dietary ranges, such as sea otters and harbor porpoises, would be more vulnerable to such indirect effects than more widely dispersed, opportunistic feeders such as Dall's porpoises and harbor seals. However, the magnitude of possible indirect impacts is not well studied.

Mammals may be subject to long-term effects of oil contamination from direct exposure and from consumption of contaminated prey. To the extent that petroleum hydrocarbons cannot be eliminated or metabolized, they are concentrated within the tissue, especially blubber. The implications of this storage are uncertain. Migrating marine mammals utilizing fat reserves may be temporarily exposed to increased levels of hydrocarbons in the blood stream. This release of bioaccumulated hydrocarbons may have subtle physiological effects or synergistic effects through interactions with other pollutants accumulating in the body. Species at greatest risk for these types of affects would be those frequenting chronically contaminated areas such as harbors and other areas of heavy marine traffic.

Sea Otters and Pinnipeds. Sea otters are at greater risk from oil spills than any other marine mammals for a variety of reasons. They spend almost all of their time in the water (resting, grooming, and feeding) and migrate little. They frequent protected coastal sites where oil is likely to persist, and are especially attracted to kelp beds, where the heavier components of oil remain. Sea otters rely on local food resources within a limited territory, particularly sedentary or slow-moving benthic species that are relatively sensitive to oil contamination. Extensive grooming of their fur would increase the possibility of ingesting toxic hydrocarbons and would prolong exposure to the vapors. Sea otters, harbor seal pups, and Northern fur seals are particularly sensitive to loss of insulation due to oil contamination because of their high metabolic rate and reliance on insulation from air trapped in their dense, clean fur.

Other adult seals and sea lions are less vulnerable to loss of insulation because they possess some blubber layers beneath the skin that insulate even when the fur is oiled. The "curious" nature of seals and sea lions could attract these species to an oil slick, but being migratory, seals and sea lions in theory also have some capacity to avoid oil spills, unless one should strike them on breeding or pupping grounds. Pupping and nursing pinnipeds that congregate in large groups are vulnerable to disruption of sense of smell—especially harbor seals, for whom smell is important to mother-pup bonding.

Kelp beds may be considered critical habitat for Washington sea otter populations,[21] and impacts of oil and petroleum development that affect kelp beds could also affect sea otters. Because otters are probably more sensitive than kelp to direct contact with oil, the significance of effects on kelp would be mainly in limiting possible recolonization and future expansion of the sea otter population. No recent inventory of kelp bed distributions that could be used to determine potential sea otter habitat has been made on the Washington coast.[77]

Cetaceans. Although many cetaceans swim and dive deep in the water, like all mammals they must surface to breathe, making them susceptible to spilled oil. The outer skin of cetaceans, composed of living cells, may be seriously affected by contact with oil. Cetacean eyes are less likely to be affected, however, since contact is expected to be brief. Smooth-skinned species such as dolphins may retain less oil and be less vulnerable than rough-skinned marine mammals such as gray whales, especially if confined in a contaminated area. Inhalation of some petroleum vapors could be harmful if an animal surfaces in a fresh, unweathered spill. Cetaceans have a unique adaptation of the larynx, however, which prevents them from inhaling regurgitated liquid oil.

Cetaceans have the greatest swimming ability, and so theoretically the greatest ability of all mammals to avoid the impacts of oil spills. However, the data on oil avoidance by cetaceans are inconclusive. Gray whales moving through California waters where natural seepage occurs have been reported to show avoidance behavior when encountering areas of natural oil seeps. The migration along particular routes may be so imprinted in mammalian behavior patterns, however, that complete avoidance would not be possible.

Baleen whales, which filter large volumes of near-surface water, are theoretically most likely to encounter slicks and contaminated sediments and food sources. The endangered whale species in state waters (Table 3.5) are mostly surface-feeding baleen whales, which would be susceptible to contamination if unable to avoid a spill. These species are vulnerable because bristles on the baleen may be fouled (especially the fine bristle filaments of right whales), interfering with feeding efficiency. Their diet of plankton also is most susceptible to contamination by oil, if not to population depletion. Baleen whales that feed by skimming the water surface (e.g., right whales) are more likely to be affected than gulp feeders such as humpbacks. Porpoises and toothed whales (e.g., sperm whales), which feed on subsurface fish and squid in open waters, should encounter relatively lower levels of contamination. Gray whales, as bottom feeders, also could be exposed to oil from sediments and benthic prey, as well as from contact at the water surface. The gray whales' habit of migrating very close to shore could expose them to highest levels of sediment contamination from spills contacting the shore. Gray whales resident in Washington apparently select preferred feeding areas (such as kelp beds), and would be vulnerable to oiling of those habitats.

Oil spills would appear to pose the major threat for impacts on marine mammals by oil and gas development off the Washington coast. Chronic contamination by small releases of oil from platforms are minimal and likely to be dispersed at sea with limited impacts. The greatest potential impacts would clearly be on sea otters if they were exposed to a spill from a drilling site on the northern coast. The small number of sea otters on the Washington coast, their limited distribution, and their particular vulnerability to external oiling, all pose the risk that an oil spill striking their restricted nearshore range could seriously reduce the local population of this state endangered species.

In general, impacts on seals and sea lions could be expected from a spill, depending on the season, but would be unlikely to affect overall populations. Intake of oil through ingestion would not appear to be a major route of contamination for most cetaceans in Washington, and external contamination of large cetaceans is probably not a serious risk, because of their avoidance abilities. A spill could become a problem if it impinged upon harbor porpoise habitat, which is poorly known, or on the Grays Harbor and Willapa Bay nursery grounds of harbor seals during the spring and summer pupping season. There also remains the possibility that an offshore spill could directly impact individuals of endangered cetacean species that occur rarely in Washington, such as blue, right, or humpback whales, if they were in the vicinity at the time of an incident, or if critical feeding areas were affected.

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4

Commercial Fishery Species of the Washington Coast and Potential Impacts of Offshore Oil and Gas Development

Several properties of fisheries are important for understanding how fishery populations and availability, the factors that affect the fishing industry, may be impacted by oil and gas development. For the most part fishing effort targets adults of fish species. However, oil and gas activities generally have the potential to affect most or all of the life stages of fish species to varying degrees.

The abundance of adult fish is believed to be determined mainly by events affecting the population when today's adults were young. Fish typically pass through egg, larval, and juvenile life cycle stages before reaching adulthood. These stages may inhabit different environments than the adults and are typically more sensitive to environmental stress. In many species (such as cod), adult female fish typically produce millions of eggs to overcome the very high natural mortality rates in the sea and produce a few surviving progeny. Other species (such as salmon, lingcod, and some rockfish) produce fewer eggs and have a higher degree of parental care.

Because fish typically reproduce once seasonally, they produce annual groups of offspring called *year-classes*. As the animals in these year-classes mature through their various life cycle stages, natural mortality acts to reduce their population numbers. Scientists theorize that there is a critical period sometime early in the life cycle of a fish stock, after which the mortality rate decreases significantly. According to the theory, the size of the adult population when the year-class matures is determined principally by the survival through this critical period. This survival rate determines what is called the year-class strength. A strong year-class promises large populations in the future, a weak year-class small populations. Typically, there is considerable variability in the abundance of year-classes from year to year.

Fish become of interest to fishermen when they become large and densely aggregated enough to be profitable to catch. The age at which this happens varies with species. At this point, the fish are said to enter, or *recruit to*, the fishery, and the population number present in the year-class at recruitment is referred to as the *recruitment strength.*

A major job of fishery managers and biologists in wild-capture fisheries (versus aquaculture) is to monitor year-class strength and predict levels of recruitment to the fishery. The size of the fishable population in a given year is the sum of all the year-classes above the recruitment age. The abundance of a fishery stock builds after a series of strong year-classes, and declines after a series of weak year-classes. Fishery managers attempt to adjust the level of fishing to the fluctuations in the stock size to prevent overfishing.

Normally, for most marine fishes, the number of eggs produced is so large that the strength of a year-class is independent of the number of spawning adults. In this situation it is believed that year-class strength is determined by environmental conditions. However, adult fish populations can drop so low that they do not produce as many offspring as the environment will support, and year-class strength becomes limited by the size of the spawning population. If the decline of the adult population has been caused by fishing, the population is said to be overfished. There are two tell-tale indications of overfishing. First, it takes more and more fishing effort to catch the same yield of fish; that is, catch-per-unit-effort (CPUE) declines. Second, the catch becomes younger and younger in average age. These warning signs indicate to fishery managers that restrictions on the fishery are needed. These take the form of restrictions on the total amount of catch (by placing limits on time or area of catch to achieve the same effect) or requirements that fishing gear allow younger animals to escape to preserve future spawning populations.

Assessment of fishery abundance and management of catch are guided by the concept of fishery stocks. A *stock* is a geographic assemblage of a fishery species that interbreeds. Each has a common genetic inheritance, spawning habitat, and migration pattern, and is presumed to be the fundamental population unit whose abundance rises and falls together. Fishery biologists attempt to distinguish stocks through common genetic characteristics such as slight variations in shape and biochemical tracer composition.

These considerations dictate the ways in which environmental stresses, such as those that might arise from oil and gas development, affect fishery populations. Simple mortalities or other effects on adult fish populations are not the primary concern arising from environmental stresses, unless they are so severe as to reduce the spawning population significantly. In general, adults have greater tolerance to stress than fish at other life cycle stages, in part because their greater mobility and geographic dispersal reduces the impact of geographically localized stresses.

The greatest concern is for stresses that affect the egg, larval, or juvenile stages and thus year-class strength. These life cycle stages are short in duration and are often bound to a limited geographic area or type of habitat. For example, some fish eggs and larvae are found only very near the sea surface, and juveniles of many species rear in nursery areas close to shore. These life stages have no means of avoiding contaminants or other stresses that might occur in such habitats. The impacts of such stresses might not have a visible effect on fishery yield for a number of years, corresponding to the age of the affected species at recruitment.

SALMONIDS

Salmonids (salmon and sea-run trout) once supported the largest and most valuable commercial and sport fisheries in coastal Washington. Salmonid catch is now exceeded in tonnage by the groundfish catch, but because of their high market price, salmonids still support a more valuable fishery. The five species of salmon and two major species of sea run trout form a complex assemblage because most of the river systems in the Northwest contain separate stocks of several species. Salmonids also are supported by, even in many cases dependent on, artificial enhancement through the hatchery system.

LIFE CYCLES OF COASTAL AND COLUMBIA RIVER SALMONIDS

The general life cycle of salmonids is well known, but there are variations between species and stocks, and some important segments of the life cycle (e.g., the period just after entering the ocean) are still poorly studied. The life cycle characteristics of major coastal and Columbia River salmonids are summarized in Table 4.1 and depicted in Figure 4.1. Generally, adult salmonids enter their streams of origin from the sea during the late summer and spawn in fall. They lay their eggs in stream gravel and the salmon species die, while the trout species can return to the sea. The eggs hatch and grow into fry during winter. In spring the fry emerge from the gravel and spend anywhere from a few weeks to a few years in fresh water. During spring and early summers, the juveniles feed and make the transition to salt water in estuaries, which are critical habitats, before migrating to the sea to grow to maturity.

Salmonid resources of Washington coastal estuaries have been summarized by the National Oceanic and Atmospheric Administration (NOAA).[75] Additional data on Columbia River estuary salmonid resources have been reviewed recently.[34] At sea, some species migrate along the shelf into the Gulf of Alaska and remain in roughly the upper ten meters of the water column. Recent data suggest that adult coho and chinook salmon remain on the Washington shelf rather than migrating long distances.[30] After six months to six years at sea, the adults return to begin the cycle again. Salmonids may be caught either at sea or in estuaries or rivers as they are returning to spawn.

The complexity of salmonid life cycles is illustrated by the chinook salmon, which exhibits at least three distinct life history patterns, distinguished primarily by the time of upstream migration and the duration of the freshwater phase.[15] Spring chinook, which head upstream to spawn from March through August, occur primarily in large river systems where flow is adequate for in-stream residence over the summer months.[97] Summer chinook enter the rivers from late spring through mid-summer, and fall chinook migrate upstream from August through November in northern streams and mid-July through November or early December in Willapa and Columbia River streams.[6,97] Chinook fry emerge from the gravel late the following winter or early spring. Juvenile fall chinook depart for the ocean at three to five months after emergence, while juvenile

Table 4.1 Salmonid Species on the Washington Coast

Species & common names	Spawning habitat preferences	Return migration/spawn	Age at return	Fresh water residence	Problem stocks
Chinook (*Oncorhynchus tshawytscha*)[1,2]					
King, tyee, blackmouth	Large rivers with adequate late summer flow (spring)	Soleduc-Hoh, Queets-Quinault, Chehalis stocks: Mar-Aug, spawn Aug-Oct (spring); Aug-Nov, spawn Sept-Dec (summer/fall) Willapa stock: July-Dec; spawn Sept-Jan Columbia stocks: Feb-Nov (peak late Aug.)	4-7 years	3-5 mos, entering the sea Apr-Jun (summer/fall)	Hoh, Queets, Chehalis spring wild stocks; Columbia Spring Creek fall hatchery stock; Columbia spring & fall, Grays Harbor spring & fall wild stocks
Coho (*Oncorhynchus kisutch*)[1,2]					
Silver, silverside, hooknose	Smaller tributary streams, side channels in large rivers	Sept-Jan (as late as Feb in Grays Harbor); (Aug-Nov in Columbia, peak Sept-Oct)	2-3 years	1 year	Queets, Grays Harbor (Chehalis) wild stocks
Chum (*Oncorhynchus keta*)[1]					
Dog		Oct-Jan	3-4 years	2-3 months; Jan-June	Humptulips?
Pink (*Oncorhynchus gorbushca*)[1,3]					
Humpbacks, humpies		July-Sept; spawn Aug-Oct	2 years; unlike Puget Sound, runs in all years	2-4 months	
Sockeye (*Oncorhynchus nerka*)[1]					
Red, blueback (kokanee, silver trout landlocked)	Rivers with large lakes (Ozette, Quinault, Columbia)	Mar-Dec (mostly Jun-Aug); May-Oct (peak Jul) in Columbia; spawn Oct-Jan	3-4 years	1-2 years in lakes; downstream Mar-Jul	
Steelhead trout (*Salmo gairdneri*; renamed *Oncorhynchus mykiss*)[5]					
Anadromous rainbow, silver trout, salmon trout, ironhead, steelies		Summer run May-Oct, spawn following spring; winter run Nov-Apr (peak Jan in Columbia), spawn Mar-May (wild stocks), Dec-Feb (hatchery)	In ocean 2-3 years (1 year for many Columbia summer stocks)	2-3 years (wild stocks); 1 year (hatchery)	

1 Phinney & Bucknell (1975); Anon. 1982
2 D. Stone, WDF (personal communication); PFMC (1988)
3 Pauley et al. (1988)
4 Gallagher (1979)
5 Gibbons (1988); Anon. (1982); Pauley et al. (1986a)

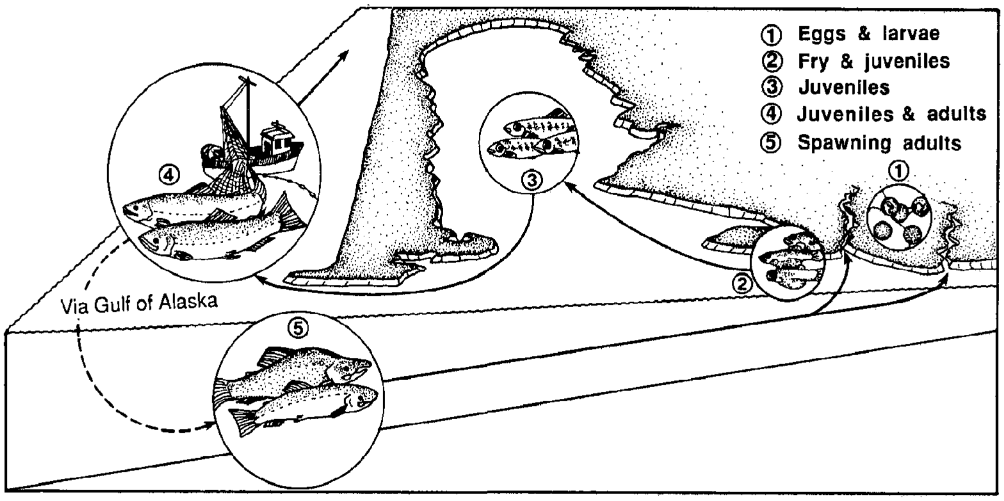


Figure 4.1 Schematic depiction of salmonid life cycle using Grays Harbor as an example of estuarine nursery grounds (after Phinney and Bucknell 1975).

spring chinook may remain in the river for more than a year and migrate seaward in the second spring after hatching.

The timing of upstream and downstream migration in coastal salmonids is summarized in Table 4.1. The major differences between the remaining salmon species are that pinks and chums have a short freshwater residence as juveniles, while coho, steelhead, and sockeye rear in freshwater (sockeye in lakes) for a year or more before entering the sea. Consequently, lakes and lake tributary systems, such as the Soleduc-Hoh (Lake Ozette), Queets-Quinault (Lake Quinault), and Columbia River basins, are important to coastal sockeye stocks. Some landlocked sockeye never migrate seaward and are referred to as kokanee.

The small size of pink, chum, and fall chinook when they enter salt water makes these species especially vulnerable to disruption of food supplies or to other adverse environmental conditions in nearshore waters, including oil spills. Also, pink salmon have a rigid two-year life cycle and coho have a rigid three-year life cycle, compared with three to six years for the other salmon species. The pink stock that returns in even-numbered years, if present at all, is much weaker than the odd-year stock.

Steelhead trout are sea-run rainbow trout [89] that are mainly fished in rivers rather than at sea. Unlike salmon, steelhead do not always die after spawning, and may return to spawn up to four times—though the occurrence of this trait varies by sex and latitude and from stream to stream. Steelhead have summer and winter runs,[41] but in large river systems such as the Columbia, upstream migration may occur for most of the year.[6,89] Commercial fishing for steelhead is limited to Indian tribes only; nontreaty sport fishermen and tribes share the resource in common.[89] Cutthroat trout (*Salmo clarki*) are also a popular anadromous sport fish that does not die after spawning. They are less abundant than steelhead and do not migrate into Alaskan waters as the other salmonid species do, but remain within about 30 km of the coast.[64]

Salmonids in general have similar food habits that are determined by their size, which in turn is related to their stage of development.[64,105,106] Seaward-migrating juvenile salmonids in estuaries feed mainly on benthic crustaceans, other benthic invertebrates, and insects at the water surface. As they grow and move into open waters, they switch to zooplankton prey, and at larger sizes they increasingly take small fishes, including baitfish such as herring, anchovy, sand lance, smelt, and juveniles of other fish species including salmon.

EARLY OCEAN RESIDENCE

In general, many scientists believe that the upper limits of salmonid catches are determined by the amount of spawning habitat in rivers, rather than by conditions in the ocean. Production can be important in determining year-class strength. According to this line of reasoning, ocean conditions (including fishing pressure) can affect whether salmonid populations achieve the potential that existing spawning habitat (and hatcheries) can support. Current thought is that the period right after salmonids enter salt water is a critical stage for survival of the year-class. Conditions such as food supplies and offshore transport, both related to upwelling, may affect survival. Validation of these hypotheses is hampered by lack of research, however.

The large-scale movements of salmonids in the northeastern Pacific have been well documented. Research conducted by the International North Pacific Fisheries Commission (INPFC) since 1955[44,45,81] has generated working models of migration for many species.[37,45] Many juvenile salmon from the Washington coast, along with stocks from California and Oregon, are believed to migrate northward in a narrow band along the coast into the Gulf of Alaska.[45]

Juvenile salmon are known to feed in the shallow waters of coastal estuaries such as Grays Harbor and Willapa Bay.[103] Recent work conducted off the coasts of Washington, Oregon, and Vancouver Island has documented some juvenile salmon distributions and movements in Northwest coastal waters.[29,32,33,92,117] This work suggests that many juvenile coho salmon linger on the Washington/Oregon inner shelf during their first year in salt water. Purse seining off Oregon and Washington during the summer of 1983 (an El Niño year) resulted in the capture of seven species of salmonids; chinook and coho were most abundant, followed by steelhead, cutthroat, pink, chum, and sockeye.[33] In a 1984 sampling, coho were most abundant, followed by chinook, chum, and pink salmon.[29] This survey covered only the area from 37 meters depth to 37 kilometers offshore, however.

In contrast to salmon, steelhead apparently migrate directly offshore from their stream of origin, rather than migrating northward and westward along the coastal belt.[45] This pattern of movement was confirmed by purse seine sampling off the Oregon and Washington coasts, where juvenile steelhead migrating out of adjacent streams generally occurred farther offshore than juvenile coho and chinook salmon, and apparently moved out of the sampling area earlier than the salmon.[73,93,117] Less is known about the open-sea distribution of steelhead than of other salmonid species, because they do not school in commercial salmon fishing areas.[89]

The period of early ocean residence is believed to be critical for determining year-class strength in salmonids. Feeding and predation conditions in this small area and short time appear to be the dominant factors affecting salmonids in salt water.[31]

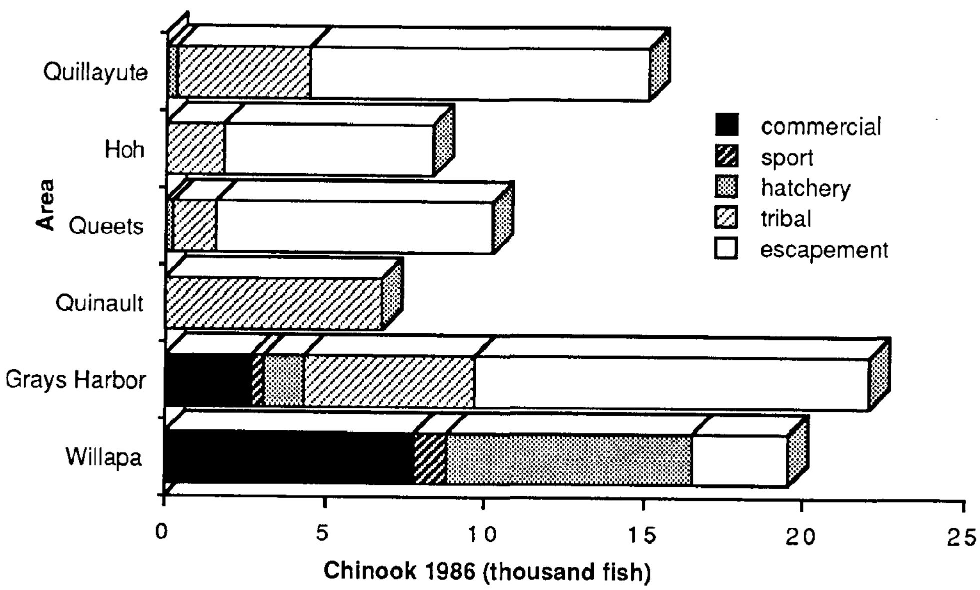
DESCRIPTION OF FISHERIES

Salmonids in the ocean off Washington are most commonly caught by trolling or in ocean recreational fisheries. Trolling involves pulling a number of baits or lures behind a moving boat. Recreational fishery is done on charter boats and private boats. Drift or fixed gillnets and purse seines, gear used elsewhere for salmonid fishing, are not allowed off the Washington coast. Estuarine fisheries include both hook and line recreational fisheries and both drift and set gillnet commercial fisheries. Salmonids in rivers may be caught recreationally by hook and line, but most of the river take is by gillnets, commonly near the river mouth. Gillnetting is conducted only during the upstream migration period, whereas trolling can be conducted at all times of year. Gillnetting is the primary method used by Indian tribes. Determining which fish can be caught where and by whom is a complex management issue. In general, fish in the north coast rivers, and steelhead, are available only to the tribes, and to sports fishermen in some locations.

Because of their anadromous habit and broad migration patterns, the geographic scope of salmonid stocks that might be affected by offshore oil development is not easy to define. Salmon and steelhead from virtually all streams in Washington—as well as many in Oregon, California, and British Columbia—migrate through Washington shelf waters, so that any positive or negative impacts could be felt in all of those locations. This report focuses only on stocks in coastal streams (including the Columbia River). In part this is because salmonid resources of the Strait of Juan de Fuca and Puget Sound were reviewed in previous documents relating to oil transshipment.[74,107,108] It should be remembered, however, that the analysis presented here needs to be extended to include salmonid stocks from a broader geographic area.

The sizes of salmonid runs can be measured by the number of fish that are caught and that enter the mouths of rivers on their spawning migration. Fish entering the river may be caught by Indians, nontreaty commercial fishermen, or sports fishermen, or they may *escape* to spawn in a hatchery or in the wild. The catch is managed to assure a minimum level of *escapement* for each salmonid stock, a goal that is not always achieved.

The total in-river commercial, sport, and tribal catches, hatchery returns, and wild escapements of coho and chinook salmon in 1986 (the most recent final data published) by river of origin are shown in Figures 4.2 and 4.3. These figures show that commercial catch dominates the southern (Columbia and Willapa) stocks and tribal catch dominates the remaining stocks. These data also show that, despite the tremendous reductions in the populations due to damming and other habitat losses, the Columbia still is the dominant river in terms of salmon production. In



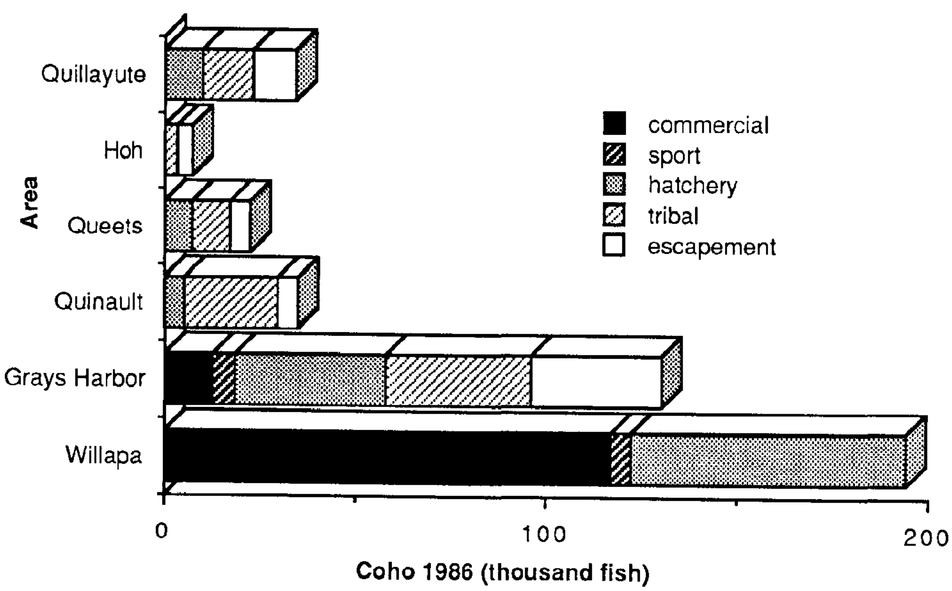


Figure 4.2 Estimated in-river fates of coho and chinook salmon in 1986 by major river on the Washington coast. Salmon species may be caught by tribal, commercial, or sport fishing, they may return to hatcheries, or they may escape to spawn in the wild (data from PFMC 1988).

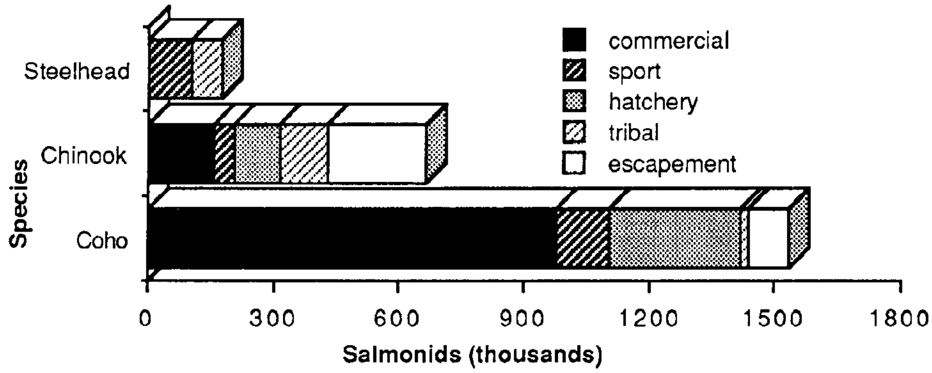


Figure 4.3 Estimated in-river fates of coho and chinook salmon and steelhead in 1986 in the major streams of the Columbia River system. Includes winter and summer runs, but does not include Oregon streams. Salmonid species may be caught by tribal, commercial, or sport fishing, they may return to hatcheries, or they may escape to spawn in the wild (data from PFMC 1988).

1986, an abnormally high year, Columbia returns equaled all other runs combined.[111] Data on what proportion of ocean-caught fish come from each river stock are available but are very complex.[111]

Commercial Fisheries

The principal ocean commercial salmon fisheries operating off the Washington coast are treaty and nontreaty troll fisheries. Figure 4.4 shows general salmon fishing areas off the Washington coast. "Inside" fisheries also harvest salmon in bays and rivers, and include treaty and nontreaty gillnet fisheries. The growth of these fisheries is documented by Henry.[46] Figure 4.5 shows the 1987 ocean commercial salmon troll landings by Pacific Fisheries Management Council (PFMC) area and species. Most of the fishing activity occurs in the Grays Harbor and Flattery areas; the Flattery area has a higher catch per unit of effort.

Historically, the nontreaty troll fishery has landed large numbers of chinook, coho, and pink salmon from off the Washington coast,[46] but fishing effort and landings have declined substantially for this fishery in recent years.[87] Trends in total salmon catch by species for the last decade are shown in Figure 4.6. Boat-days fished averaged 52,200 in 1971-75, fell to 43,400 in 1976-80, and totalled only 3,100 in 1987. Average chinook landings declined from 262,000 fish in 1971-75 to 183,400 fish in 1976-80, and the 1987 catch was 54,600. Average coho landings declined from 849,600 in 1971-75 to 704,500 in 1976-80, and totalled 47,400 in 1987. Landings of pink salmon (in odd years) averaged 49,400 in 1971-75 and 413,000 in 1976-80, but totalled only 2,700 in 1987.[87] These declines have been accompanied by management closures.

Most fishing effort has centered on the Grays Harbor PFMC area where chinook and coho are targeted; pinks are taken primarily off the north coast from the Cape Flattery and Quillayute areas.[87] Historically, most fishing effort has occurred between May and September and is typically highest in July and August. Non-Indian commercial gillnetting occurs in the Columbia River for coho, spring and fall chinook stocks, and occasionally sockeye; in Willapa Bay for chinook, chum, and coho; and in Grays Harbor for coho and fall chinook.[87]

A land-based salmon net-pen culture site is being developed at Westport.

Tribal and Recreational Fisheries

The treaty Indian troll fishery, less restricted by management closures, operates more continually throughout the year than the nontreaty troll fishery. Most of the fishing effort occurs in the western Strait of Juan de Fuca, Cape Flattery, and Quillayute PFMC areas, and landings are typically highest from the Cape Flattery area.[87] Chinook landings averaged 21,140 fish in 1979-87 (range 9,617-36,927), mostly from the same areas, and totalled 28,830 in 1987. Coho landings averaged 60,568 in 1979-87 (range 10,349-123,832), mostly from the Cape Flattery and Quillayute areas, and totalled 88,631 in 1987. Pink landings averaged 10,943 in 1979-87 (odd years) (range 5,063-19,864),and totalled 16,514 in 1987.

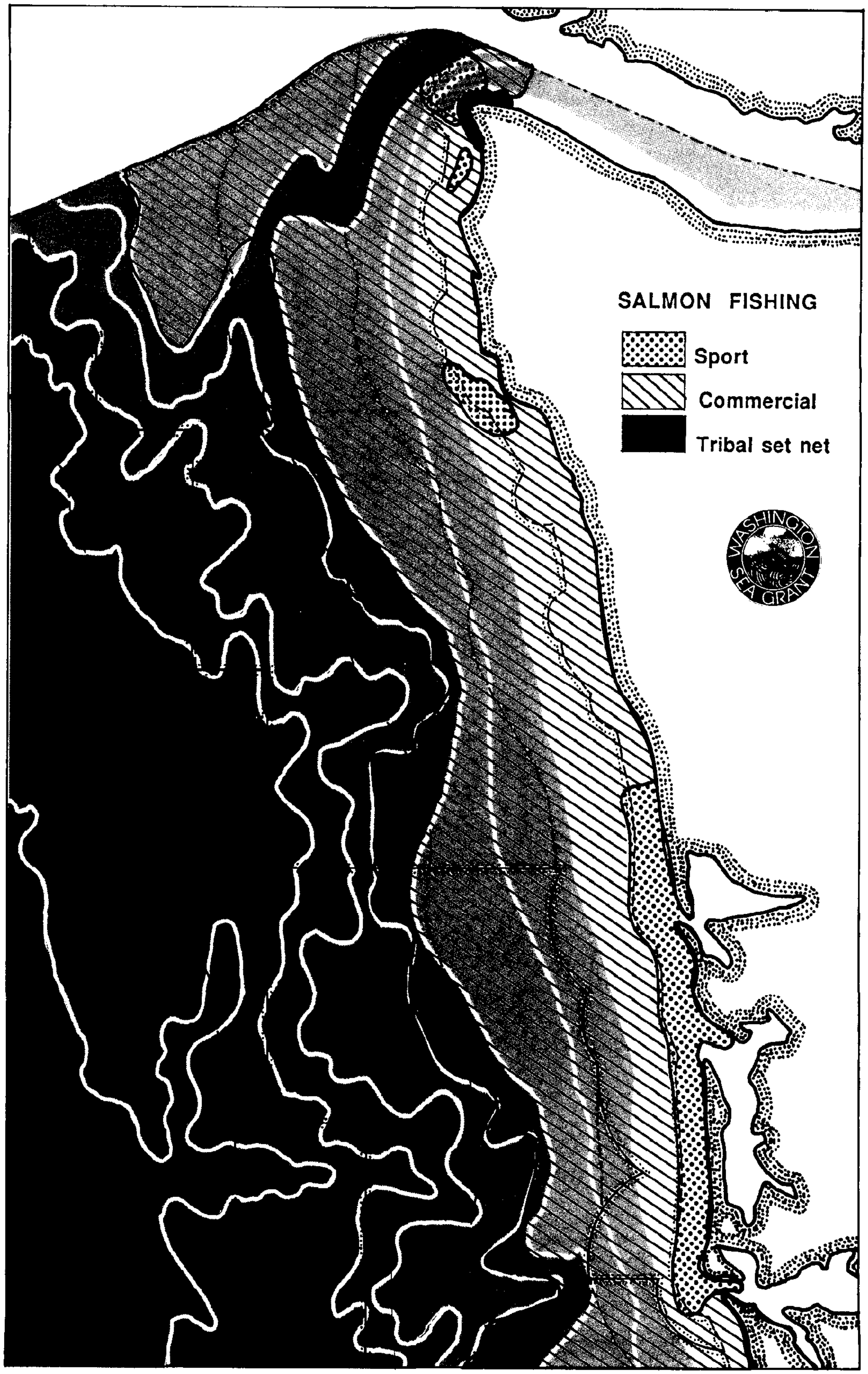


Figure 4.4 Areas for non-Indian commercial and sport salmon fishing and tribal set-net salmon fishing off the Washington coast (after Mills et al. 1983).

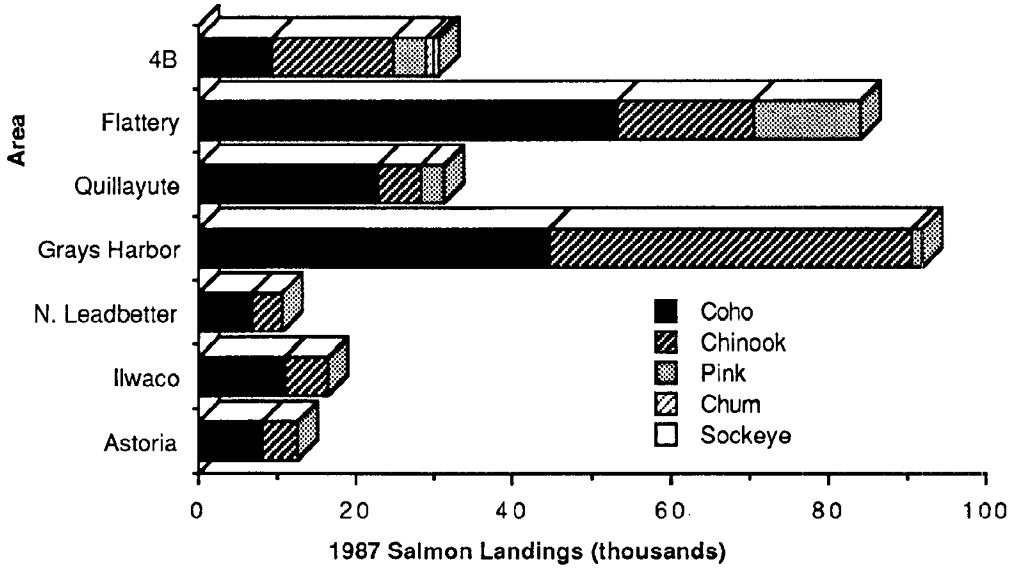


Figure 4.5 Estimated commercial ocean catch of salmon species off the Washington coast in 1987, by PFMC area of landing (4B=western Strait of Juan de Fuca) (data of PacFIN).

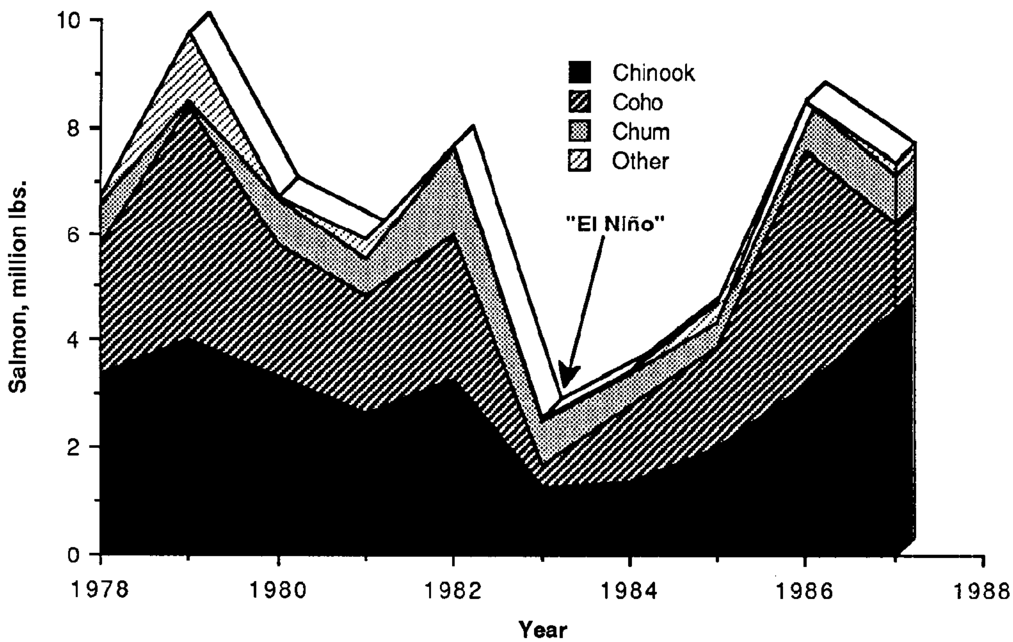


Figure 4.6 Total reported ocean commercial salmon catch trends by species over the last decade off the Washington coast (data provided by Dale Ward, WDF).

Indian gillnet fisheries on coho, sockeye, and spring, summer, and fall chinook stocks operate in the Columbia River; on fall chinook, chum, and coho in Grays Harbor; on coho and spring, summer, and fall chinook stocks in the Queets, Hoh, and Quillayute rivers; and on chum, sockeye, and spring and fall chinook in the Quinault River.[87] Indian tribes dominate the steelhead catch except in Willapa Bay and the Columbia River (Figures 4.3 and 4.7).

The Makah tribe has a designated treaty fishing ground that extends 40 miles off Cape Flattery and a set net fishery along shore near Cape Flattery.

The Washington ocean recreational salmon fishery operates primarily out of Westport, Ilwaco, Neah Bay, and La Push. Landings and effort have declined in recent years due to management restrictions on the catch. In recent years the sport salmon fishery on the lower Columbia has been smaller that the sport sturgeon fishery. Trends in sport salmon catch over the last decade are shown in Figure 4.8. From 1971 to 1975 angler trips for all four ports averaged 482,900, which declined to an average of 428,300 in 1976-80; the total was 100,000 in 1987. Historically, the majority of salmon recreational salmon fishing effort has occurred out of Westport and Ilwaco and operated mainly from April to October, with peak effort and landings in July and August. Chinook landings in 1971-75 averaged 210,400 and declined to 114,500 for 1976-80; the 1987 total was 40,400. Coho landings averaged 567,400 for 1971-75 and 510,900

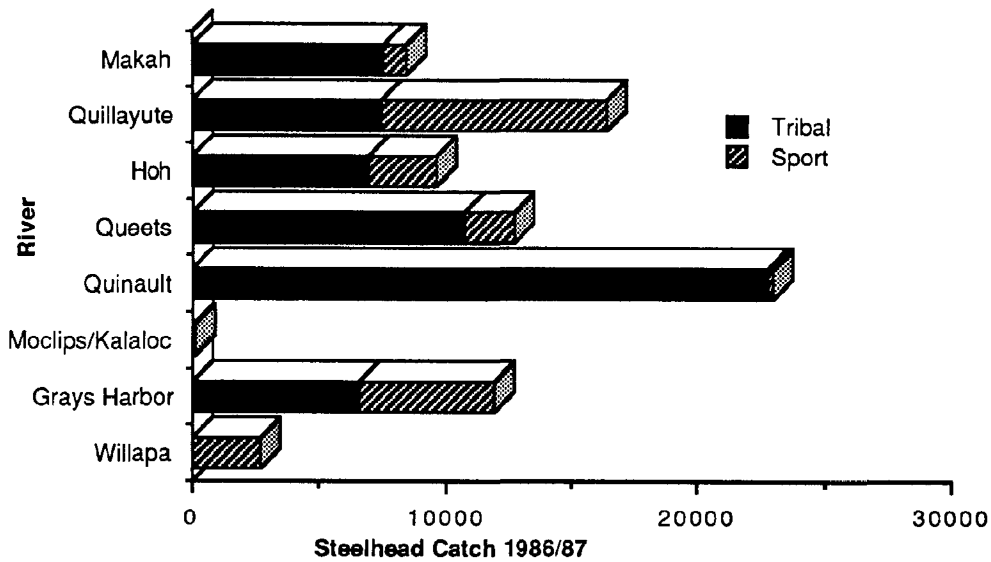


Figure 4.7 In-river tribal and sport steelhead catch by river for the 1986-1987 season (data of WDW). Makah area includes streams entering western Strait of Juan de Fuca. Escapement levels not reported.

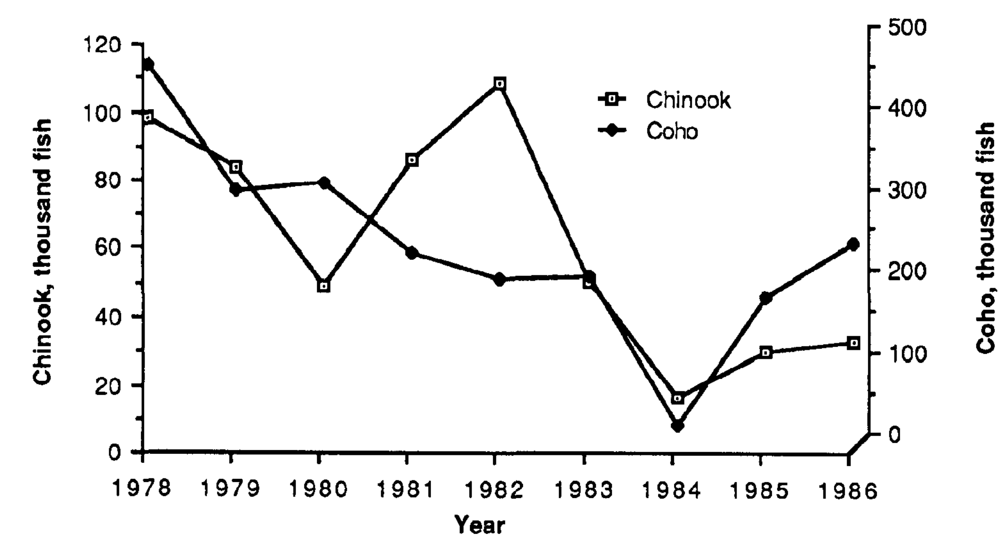


Figure 4.8 Total reported ocean sport salmon catch trends by species over the last decade off the Washington coast (data provided by Dale Ward, WDF).

for 1976-80, and totalled 123,100 in 1987. Pink salmon landings averaged 10,100 for 1971-75 and 26,500 for 1976-80, and totalled 1,600 in 1987 (1987 data are preliminary).[86,87]

STATUS OF STOCKS

Catch in all areas is dominated by coho and chinook although chum salmon are sometimes the highest. Data are presented in Figures 4.5 and 4.6. The following is a rundown of usage of river basins by all species.[97]

Steelhead trout and all five species of Pacific salmon utilize the streams of the Soleduc-Hoh basin. Coho and chinook are virtually all natural production. Chum and pink production is limited. Sockeye utilize Lake Ozette and other streams. The WDF hatchery on the Soleduc River opened in 1970.

All five species of Pacific salmon and steelhead are present in the Queets-Quinault basin, where adult salmon are present virtually the entire year. Chum and pink are present in small numbers, estimated to be less than 1,500 fish. Sockeye utilize Lake Quinault and other streams. A federal hatchery in the Quinault system was constructed in 1971 for production of chinook, coho, and chum.

Chinook, coho, chum, and steelhead and cutthroat trout are common in the Chehalis River basin; pink and sockeye are rarely encountered and believed to be strays from other areas. Spring and fall chinook are present; springs are at low level of abundance. The WDF Simpson Hatchery on the East Fork Satsop River and the Humptulips hatchery on the Humptulips River produce fall chinook, coho, and small numbers of chum. Most of the small drainages and the estuarine area of Grays Harbor have experienced degraded water quality due to domestic, agricultural, and industrial effluents.

Fall chinook, coho, chum, and some spring chinook utilize the Willapa basin. Hatcheries are maintained on the Willapa River for chinook and coho, and on the Nemah River and Naselle River for chinook, coho, and chum.

The six major stocks of anadromous fish utilizing the Columbia River basin are spring, summer, and fall chinook, sockeye, coho, and summer steelhead. Escapement goals for these stocks were developed by the Northwest Power Planning Council,[6] based on estimates of run sizes prior to the construction of McNary dam in 1953. The construction of dams for hydroelectric power production has been a major source of fishery resource depletion in the Columbia River basin. The impacts of dams on fishery resources include delays in upstream migration, mortality of downstream migrants in turbines, increased river temperatures, nitrogen supersaturation, altered flow regimes, and, in the case of Grand Coulee dam, the complete blockage of migration and subsequent elimination of certain upstream runs.[46]

Stocks that have been a chronic problem on the Washington coast include Queets wild coho, Grays Harbor coho (especially Chehalis River), spring chinook stocks of the Hoh and Queets (and to a lesser extent Chehalis River), and some Columbia River chinook stocks.[111] Columbia River summer and spring chinook and Grays Harbor spring and fall chinook were expected to be at levels of abundance below their escapement goals in 1987.[87]

All the stocks of salmon and steelhead on the Washington coast are far below their historic levels of abundance, which were tallied in the early part of this century. It is theoretically possible to restore some salmon populations through catch restriction and artificial enhancement, but in practical terms these measures have not restored populations. Instead, abundance has continued to decline consistently for most stocks.

GROUNDFISH

The term *groundfish* refers to species of finfish that are caught mainly on or near the bottom. Groundfish also may be referred to by names such as demersal fish and bottomfish. This group includes among them flatfishes, rockfishes, and roundfishes, the gadids (codfishes), lingcod, and sablefish (blackcod).

DESCRIPTION OF SPECIES AND LIFE CYCLES

Life cycle and habitats of major species of selected commercially important rockfishes, flatfishes, and roundfishes are summarized in Table 4.2 and illustrated in Figure 4.9. All species live more or less in association with the bottom as adults, but their early life histories and preferences for depth and bottom substrate differ. Many species, such as Pacific Ocean perch, sablefish, lingcod, and English sole, have seasonal onshore-offshore migration patterns associated with both adulthood and the reproductive cycle. Most species spawn in late winter and early spring.[47] The examples presented in Table 4.2 and Figure 4.9, and discussed below, illustrate three life history strategies: planktonic eggs and larvae; benthic eggs and larvae; and female brooding of eggs, with larvae born alive.

Rockfishes

Most rockfish are members of the genus *Sebastes*, which includes more than 20 species occurring in Washington's commercial fisheries.[115] Rockfish are commonly marketed as "snapper." Rockfish occupy a variety of habitats, having evolved a variety of strategies to utilize a wide range of niches in the marine environment. In most rockfish species (widow rockfish being an exception), eggs are fertilized within the body of the female in fall and winter and brooded there for one to two months until after hatching.[40,119] The larvae and juveniles are pelagic, but little is known of the duration or distribution of these phases for most rockfishes in Washington.[66] Adult rockfishes form two assemblages: shelf (0-200 meters) and slope (greater than 200 meters).[79] In Washington, commercially important shelf rockfishes include widow, yellowtail, canary, and silvergrey. Important slope rockfishes include Pacific Ocean perch and redstripe.[52] The dominant commercial rockfish in 1987 were widow (46 percent of total catch), yellowtail (24 percent), and canary (13 percent). Selected rockfish species dominating the groundfishery are discussed below and summarized in Table 4.2.

- Pacific Ocean perch (POP) is not actually a perch but is historically and currently the most important commercial rockfish in the eastern Pacific.[80] It was heavily overfished coast-wide in the 1960s. The major area of catch is north of Washington, and POP now composes less than 10 percent of the Washington groundfish catch.[52]
- Widow rockfish (or "brownies") landings have expanded since 1978 to comprise a substantial portion of the Washington rockfish catch. Taken mostly by midwater trawl gear, this species differs from other rockfish because it feeds on crustaceans, fish, and small squid in mid-water (below 100 m) during the day.[1,3] Widow rockfish are taken in large numbers in the vicinity of Astoria Canyon (Figure 4.10).[114]
- Yellowtail rockfish ("greenies") are abundant in the Guide Canyon area off Willapa Bay, where they are targeted by the coastal bottom trawl fleet.[114]
- The black rockfish is an important sport groundfish. It is the principal target of charter boat fisheries due to reduced salmon quotas in recent years.[59] Some data are available on migrations,[8] but little is known about where they are spawned.[62,76] Black rockfish feed primarily in the water column and near the surface[59,62] on small fishes and zooplankton.[102,109]

Flatfishes

Flatfishes are unique among marine fish because both eyes are on one side of the body. Left-eyed flounders (Family Bothidae), including various soles and California halibut, are not commercially important off Washington. Right-eyed flounders (Family Pleuronectidae) are more important off Washington and include Dover sole, English sole, petrale sole, starry flounder, arrowtooth flounder, and Pacific halibut. Flatfishes lie on the bottom and are often buried in soft sediments with just the eyes exposed. The top side of a flatfish is usually dark or mottled in a pattern closely matching the appearance of the sea floor, while the bottom side is usually pale or white.[27] Flatfishes spawn near the bottom by liberating their eggs into the surrounding seawater where they are fertilized. Eggs and larvae float in the plankton before settling back to the bottom in the juvenile phase. Selected flatfish species dominating the groundfishery are discussed below.

- English sole is a moderately important commercial species.[3] English sole juveniles are found in estuaries such as Grays Harbor and Willapa Bay, and from the intertidal zone out to shallow coastal depths; adults range from nearshore out to depths of 550 m but are most common in depths less than 100 m and frequently occur out to 250 m.[3] Adults are

Table 4.2 Dominant Groundfish Species on the Washington Coast

Species	Reproduction	Larvae/juveniles	Adults	Substrate	Diet
Rockfishes (Family Scorpaenidae)					
Widow rockfish (*Sebastes entomelas*)[1]	Mate late fall-winter, spawn winter-early spring; eggs planktonic	Larvae planktonic; Juveniles pelagic 0-37m depth, nearshore - 300 km offshore	Near bottom @ 50-300m; school at night & disperse by day; not known to migrate seasonally	Rocky banks, seamounts, ridges near canyons, headlands, mud near rocks	Zooplankton, small fishes, squid during the day
Yellowtail rockfish (*S. flavidus*) [2]	Female broods eggs; mate Sept-Oct, larvae released Mar-Apr	Larvae planktonic; young juveniles pelagic 24-266 km offshore; older juveniles benthic near shore	Near bottom @ 100-200m depth; not known to migrate extensively	Canyon edges	Zooplankton, small fishes, squid
Black rockfish (*S. melanops*)[3]	Female broods eggs; mate late summer-early fall; larvae released 1-5 months later	Larvae drift in pelagic zone up to 1 year; juveniles near semi-protected rocky reefs, kelp, in estuaries	Mostly near bottom @ 1-50m depths, 1-10 km from shore; some migrate up to 40 miles	Irregular rocky bottoms, underwater pinnacles, vertical rock walls	Zooplankton, small fishes, squid in water column, even at surface
Flatfishes (Family Pleuronectidae)					
English sole (*Pleuronectes or Parophrys vetulus*)[4]	Oct-May (peak Jan-Feb near bottom @ 55-70m in muddy channels; eggs planktonic nearshore to 37 km offshore	Larvae planktonic nearshore to 37 km offshore; juveniles benthic in estuaries & shallow coastal waters	Near shore to 550m; mostly 100-250m; migrate onshore to spawn & offshore to feed	Buried in mud & sandy bottom	Larvae: zooplankton; juveniles & adults: benthic invertebrates
Dover sole (*Microstomus pacificus*)[5]	Near bottom @ 80-550m Nov-Apr; eggs planktonic in upper 50m	Larvae planktonic in upper 50m, near shore to 840 km offshore; juveniles benthic @ 10-180m	Benthic mainly 100-1100m; migrate offshore to spawn in winter, onshore to feed in summer	Mud bottom	Larvae: zooplankton; juveniles & adults: benthic invertebrates
Arrowtooth flounder (*Atheresthes stomias*)[6]	Near bottom @ 100-360 m in spring; eggs planktonic below surface over outer shelf & slope	Larvae planktonic over inner & outer shelf; juveniles benthic 80-200m	Adults benthic on slope, migrate from 200-500m in summer to 300-500m in winter	Soft sand & sand-gravel bottom	Pelagic prey. larvae: zooplankton; juveniles mostly shrimp & other crustaceans; adults mostly gadids & flatfishes

Pacific halibut (*Hippoglossus stenolepis*)[7]	On or near bottom @ 180-550m, Nov-Mar; eggs planktonic@ depths of 85-425m	Larvae planktonic @ depths 200-950m, decreasing with age to <100m; juveniles benthic nearshore, deeper with age to 370m	Mostly just outside surf zone to 500m; 100-500m fall & winter to spawn, 25-50m spring & summer to feed; may migrate long distances along	Sand, soft mud, clay	Larvae: zooplankton; juveniles: small crustaceans & fishes; adults: flatfishes, gadids, crab, squid
Roundfishes					
Pacific cod (*Gadus macrocephalus*; Family Gadidae)[8]	Dec-Mar near bottom mostly @ 100-200m; eggs adhere to bottom near where spawned	Larvae planktonic in deep layer; juveniles demersal @ 60-150m	Near bottom mostly @ 50-200m; migrate offshore to spawn in winter, onshore to feed in spring, back to deep water in summer	Mud, clay, sand bottom	Larvae: zooplankton; juveniles: benthic worms, crab, shrimp; adults: pelagic fish, benthic fish, crabs, shrimp
Pacific hake (*Merluccius productus*) (Family Gadidae)[9]	Off California in winter	Not present off WA	Shelf & slope, 50-500m depth, also to 400 km offshore	Open water	Large zooplankton, shrimp, small fishes, other hake
Lingcod (*Ophiodon elongatus*; Family Hexagrammidae)[10]	Eggs laid in masses in shallow rocky reefs Dec-Apr, guarded by male	Young larvae hide in rock crevices & vegetation; older larvae & young juveniles pelagic Mar-May @ 0-150m, near shore to 30 km offshore	Older juveniles benthic at greater depths with age, tidepools to 60m; adults near bottom mostly near shore to 300m; few may migrate 500 km	Older juveniles: sand & mud, in seaweed beds; adults on rocky reefs, esp. steep slopes & strong currents	Larvae & young juveniles: plankton; old juveniles & adults: pelagic & demersal fish & shellfish
Sablefish or Black Cod (*Anoplopoma fimbria;* Family Anoplopomatidae)[11]	Far offshore near the bottom @ 175-1450m in winter; eggs pelagic >400m	Larvae & young juveniles near shore to 370 km offshore @ 0-100m depth; older juveniles (1 year) near bottom @ 100-200m depth	Near bottom mostly 150-1000 m; may migrate into shallower water in late summer-eaerly fall	Mud & clay bottom on continental slope	Larvae: zooplankton, fish eggs & larvae, smll fishes; adults: fish, crustaceans, squid
Thresher Shark (*Alopias vulpinus*; family Alopiidae)[12]	Larvae born alive; spawning ground & season uncertain	Uncertain	General surface waters within 40 miles of coast	Open water	Small pelagic fishes. e.g., herring, anchovy

[1] Allen et al. (in prep.); Adams (1987); Allen & Smith (in prep.); Garrison & Miller (1982), [2] Fraidenberg1980); Westrheim (1975); Gunderson et al. (1980); La Roche & Richardson (1980); Richardson & Pearcy (1977); Tagart (1982), [3] Kuzis (1985); Gunderson et al. (1980); Leaman (1976); Moulton (1977); Rosenthal et al. (1981, 1982); Field (1984); Steiner (1978); Alverson et al. (1964); Niska (1976), [4] Garrison & Miller (1982); Allen et al. (in prep.); Frey (1971); Simenstad (1983); Becker (1984); Richardson & Pearcy (1977), [5] Fraidenberg (1980); Westrheim (1975); Gunderson et al. (1980); La Roche & Richardson (1980); Richardson & Pearcy (1977); Tagart (1982), [6] Allen et al. (in prep.), [7] Allen et al. (in prep.), NMFS (in prep.), [8] Allen et al. (in prep.), [9] NMFS (in prep.), [10] Miller & Geibel (1973); Garrison & Miller (1982); Allen et al. (in prep.); Jagielo (in preparation); Tagart & Short (1987); Matthews & La Riviere (1987), [11] Garrison & Miller (1982); Allen et al. (in prep.), [12] Strasburg (1958); Stick & Hreha (1988); Hart (1973); Bedford (1985)

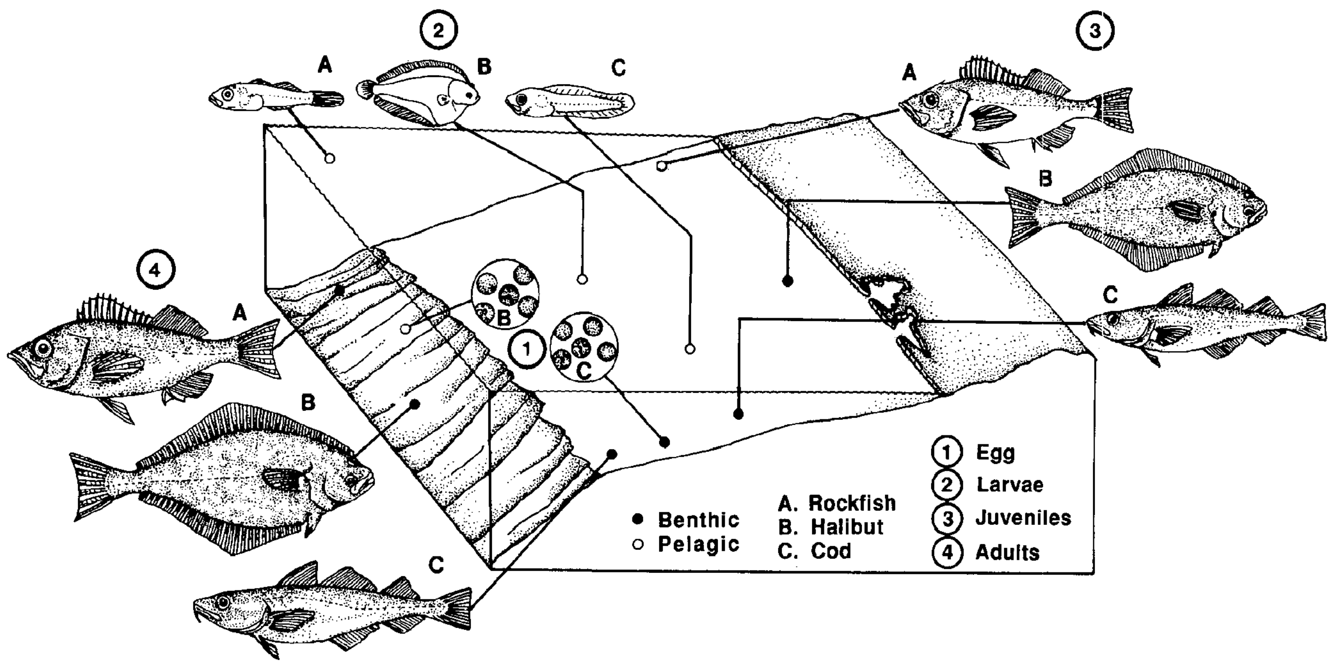


Figure 4.9 Schematic diagram of life cycles of a representative rockfish (Pacific Ocean Perch—A), flatfish (Pacific halibut—B), and roundfish (Pacific cod—C). Typical groundfishes (such as halibut) have planktonic eggs (1) and larvae (2), pelagic or shallow benthic juvenile stages (3), and inhabit the benthic zone of the shelf and upper slope as adults (4). These species were selected to show differences that could affect the responses of groundfishes to impacts of offshore oil and gas development. Most rockfish do not have pelagic eggs; Pacific cod, unlike most roundfish, have benthic eggs (sources cited in text and NMFS in prep.).

reported to perform limited seasonal onshore movements to spawn but have not been observed to move great distances along the coast.[3] Estuaries are nursery habitat for English sole.[100] Juvenile English sole are found at all depths of Grays Harbor, with maximum populations of newly settled individuals observed in shallower water between May and July.[100,116] Older individuals appear to migrate seaward out of the harbor in deeper waters from June through the summer.

- Dover sole is a high-quality food fish used for filets. It supports a major commercial bottom trawl fishery[3] but is rarely recreationally captured because of its small mouth [27] and deep distribution.[3] Dover sole is the dominant flatfish on the outer continental slope from Washington to southern California.[3] Fishing depths are deeper for Dover sole than for most other groundfish (200-1,000 m); the peak catch period is March-May off Washington.[3]
- Arrowtooth flounder is a low-quality food fish usually used for animal food and fish meal, and occasionally taken incidentally by sport fishermen near Cape Flattery.[80] There is a growing commercial fishery for arrowtooth for human consumption (greater than 2,000,000 pounds in 1987).[25]
- Pacific halibut is an excellent food fish sought by commercial and sport fishermen alike in the Cape Flattery area. Due to its value and its slow reproductive cycle (5-20 years to

reach maturity), it is highly vulnerable to overfishing, and the catch is strictly limited.[80] It is managed by the International Pacific Halibut Commission. Fishing is limited to longline, regulations are imposed restricting foreign catch and minimizing by-catch in trawls, and seasons are kept short. Recreational fishing occurs at depths of 38-183 m in summer. Stocks are currently rebuilding after being quite low in the early 1970s.

Roundfishes

Unlike the rockfish and flatfish, roundfishes are a varied group of generally unrelated fishes that share similar habitats and feeding habits. All share external fertilization. Selected species dominating the groundfishery are discussed below.

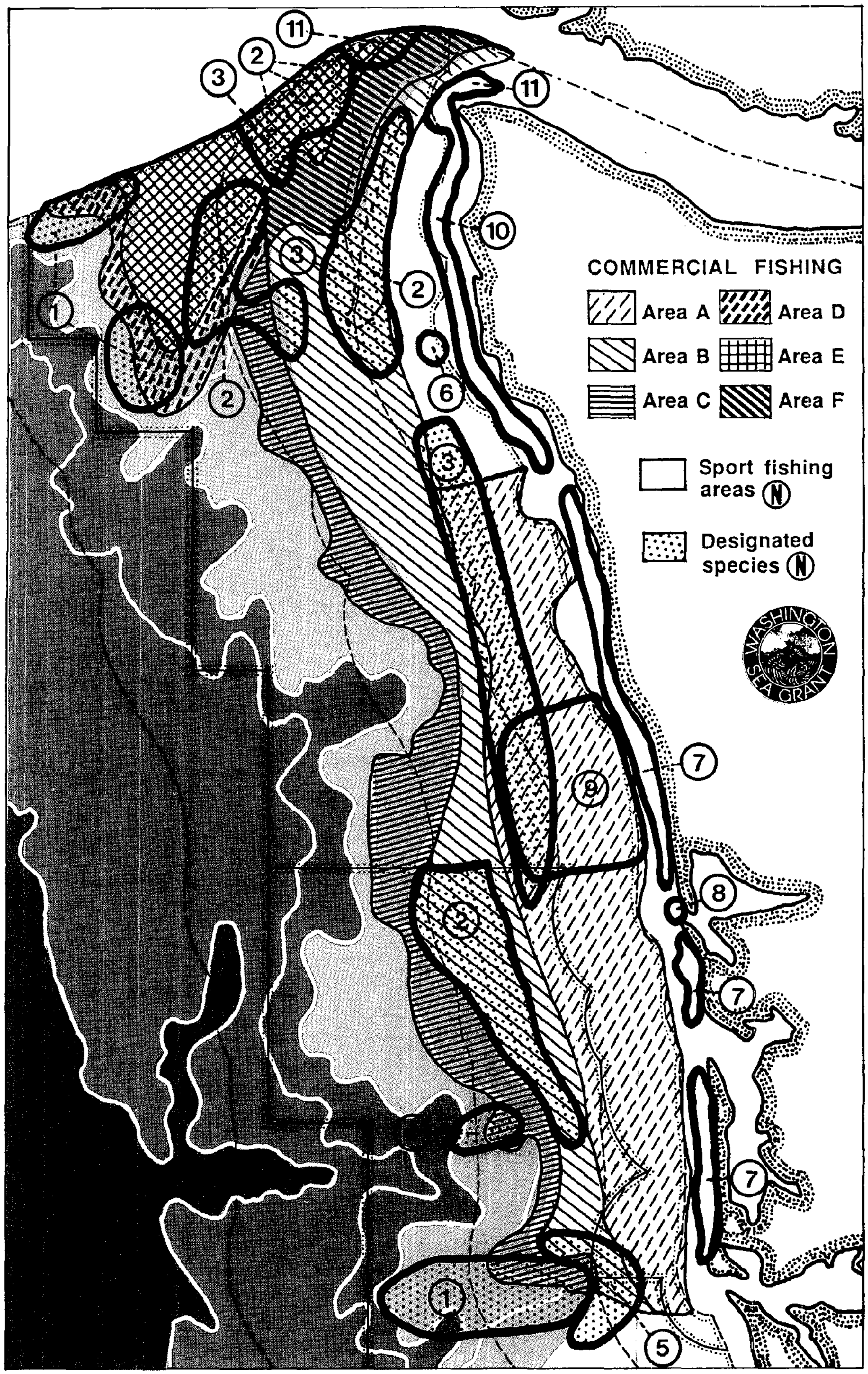
- Pacific cod is an important continental shelf species targeted by both commercial and recreational fisheries in Washington. This species is distinct because its eggs sink and stick to the bottom on the outer shelf after fertilization; larvae are pelagic but remain close to the bottom.[3] Adults are bottom-oriented in their feeding, eating some pelagic fish but also benthic fish, crabs, and shrimp.
- Pacific hake (marketed as whiting) is a highly migratory relative of the Pacific cod. The oceanic stock spawns off California and Baja California during winter, and adults migrate northward along the coast to feed off Oregon, Washington, and Vancouver Island during summer.[80] Separate, nonmigratory stocks inhabit Puget Sound and the Strait of Georgia. The summer coastal stock is fished primarily by foreign and joint-venture operations on the outer continental shelf. Reproductive success of the stock has been shown to be greatly affected by upwelling along the California coast—very strong upwelling being detrimental to year-class success.[36]
- Lingcod is a species important to both recreational and commercial coastal fisheries in Washington. Eggs are laid in masses on shallow rocky reefs from December to April and are protected by nest-guarding males after fertilization. Males may mate with one or more females in a nest and remain on the nests for 5-7 weeks. Yolk sac larvae hide in rock crevices and in vegetation.[72] Larvae are pelagic, but juvenile lingcod prefer shelter in tidepools, eelgrass meadows, and seaweed beds; adults prefer reefs with steep slopes and swift tidal currents. [3] Females predominate in the trawl catch off Washington, which peaks in May-July, while males compose most of the sport catch occurring closer inshore.[54] Washington's major coastal estuaries (Willapa Bay, Grays Harbor) are believed to be important as habitat for the early life stages of coastal lingcod.[116] Lingcod feed on active prey at or near the bottom and are one of the most important reef predators throughout their distribution.[3]
- Sablefish or black cod is one of the most abundant continental slope species in the northeast Pacific ocean and supports a multinational fishery off the United States and Canada.[3]

CRITICAL HABITAT

The Grays Harbor, Willapa Bay, and Columbia River estuaries are nursery habitat for English sole.[100] Juvenile English sole are found at all depths of Grays Harbor, with maximum populations of newly settled individuals observed in shallower water between May and July.[100,116] Older individuals appear to migrate seaward out of the harbor in deeper waters from June through the summer. Juveniles of other species are present in the estuaries, but the importance of those habitats in their life cycles is unknown (e.g., lingcod[116]). Groundfish resources of Washington coastal estuaries have been summarized by NOAA.[75]

The sea surface microlayer is thought to be a critical habitat for many species of groundfish having planktonic eggs and larvae.[104] There are a small number of studies demonstrating the presence of organisms in this layer and their sensitivity to concentrations of contaminants that may occur there. Little more than that is known; no broad study has been made of the species present and their distribution and abundance, or of the possible mortality and population impacts that might result from contamination in the microlayer.

The vicinity of the shelf break (approximately 200 m isobath), especially along submarine canyons, is an important habitat for adult groundfish, including during the spawning


COMMERCIAL FISHING
Area A
Area B
Area C
Area D
Area E
Area F
Sport fishing areas (N)
Designated species (N)
WASHINGTON SEA GRANT
1
2
3
5
6
7
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9
10
11

Figure 4.10 Distribution of groundfishing and catch of designated species off the Washington coast.

General Commercial Fishing Areas (after Mills et al. 1983)

Area A (50-100m): Year-round trawling for English sole, dover sole, petrale sole, Pacific cod, lingcod

Area B (100-200m): Year-round trawling for English sole, petrale sole, Pacific cod, lingcod, rockfish; setline fishing May-October for lingcod, rockfish, halibut

Area C (200-800m): Year-round trawling for rockfish, dover sole, sablefish, hake; setline and bottom pot fishing May-October for sablefish

Area D (200-800m): Trawling December-August for petrale sole, dover sole, rockfish, sablefish

Area E (100-200m): Trawling April-August for Pacific cod, lingcod, petrale sole, rockfish

Area F (200-300m): Trawling all year for rockfish, Pacific cod, dover sole, sablefish

Designated Commercial Species Fishing Areas (Sources: J. Tagart, WDF; Mills et al. 1983)

1) Sablefish

2) Rockfish

3) Hake

4) Yellowtail rockfish

5) Widow rockfish

6) Starry flounder, sand sole (March-June)

Designated Recreational Species Fishing Areas (Sources: J. Tagart, WDF; Mills et al. 1983)

7) Surf perch, starry flounder (all year)

8) Lingcod, greenling, rockfish, starry flounder all year

9) Black rockfish

10) Rockfish, lingcod, halibut (April-October)

11) Black rockfish, lingcod, halibut

stage. As a result, these are also areas of concentrated fishing effort and catch (Figure 4.10). Many species of groundfish are associated with broad areas of soft sandy or muddy bottom, which are plentiful on the Washington shelf and slope, but certain rockfish species are restricted to underwater rocky areas and would not easily be able to relocate if displaced from this habitat. Many groundfish species also have localized spawning grounds, but their locations are poorly documented.[114]

GROUNDFISHING GEAR & METHODS

Groundfish are caught off Washington using several types of gear. The dominant method is otter (bottom) trawling, and it and other methods—mid-water trawling, longlining or setlining, bottom trolling, and hand-line jigging—are described below.

• Otter or bottom trawls are funnel-shaped nets made of twine webbing that are towed along the sea bottom. Floats and weights are used to keep the mouth of the net open; otter boards (trawl doors) keep the mouth spread apart so that it will cover the largest possible area.[96] Otter trawls are the most wisely used gear and are used to capture most rockfish, flatfish, and roundfish species. Washington trawlers targeting rockfish most commonly attach rollers to the otter trawl which allow the net to roll over obstacles on rocky bottoms.

• Mid-water trawl gear is essentially an otter trawl designed to fish off the bottom. It is not uncommon for trawlers to carry both bottom and mid-water trawl gear and to fish both gears on a trip. The mid-water trawl fishery off Washington targets primarily on rockfish (Table 4.3). The most abundant species are widow rockfish and yellowtail rockfish, which are taken mostly from area 3A (in recent years, yellowtail rockfish have been abundant in the Guide Canyon area; widows are abundant in the Astoria Canyon area).[114]

• Longline or setline gear consists of a long length of line (usually polypropylene) to which numerous shorter lines (of wire or fine nylon) with baited hooks are attached.[96] Fishing this gear involves anchoring and buoying one end of the ground line, stretching the gear along the bottom, and anchoring and buoying the other end. Each line fished in this manner is termed a *skate*. A vessel may fish up to three skates at once; skates are typically left on the bottom for 2 to 24 hours.[96] Species caught by this method include sablefish, lingcod, Pacific cod, a variety of bottom-dwelling rockfish (few yellowtail or widow), and a variety of flatfish species including turbot, Dover sole, and petrale sole.

• Bottom troll gear consists of hooks attached to leaders that are dragged close to the bottom behind a slowly moving boat. One or two heavy steel lines are weighted with 40-60 pound weights. Shorter lines (spreads) are attached to the heavy steel lines, which may have one or more leaders, each with a lure or bait attached. When several leaders are

Table 4.3 Catch Distribution of Groundfish Species
(Source: WDF unpublished data)

Species	Depth of range of catch	Depths of maximum catch
Otter trawl		
Dover sole	10-330 fm	20-100 & >200 fm
English sole	10-260 m	<90 fm
Petrale sole	10-350 fm	<100 fm
Rex sole	10-180 fm	20-80 fm*
Turbot	10-400 fm	60-100 fm
Sablefish	40-400 fm	<110 fm
Lingcod	10-200 fm	50-100 fm
Pacific cod	10-260 fm	40-100 fm
All Rockfish	10-400 fm	50-100 fm
Pacific Ocean perch	60-400 fm	100 fm
Mid-water trawl		
All Rockfish	30-160 fm	60-100 fm**

* Areas 3A and 3B only; see Figure 4.11

** widow & yellowtail, mostly area 3A

attached to a spread, the line is buoyed by floats spaced at intervals along the spread, to keep the spread from snagging the bottom. Species taken by this method include rockfish and lingcod. Some fishermen have been quite successful in targeting lingcod by this method.

• Hand-line jigging is a new and increasingly popular fishing method very similar to recreational fishing.[96] One or more baits or lures attached to a line (a rod may or may not be used) are lowered to the bottom and then moved up and down ("jigged"). The recent introduction of jigging machines has resulted in increasing the efficiency and thus the amount of fish taken by this method. Rockfish, lingcod, and some flatfish are taken by this method. In recent years, black rockfish and lingcod have accounted for most catches by this gear type. The main ports of departure are Westport, LaPush, and Neah Bay. Fishing typically occurs on reefs or pinnacles fairly close to shore; however, anglers travel some distance from land at times (e.g., to fish on Swiftsure Bank off the Strait of Juan de Fuca).

Sport fishing for bottomfish in Washington's coastal waters has been on the rise in recent years due to cutbacks in salmon sportfishing quotas.[59] Sport fisheries on the coast include charter boat, private boat, and SCUBA diver fishermen. There are also share and jetty fisheries for rockfish, surf perch, etc. The sportfishing areas are Westport, Ilwaco, Neah Bay, and LaPush. The sport season typically runs from May to October with a peak of effort in August. Effort directed toward bottomfish typically declines during salmon openings on the coast, though a number of bottomfish are taken incidentally to the salmon fishery. Black rockfish and lingcod are the most important sport fishes, followed by a variety of rockfish, flatfish, cod, and halibut. Directed bottomfish trips in 1987 totalled 1,686 from Ilwaco, 21,381 from Westport, 452 from LaPush, and 21,058 from Neah Bay.

MAGNITUDE AND DISTRIBUTION OF CATCHES

Commercial groundfishing has taken place on a small scale on the U.S. West Coast since at least 1879.[51] It can be divided into domestic, foreign, and joint-venture operations. The total groundfish catch for Washington domestic and joint-venture fisheries in 1987 was 56,000 metric tons.[114]

The following description of state domestic groundfisheries was obtained from the Washington Department of Fisheries.[54,114] The total annual commercial groundfish catch in Washington is in the range of 20,000 metric tons, representing about 50,000 hours of effort by roughly 100 active vessels. Total effort is roughly constant year-round, and most species show some take in every month, but the predominant areas and species fished vary with the seasons. Total monthly effort for all species in 1987 is presented by PMFC area in Figure 4.11. The distribution of catch by species and PMFC area in 1987 is shown in Figure 4.12. These figures show that, as data are currently reported, groundfish catches off Washington appear to be important in all areas and all seasons.

There are finer-scale preferred groundfishing locations that are not revealed in these data, however; samples of such information are presented in Figure 4.13. The active area of commercial fishing is over depths of 10 to 350 fathoms, and over canyons out to the continental slope. In 1979, a typical year, 75 percent of the catch was taken between depths of about 50 and 100 fathoms. During that year the fishery was conducted mainly on relatively shallow flats, targeting Pacific cod and English and petrale sole. Rockfish and lingcod were most commonly caught at depths of 60-80 fathoms near canyon edges. The recent trend is toward deeper fishing, however, with increased targeting of deeper-living species such as Dover sole. Such areas are typically around the 100-fathom isobath in the vicinity of canyons. The Washington Department of Fisheries has hydroacoustically mapped fishery habitats such as rocky reefs in the nearshore area shallower than 60 meters, and the data report is in preparation.[114]

The historical levels of domestic commercial trawl landings of each species at Washington ports are published only for the West Coast as a whole, including Puget Sound.[54] These data are displayed in Figure 4.14. The "other" category includes mainly Pacific hake, spiny dogfish, and starry flounder caught mostly in Puget Sound. Certain other species indicated in Figure 4.14 also have a significant fraction of their catch contributed from Puget Sound: in 1987, 40 percent of the total state English sole catch, 34 percent of Pacific cod, and 5 percent of lingcod

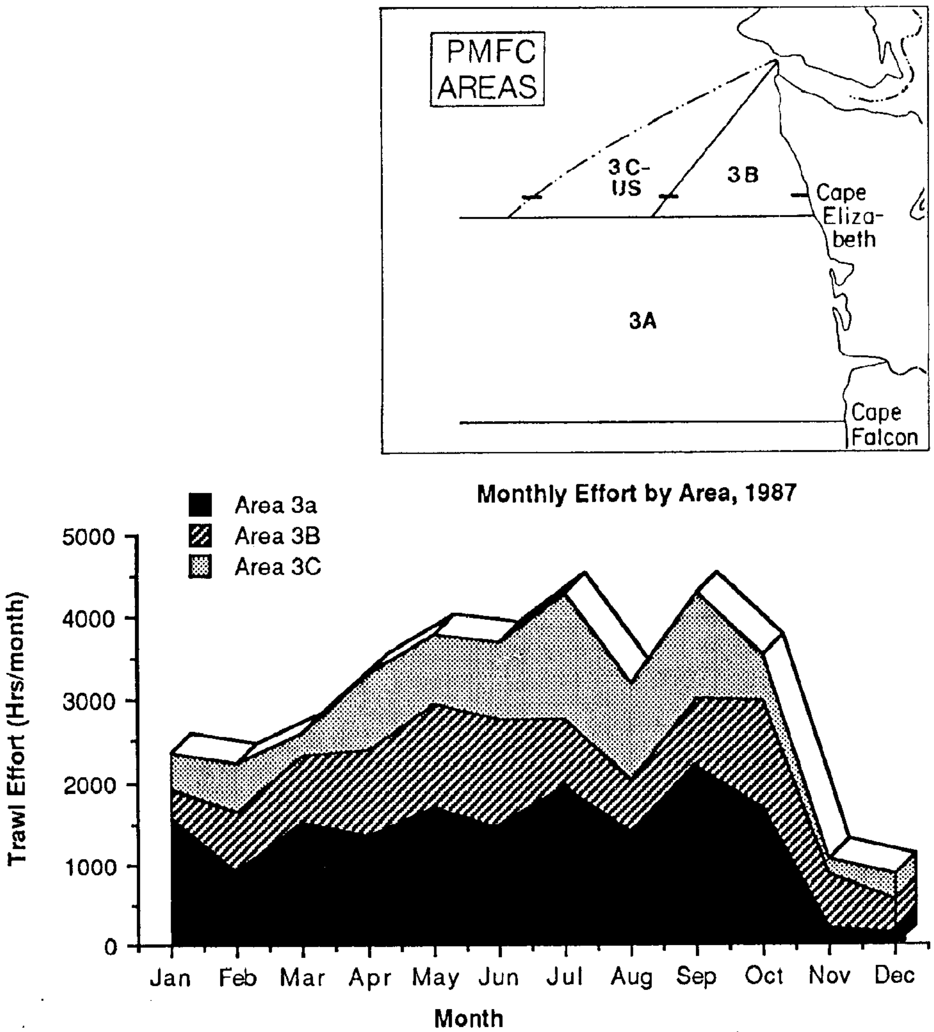

Figure 4.11 Groundfishing effort by month for the three PMFC fishing areas off the Washington coast in 1987 (data from Jagielo 1988a).

were taken in the Sound. The data in Figure 4.14 indicate a recent increase in total trawl catch in the late 1980s following a decline in the early '80s. This trend appears to be accounted for mainly by the catch of rockfish; landings of other species are relatively constant by comparison.

Not all species of groundfish in Washington waters are taken exclusively or even predominantly by trawl. Other catch methods include shrimp trawl, setline, longline, and pot (trap). To the extent that these other methods are used, Figures 4.12 and 4.14 do not reflect the complete picture of catch for certain species. In 1987 roughly 11 percent of rockfish, 72 percent of sablefish, and 19 percent of lingcod in coastal areas were taken by non-trawl gear.[52]

Foreign mothership fleets, predominantly from the Soviet Union, began fishing Washington's groundfish heavily in 1966, targeting mainly rockfish and hake. Foreign and joint-venture fishing is currently limited to hake, with the fleet following the migratory stock present on Washington's outer shelf mainly in late summer. Total and foreign hake catches have decreased and joint-venture and domestic hake catches have increased since the early 1980s, especially in Washington with the decline of the commercial salmon fishery. The overall domestic, foreign, and joint-venture hake landings for the entire West Coast are shown in Figure 4.15. A mean of 87.6 percent of the foreign and joint-venture hake catch was taken in the U.S.-Vancouver and Columbia PFMC areas in 1986-87.[83] This indicates that Washington-Oregon waters are significantly more

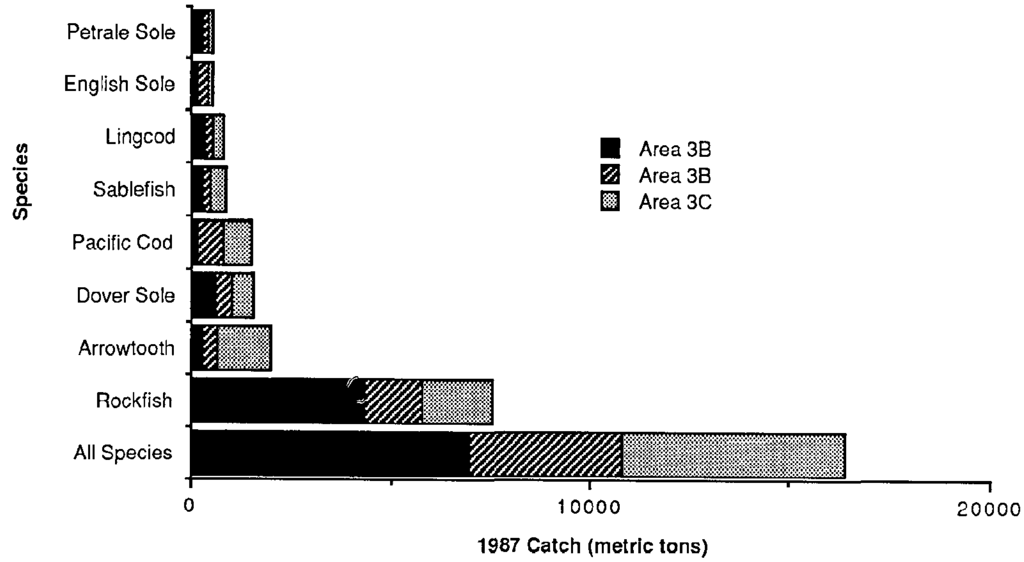

Figure 4.12 Groundfish catch by species and PMFC area off the Washington coast for 1987 (data from Jagielo 1988a).

important than California waters for this fishery. Since foreign catch was restricted in 1977, hake stocks are thought to be underfished.[51]

Trends in groundfish stocks are presented in PFMC annual status reports,[86] which are derived from both catch and available survey data. Of the roughly 20 rockfish species monitored, one species—Pacific Ocean perch—remains depleted after overfishing by foreign fleets in the late 1960s. Allowable catch for this species is currently zero, but some occurs as incidental catch. Stocks of yellowtail rockfish also are currently declining,[86] as are Dover sole and sablefish [68] stocks. A Northwest and Alaska Fisheries Center report on groundfish distribution and abundance trends observed in surveys from 1977-1986 is in preparation.[26]

One roundfish recently sparking new commercial interest off Washington is the thresher shark, a single stock of which is found off Washington/Oregon.[110] Adult male sharks, believed to have migrated northward from California in spring, predominate in the catch off Washington and Oregon in summer. Using drift gillnets up to 1000 fathoms long, fishing effort was concentrated 19-111 km offshore between Cape Lookout and Cape Disappointment, 37-111 km offshore between Leadbetter Point and Point Grenville, and 93-148 km offshore of Cape Alava in 1986 and 1987.[110] Thresher sharks bear two to four young alive[43] and are believed to be relatively long-lived with a low natural mortality rate. Very little is known about the biology and life history of this fish, which is believed to be particularly vulnerable to overfishing.[17] This species may serve as an example of unexploited fisheries resources off the Washington coast. Until 1986, little evidence suggested that thresher shark could be harvested in commercially significant numbers. In 1986, however, the Washington/Oregon catch totalled 646,632 pounds, with the ex-vessel price ranging from $0.95 to $1.50 per pound.[110]

The coastal recreational charter fisheries have targeted groundfish increasingly in the 1980s, particularly black rockfish and lingcod. The recreational fisheries are generally geographically limited to one-day round trip distances from marinas (Figure 4.10). Examples of recent ocean recreational catch are presented in Figure 4.16. There are also shallow-water recreational fisheries: surf fisheries along beaches between Copalis and Grays Harbor; and jetty fisheries for lingcod, rockfish, and surf perch.

SHELLFISH

Shellfish are invertebrates of the phyla Arthropoda (class Crustacea) and Mollusca with a hard exoskeleton. The major sport and commercial shellfish species taken along the Washington coast are the Dungeness crab and pink shrimp (Crustacea) and the Pacific oyster and razor clam

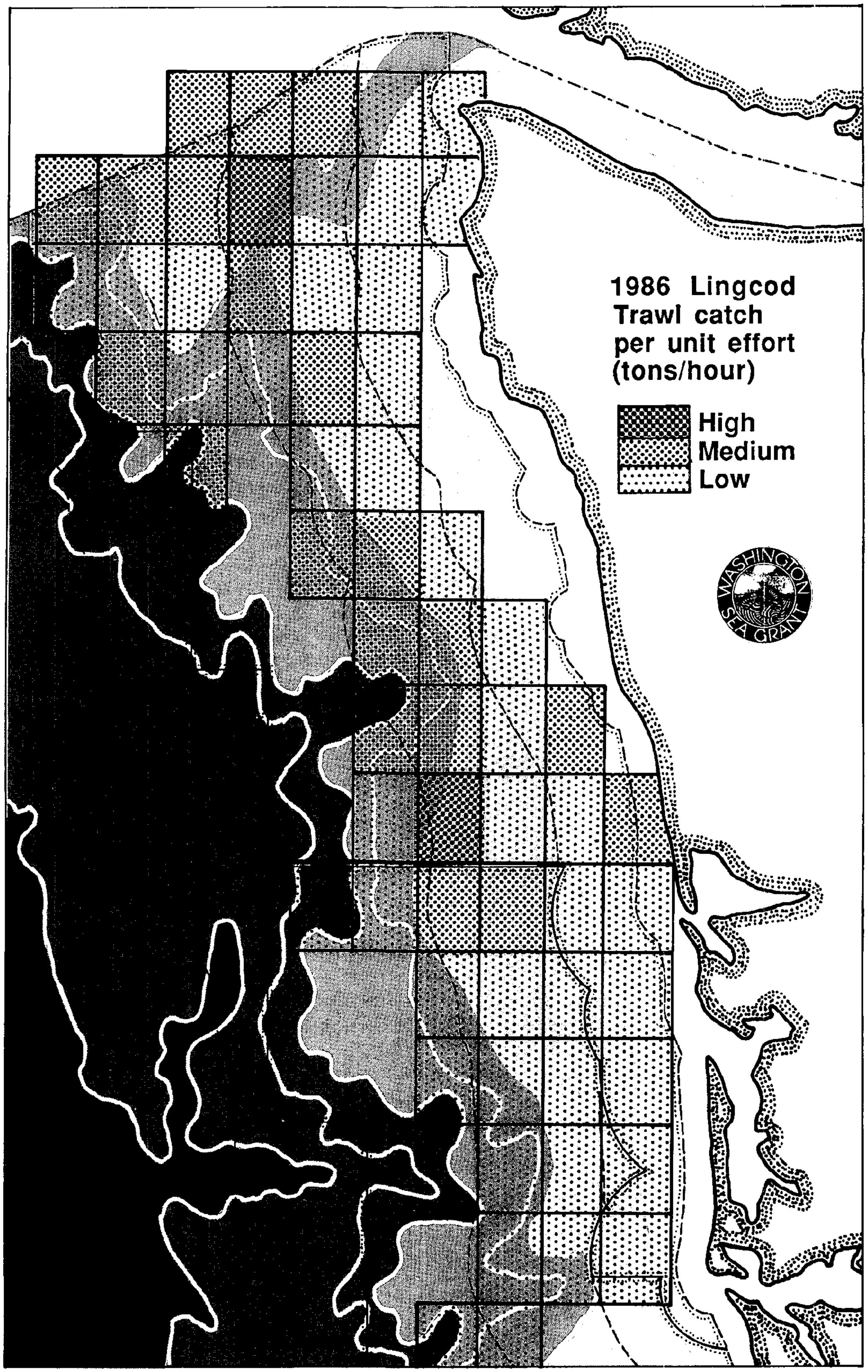

Figure 4.13 Lingcod trawl catch per unit effort (CPUE) by 10 minute latitude-longitude blocks off the Washington coast in 1986 (Source: Jagielo 1988b).

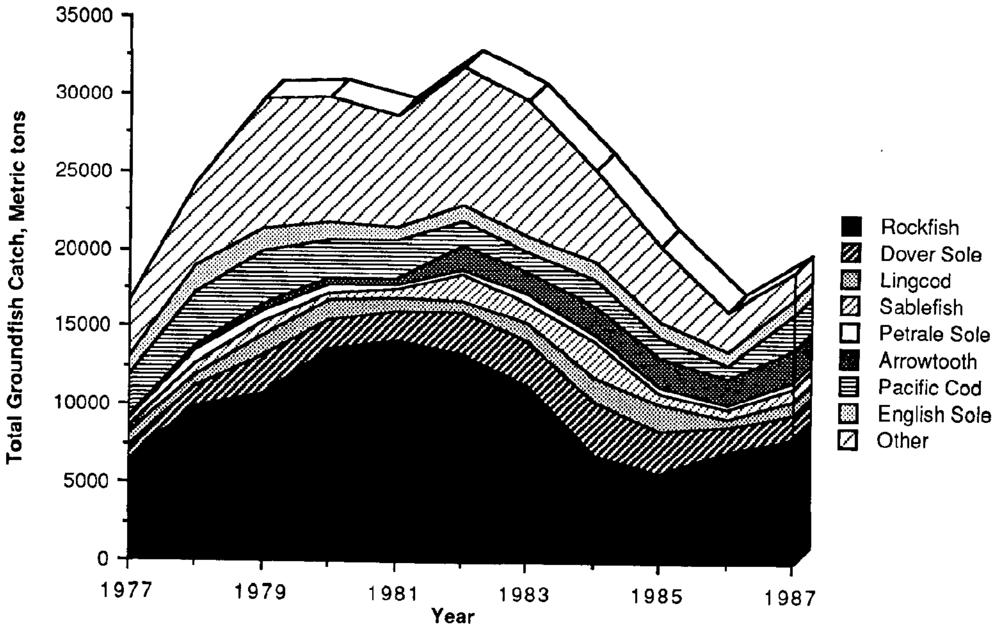

Figure 4.14 Total Washington state domestic commercial groundfish trawl landings by year and species (data from Jagielo 1988a). Includes fish caught off California and Oregon and in Puget Sound.

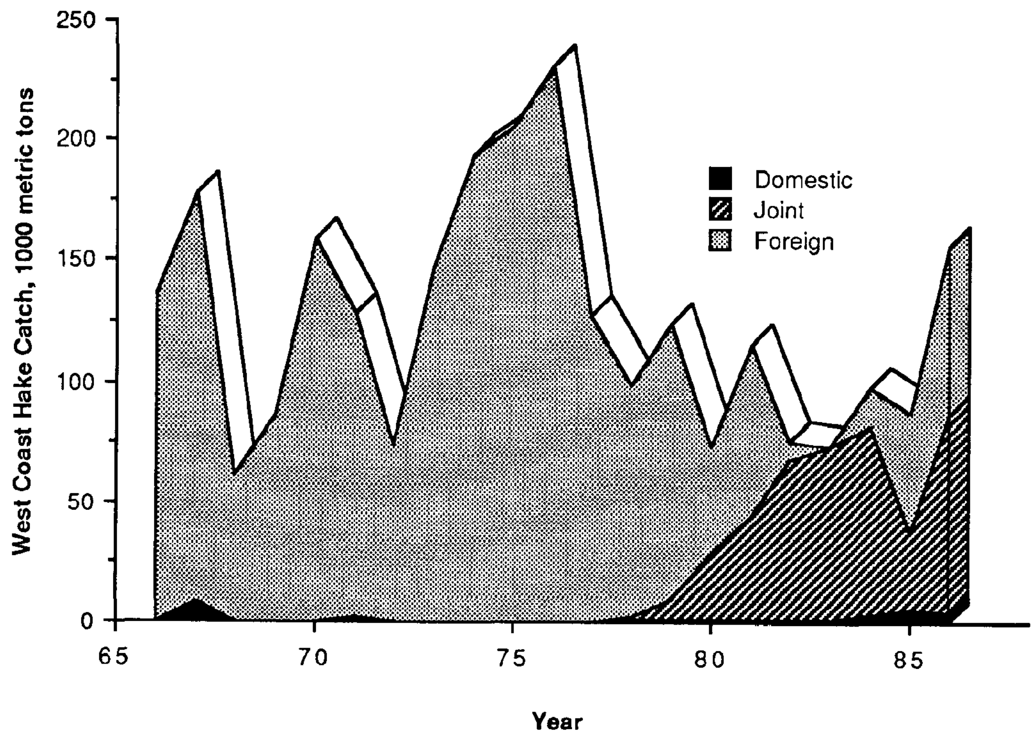

Figure 4.15 Total foreign, domestic, and joint-venture hake (whiting) catches over the last two decades along the entire U.S. west coast (data from Hollowed et al. 1988).

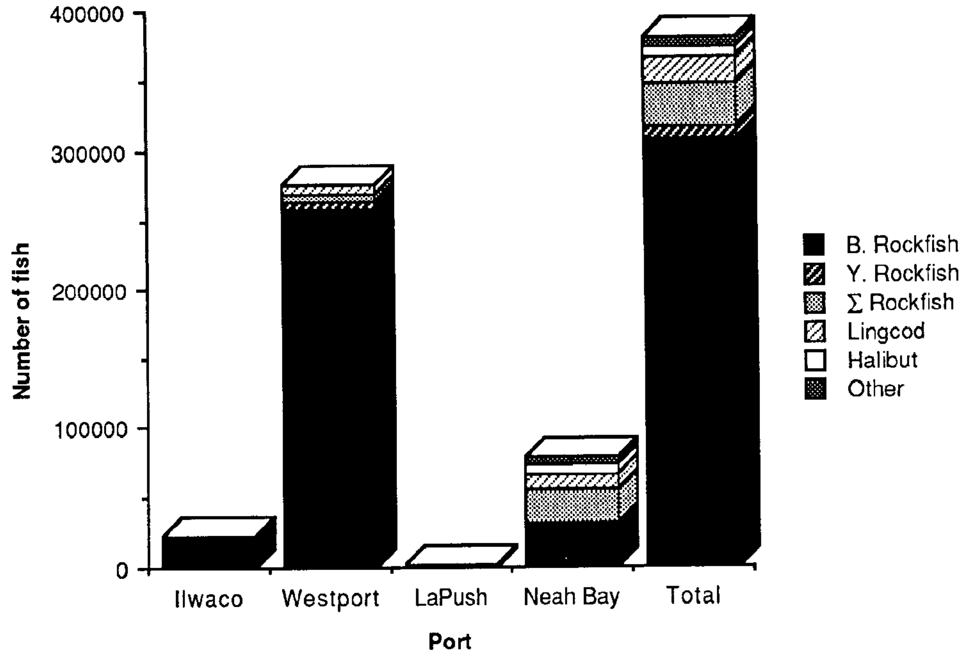

Figure 4.16 Recreational landings of groundfish by species and port of landing on the Washington coast in 1986 (data from Hoines & Ward 1986).

(Mollusca). Life cycle, food web, and habitat data for these species are presented in Table 4.4. Other minor shellfish species (Mollusca) taken recreationally along the coast include mussels and hardshell clams. Estuaries are critical habitats for crab and oysters. Shellfish resources of Washington coastal estuaries have been summarized by NOAA.[75]

DUNGENESS CRAB

Dungeness crab at times is the most important shellfish harvested on the Washington coast in terms of both the weight of sport and commercial catch and its economic value. The abundance of Dungeness crab is highly cyclic, with about a ten-year period (Figure 4.17), and rebounded dramatically in 1987-88 to reach the highest level since 1969, after being depressed through most of the 1980s. The reasons for this cyclic abundance pattern are unknown; theories correlating it with upwelling rates, water temperature, competition, cannibalism, parasitism, predation, and disease have been advanced.[19]

The life cycle of Dungeness crab, summarized in Table 4.4 and depicted in Figure 4.18, has been well studied in recent years.[19,90] Female crab on the Washington coast molt to maturity and mate in the nearshore zone during spring. Eggs are carried by the female before being released in winter and hatching between December and March. Crab spend the first two to three months of life after hatching as free-floating planktonic larvae (zoea and megalops stages), which are believed to remain close to the water surface. These larvae are believed to be abundant in the surface microlayer, especially around surface convergence zones.[104] In April and May, the crab settle out of the plankton into the intertidal zone on the outer coast and in the estuaries. The means by which they migrate from open offshore waters into the shallows of the coast and the estuaries are unknown but are thought to be either swimming or riding currents. They also may be aggregated in windrows with surface debris.

Upon settling to the bottom, the crab enter the juvenile stage. They inhabit the intertidal zone of both the outer coast and the estuaries during their first summer. In the autumn of their first year the juvenile crab move out of the intertidal zone into the subtidal, and late in their second year crab move into offshore waters. Many crab from offshore waters are believed to migrate into the estuaries during their second summer, then return offshore in fall. They reach sexual maturity at age two and recruit to the fishery in summer and fall at about age four. Male crab molt in the

Table 4.4 Dominant Shellfish Species on the Washington Coast

Species	Diet	Predators	Habitat	Distribution/ Migration	Reproductive Cycle
Crustaceans					
Dungeness crab[1] (*Cancer magister*)	Small crab (cannibalistic), shrimp, fishes, mollusks, annelids	Large crab (cannibalistic), groundfishes, sea otters	Intertidal zone to 200 m on sand, mud, eelgrass, Aleutians to Mexico	Close to shore as juveniles and in fall, offshore as subadults & adults and in summer; subtidal by day & intertidal at night	Mate March-April offshore; eggs laid Oct.-Dec., hatch Jan.-April; settle as juveniles inshore April-May; mature in 2 years; marketable in 4 years; live 8-10 years. Molt July-Nov.
Pink Shrimp[2] (*Pandalus jordani*)	Zooplankton, benthic crustaceans & worms, detritus	Finfish	"Green mud" 25-50 m deep, N. California to Vancouver Island	On bottom during day, in water column at night; migrations unknown	Spawn Sept.-Oct., hatch in March, larvae planktonic till mid-summer; mature as males at 1.5 years & as females at 2.5 years; live 4 years.
Molluscs					
Razor Clam[3] (*Siliqua patula*)	Surf-zone diatoms (phytoplankton)	Birds, finfish, crabs	Intertidal & subtidal outer coast sand beaches, Oregon - Aleutians	Non-migratory; planktonic larvae dispersed by currents	Spawn mid-May- July; planktonic 5-16 weeks; mature in 2 years, live 9-11 years
Pacific Oyster[4] (*Crassostrea gigas*)	Phytoplankton	Crabs, starfish, flatworms, finfish, oyster drills	Intertidal & subtidal zone in estuaries, California-Alaska	Non-migratory; planktonic larvae dispersed by currents	Spawn late summer; larvae set on oyster shell; mature 2-4 years

1 Pauley et al. (1986b); PFMC (1979)
2 McIntosh (1987); PFMC (1981)
3 Lassuy and Simons (1988)
4 Cheney and Mumford (1986)

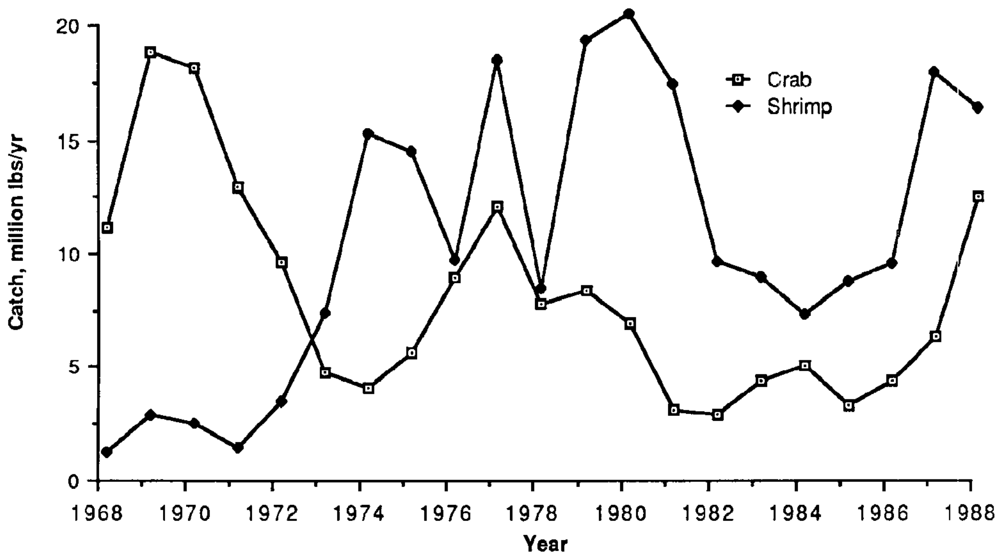

Figure 4.17 Dungeness crab and pink shrimp catches off the Washington coast over the last two decades (data from PFMC 1979, 1981; Dale Ward, WDF).

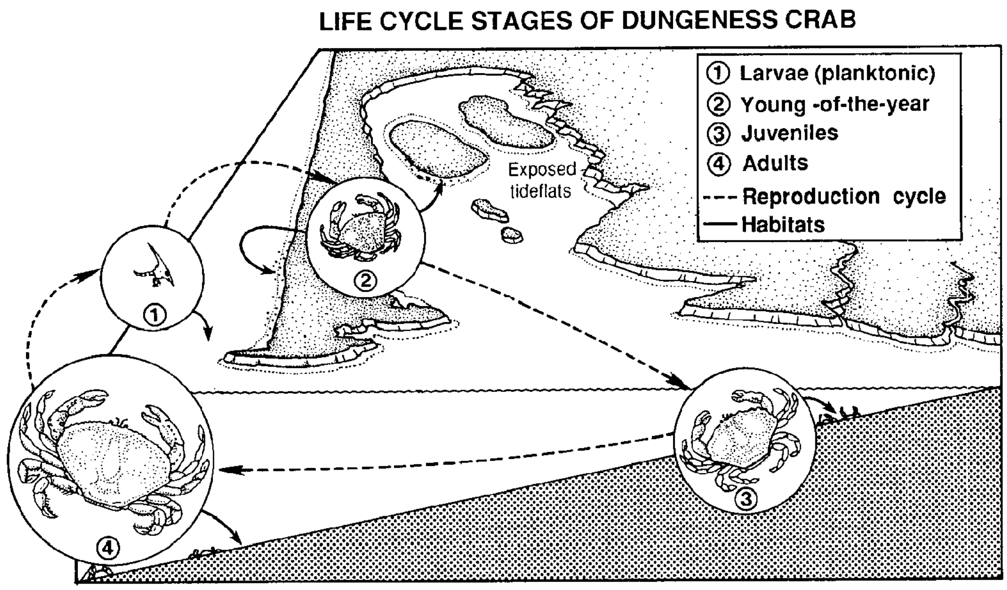

Figure 4.18 Schematic diagram of Dungeness crab life cycle using Grays Harbor as an example of estuarine nursery grounds (based on Botsford et al. in press and Pauley et al. 1986b).

fall and females in the spring, times when they are sensitive to being handled. Some molting crab may be present at any time of year.

Estuaries are important nursery grounds for survival of juvenile crab during their first summer of life. Juvenile survival in the ocean appears to be lower than in the estuaries. Shelter from predation found by juvenile crab under empty clam and oyster shells in the estuaries appears to account for this difference in survival. Crab also grow faster in estuaries. These findings suggest that the estuaries play a critical role in maintaining crab populations during years of low population abundance. In contrast, the additional area of habitat on the outer coast may be important to producing strong crab year-classes in years when conditions (still unknown) favor high survival of coastal juveniles. Such a situation occurred in 1984 and probably accounts for the high abundance in 1987-88.[7]

Dungeness crab take a wide variety of prey as adults (Table 4.4) and appear to be opportunistic feeders on whatever prey of the right size are present on or within the sediment.[84] Adult and subadult crab are believed to heavily cannibalize juvenile crab in the intertidal zone during summer.[84,90] Dungeness crab are preyed upon as larvae by plankton-feeding fishes such as salmon, and as adults by bottomfish such as lingcod, halibut, and rockfish, as well by octopi. Concern has been expressed by crab fishermen that predation on crab larvae by increasing populations of hatchery-reared salmon may be detrimental to commercial crab yield.

The southern Washington coastal Dungeness crab population is part of a distinct stock with a range extending to central Oregon. A few individuals have made movements of more than 75 nautical miles within this range, although most crabs move within a 30 nm range.[14] A separate crab stock appears to exist in an area around Destruction Island.[11,12]

Dungeness crab are caught commercially using baited traps or pots that lie on the sea floor and are marked with floating buoys. Fishing takes place over sandy/muddy bottom, and none takes place over hard bottom.[14] The area of fishing extends all along the southern Washington coast from the Columbia River to Point Grenville (Figure 4.19) between the coast and depths of approximately 140 meters.[112] Fishing is conducted out to about 120 m through February and moves into shallower water as the season progresses: to 60 m, then to 40 m at the start of May.[11,112] In March, an additional area of fishing effort occurs in the vicinity of Destruction Island, and this area has been increasingly exploited during winter as well in recent years. Roughly equal catches are estimated to be taken in state and federal waters.[84] In 1988, some fishing effort was reported as far north as Cape Flattery.[14]

The commercial crab season is limited to the period between December 1 and September 15, with provision for a 15-day extension if conditions warrant. Gear is allowed to be set out approximately 64 to 96 hours before the season starts. The recent seasonal pattern in crab catch is shown in Figure 4.20. Landings are typically lower after March, with only about 25 percent of the annual catch taken in summer.[10,11,12,13] The seasonal closure is intended to prevent take of newly molted crab in the fall, when they are vulnerable to mortality from handling during fishing operations. Molting and hardening may occur earlier or later than this, however, and some molting crab may be present at any time of year. Softshelled crab take is explicitly prohibited in Washington. Condition of crab begins to deteriorate in late spring as molting commences. In recent years, the peak of molting has occurred before the September 15 closure date. Until the increase in catch in 1988, summer fishing was widely blamed for the low catches. Foreign crab fishing is prohibited.

Crab vessels are typically 40 to 60 feet long and capable of fishing for tuna, salmon, shrimp, or groundfish in other seasons, as well as for crab in winter. About 100 to 145 boats are currently active on the Washington coast, with only about 40 of those fishing during the summer. Each boat fishes about 100 to 900 pots depending on length, totaling about 37,000 to 45,000 pots in use in coastal waters.[13,112] Pots are typically set out 20 to 150 at a time [14] less than 200 feet apart [112] in lines parallel to the coast, and left in place typically two to five days.[14] The crab pots are licensed and required to be equipped with two escape ports (4.25 inches) to allow escapement of undersized crab. In addition, all female crab and those males of less than 6.25 inches carapace width are required to be returned to the sea unharmed. Washington regulations prohibit targeting crab with trawls or nets that could injure or kill female and undersize crab. Commercial gear in Washington state is not required to be marked with the name of the owner, but marking of buoys with a WDF buoy brand is required. An estimated 15 percent of crab pots are lost annually due to cut buoy lines, sanding-in, and scattering by storms.[13,84]

Good data are not available for the coastal recreational Dungeness crab fishery in Washington, but it is estimated that sport take is less than one percent of the commercial catch.[84] Sport fishing areas are mainly in Willapa Bay and Grays Harbor, and along beaches north of the Columbia River and at Kalaloch. Peak utilization is estimated at less than 60 sport fishers per/day in Willapa Bay and less than 50 on ocean beaches. The sport fishery is unlicensed and open all year, with a daily limit of six males over six inches, and no soft shells. Use of pot gear is prohibited from September 16 to November 30.

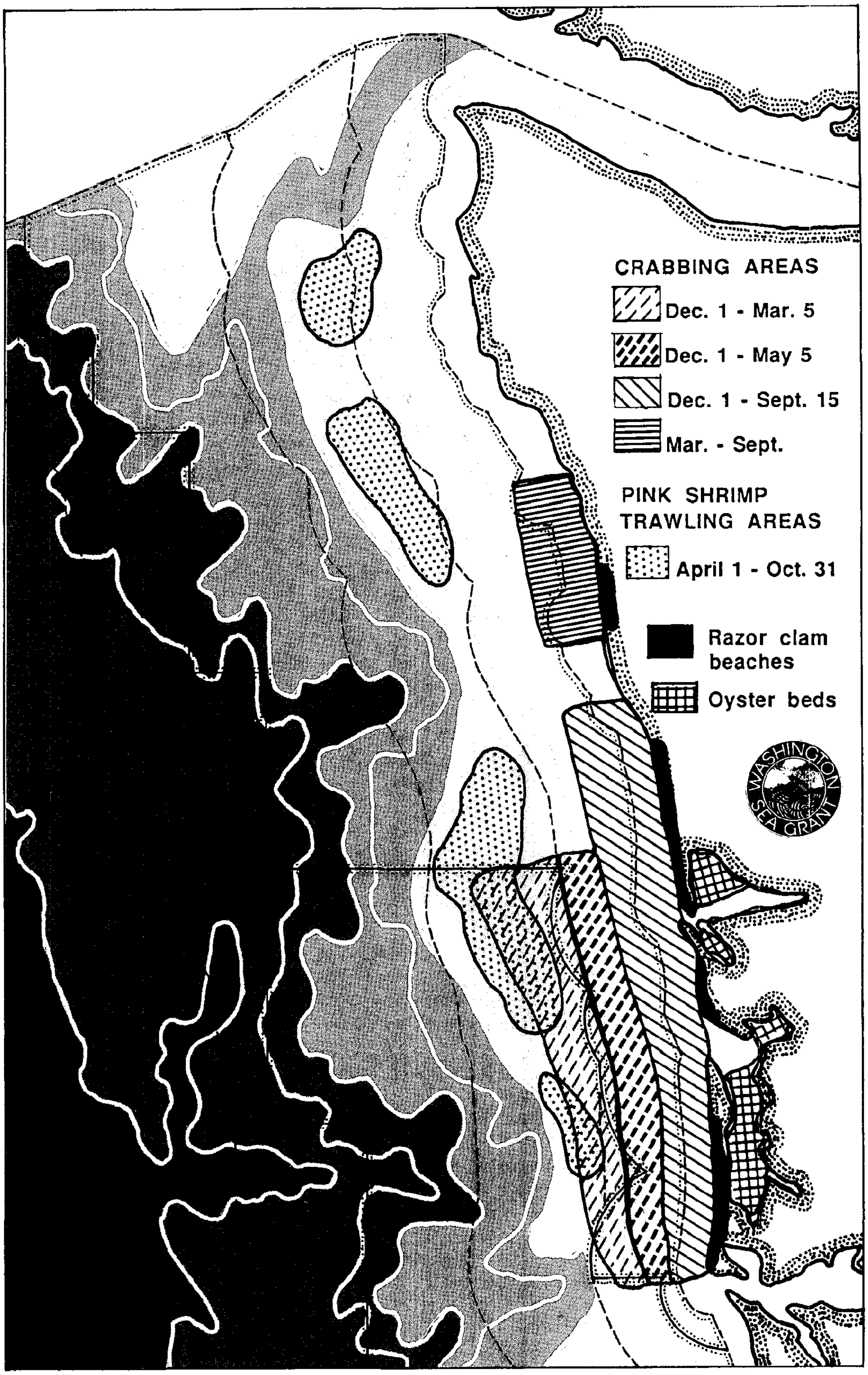

Figure 4.19 Fishing areas for Dungeness crab, pink shrimp, razor clams, and oysters in coastal Washington (S. Barry, WDF; E. Summers; PFMC 1981; Lassuy & Simons 1988; L. Bonacker).

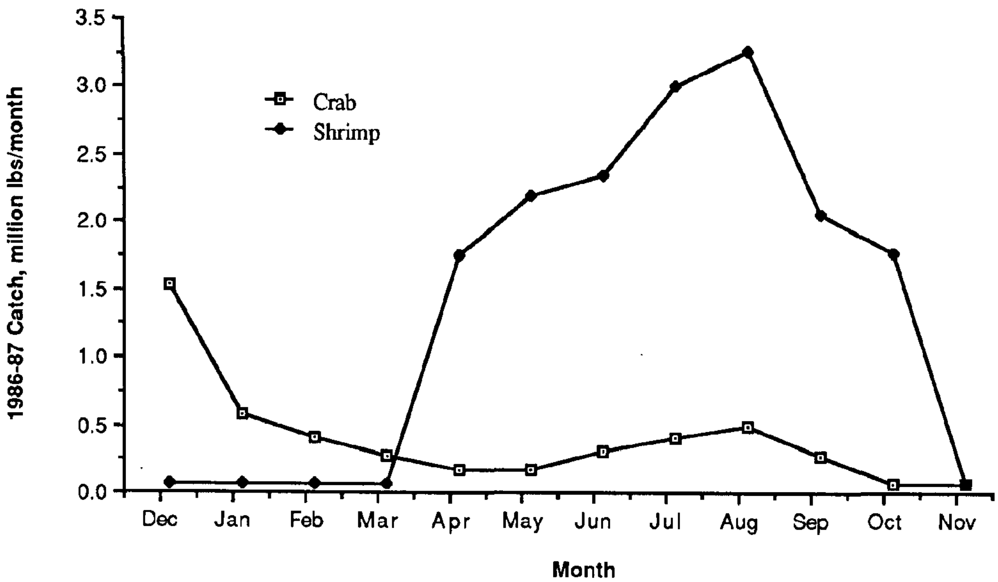

Figure 4.20 Monthly pattern of crab and shrimp catches off the Washington coast (Sources: Barry 1988, McIntosh 1988).

PINK SHRIMP

The life cycle of pink shrimp is summarized in Table 4.4.[71,85] The species ranges from the Aleutians to San Diego, and is commercially abundant from northern California to Vancouver Island. Spawning occurs in September and October, and females carry the eggs through the winter until hatching in March. After hatching, the larvae float in the plankton below the surface until they metamorphose to the juvenile stage in midsummer and sink to the bottom. They reach fishable size in April a year later. The shrimp mature sexually first as males at age 1 1/2. They change into females the following year and usually do not survive beyond four years. In some years, apparently in response to low abundance of older females, some shrimp skip the male phase and mature directly as females during year one.

The habitat of shrimp is on "green mud" (fine-grained sediment with a high organic content). The entire west coast shrimp population is considered a single stock, but this stock appears in ten discrete subunits, or "beds," mainly between depths of about 50 and 100 fathoms approximately 12 to 24 miles offshore (Figure 4.19). Abundance varies between different beds from year to year, probably due to environmental variability, but no regular migration pattern has been observed. The degree of migratory or reproductive interchange between these beds is unknown. Abundance trends in the fishery tend to be uniform all along the West Coast, however, suggesting that there is a single coast-wide stock, or possibly stock subunits that are intermixed by transport of planktonic larvae.

Shrimp school and feed on the bottom during the day, consuming detritus (dead organic matter) and small invertebrates such as worms and crustaceans. At night they disperse and swim off the bottom and consume large zooplankton (copepods and krill). Shrimp are preyed on by groundfish such as whiting, sablefish, flatfish, dogfish, and skates.

Shrimp are caught using shrimp trawls, which are smaller modified versions of otter trawls used for catching groundfish. Vessels can be converted between shrimp and groundfish use depending on abundance and market conditions. The trawls can be very efficient at catching young (one to two year old) shrimp, which can threaten the fishery if carried to excess, especially under conditions of poor year-class strength. For this reason, a minimum mesh size of 1.325 inches is required, and liners for the end of the net are prohibited. This regulation can be inadequate, however. A maximum count per pound in possession regulation restricts the catch to 160 whole animals per pound of catch for loads exceeding 3,000 pounds. In recent years, wholesale buyers have been accepting only larger shrimp (140 per pound or less) or paying fishermen based on the count per pound. The fishery is closed during the egg-bearing period from November 1 to March 31.

The coast is divided into three catch areas that reflect three separate subunits: Destruction Island (Cape Flattery to Cape Elizabeth), Grays Harbor (Cape Elizabeth to Cape Shoalwater), and Willapa (Cape Shoalwater to the Columbia River). In 1987, catch rates (CPUE) were similar in the three areas, but the northerly two areas are historically more productive. Over the last decade, effort has shifted significantly to the north. The Grays Harbor area received most of the effort until 1977, but since then effort has shifted to the Destruction Island area, and even into the northern reaches of that area. This shift is thought to indicate more a retargeting on existing subunits than a shift in subunit distribution. The Willapa area, which traditionally received little effort, appears to have undergone a decrease in shrimp abundance.[69,70]

These northern areas each produced 36 percent of Washington landings in 1987, while the southernmost area only produced 2 percent. The remainder of Washington shrimp landings in 1987 (25 percent) were taken off Oregon. In recent years the northern areas have produced virtually all the catch, the southern area has produced little, and few shrimpers have operated off Oregon. Recent catches in the Willapa area represent an increase from even lower levels during the early 1980s. Catch was lowest in midsummer and highest in October (Figure 4.20).

There was a great increase in effort in the late 1970s as shrimpers moved into Washington from other states in response to depletion elsewhere and high prices. Fishing effort peaked in 1980, but many of the vessels dropped out of the fishery as yields decreased and lower-priced imports increased in the early 1980s.[69] No sport or foreign fishery exists on this species on the outer coast.

Washington shrimp populations currently are in good condition. Year-classes have been strong since 1978.[69] The 1986 shrimp catch was the highest on record, and the 1987 catch was the second highest. These catches were 60 to 90 percent above the ten-year average (Figure 4.17). Fifty-six vessels operated in 1987, a decrease of nine from 1986. CPUE is stable and all subunits appeared to show strong year-classes since 1982. This positive trend has attracted about twice as many vessels to the fishery as operated in the early and mid-1980s.

Shrimp catch was very low during 1982-84. This decrease in catch has not been explained. Foreign shrimp entered the market at low prices and discouraged some effort, but CPUE levels also were low. No year-class failures were observed, however, The possible effect of El Niño has not been assessed, but the drop in catch preceded that occurrence. It is likely that implementation of regulations, begun in 1981 in accordance with the PFMC, has aided the recovery since then.[69,70]

Interviews with deep-water (150-250 fathom) draggers were conducted and test pots were placed to substantiate rumors of possible additional fishable shrimp populations in these depths. To this date, such populations have not been located. Even if not fished, such populations, should they exist, could provide a reservoir of a spawning population that could maintain populations in spite of heavy fishing pressure in shallower waters.[69]

RAZOR CLAMS

The biology of razor clams is summarized in Table 4.4.[61] Razor clams are found on open sandy ocean beaches from southern California to the Aleutian Islands. Commercial quantities are found only north of central Oregon. Razor clams occur from the mid-intertidal zone to about 20 meters depth. Populations are densest in the lower intertidal zone but may also be substantial in the subtidal (surf) zone. If abundant, such populations could offer a reservoir of breeding adults that are unexploited.

Razor clams spawn during late spring and early summer, peaking from mid-May through July in Washington. Lower spawning levels may occur throughout the year, with a possible secondary peak in late summer or early fall. Male and female clams broadcast their eggs and sperm freely into the water, where fertilization occurs. Eggs hatch in about ten days and are reported to sink to the bottom. The larvae float in the plankton about ten weeks (a range of 5-16 weeks) before settling to the bottom. However, there is a suggestion in early observations that larvae also are bottom-oriented, which may limit their spatial distribution along the beach.

Juveniles may accumulate in large numbers on the sand surface after settling out, but they soon begin to dig into the sand. Adults reside in about the upper one foot of sand, but can quickly dig deeper when pursued. Sexual maturity is generally reached at age two in Washington, and natural life span is 9-11 years. Maximum life span of exploited populations is about 7 years.

Razor clams feed by straining phytoplankton (plant plankton) from the overlying seawater. Their diet is composed mainly of one species of surf zone phytoplankton (*Chaetoceros armatum*), which is usually very abundant in nearshore waters.[63]

The critical stage for year-class success of the population is not known but is suspected to be the stage of metamorphosis from larva to juvenile. Numerous environmental hazards face the organisms at this life cycle stage. The newly settled juveniles are vulnerable to predation by birds such as gulls, crows, scoters, and sandpipers. Surfperches, sturgeon, and crabs also are reported to prey on this life cycle stage. Winter storms are another significant source of mortality for juveniles. Temperatures above 22° C (71° F) can be lethal. Too much fine silt in the beach sand is believed to cause suffocation in early life history stages. A final critical need for razor clam survival is abundant dissolved oxygen in the overlying water, which is aerated by surf action. Occasional clam kills occur when very strong coastal upwelling suddenly brings cold, low-oxygen deep water into the surf zone.

The most serious problem currently afflicting razor clam populations is the bacteria-like gill parasite called NIX, which appeared abruptly in 100 percent of the population in spring 1983 and is blamed for a loss of over 90 percent of the adult stock by January 1984.[61] The parasite has direct harmful effects to the clam and also makes it more vulnerable to secondary infections. No harvest was allowed in 1984 or 1985 as a result of this serious depopulation. The decline in recent harvest compared with historic levels of catch is evident in Figure 4.21.

After a temporary reduction in intensity of infection in early 1985, NIX returned to serious levels in late 1985 and early 1986 and caused additional population losses, especially on northern beaches. All clams sampled on the coastal beaches still harbor the parasite, but the intensity of infection in these clams has decreased in recent years.

Razor clam larvae can be successfully raised in hatcheries for planting on ocean beaches. More than 90 million juveniles were transplanted on intertidal and subtidal areas of Washington beaches in 1985, but no efforts are currently under way because of budget cuts. Nevertheless, this ability offers some prospects for restoring the currently depleted populations, as well as for possible future public enhancement of wild stocks or for private farming of the resource.

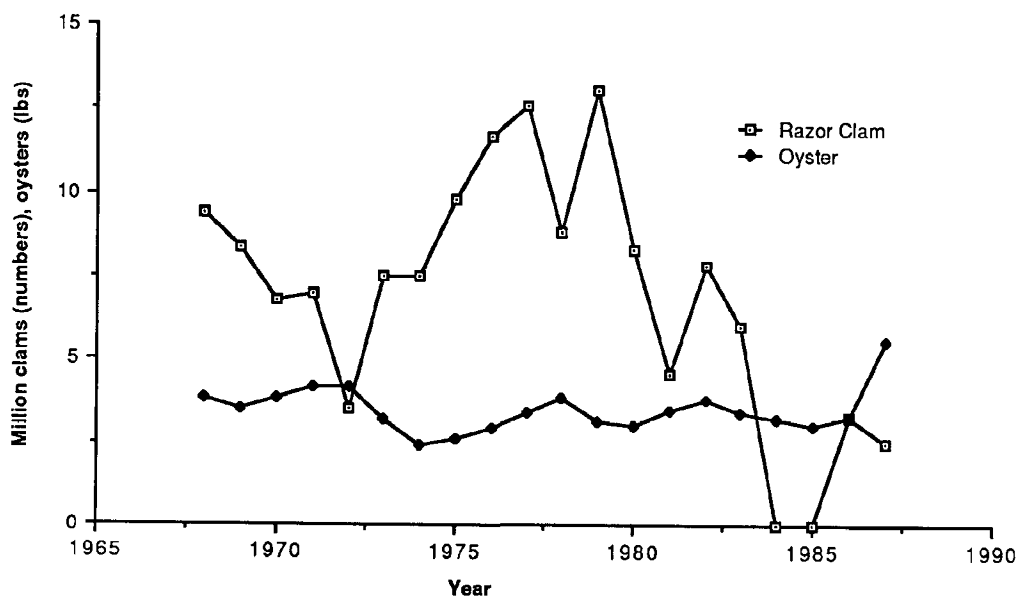

Figure 4.21 Trends in reported recreational catch of razor clams and commercial harvest of oysters along the Washington coast for the last two decades (Source: Dale Ward, WDF). Oyster harvest is reported by location of processing. Much of the oyster harvest from the coast is processed on Puget Sound. Therefore these data are systematically underestimated by as much as 50 percent.[18]

The razor clam has been used for personal consumption since native times and has been fished commercially since before the turn of the century, but it is now mostly taken by recreational digging. The last major public beach in Washington was closed to commercial harvest in 1968. Only offshore spits in Willapa Bay and the Quinault Indian Reservation currently sustain commercial take. The Quinault beaches were closed to the public in 1969. Washington recreational razor clam beaches are divided into four principal areas (Figure 4.19), with a smaller area on Kalaloch beach to the north.

The razor clamming season historically corresponds to the period of peak quality and yield immediately before the spawning season. Because of NIX, however, it has been severely restricted to preserve the stocks. The season currently is opened on alternate days for brief periods in the spring and fall. Daily bag limit since 1973 has been 15 clams per person, regardless of size or condition of the clams. Diggers are required to purchase and display a license.

OYSTERS

The life cycle of the Pacific oyster is summarized in Table 4.4. The Pacific oyster is a Japanese species introduced into the state in the 1920s after the decline of the native Olympia oyster (*Ostrea lurida*). It spawns only at temperatures above 18.1° C (65° F) during summer in Washington waters. In natural spawning, eggs and sperm are liberated into the overlying seawater where fertilization occurs. The resulting eggs and larvae float in the plankton, then enter the juvenile stage when they metamorphose and settle to the bottom or "set." The larvae set on any clean, nontoxic surface. Juveniles that have just set on shell, or "cultch," are called "spat." The oysters reach marketable size in two to four years in Washington coastal estuarine waters.

Oysters feed by filtering large quantities of seawater and straining out phytoplankton. Oyster eggs and larvae are eaten by anything that feeds on zooplankton, and although their mortality rates are certainly high, predation losses are not well documented. Juvenile oysters or spat are vulnerable to predation by crabs, starfish, flatworms, some species of fish, and oyster drills, several species of snail that can drill through the oyster shell and consume the animal inside. Starfish, Dungeness crab, and drills are serious predators of adult oysters.[23]

Oysters are a highly managed species in coastal Washington; approximately 10 percent of harvested oysters originate on Washington States oyster reserve tidelands. These oysters are wild stock. An additional 10 to 15 percent of the annual harvest is wild stock oysters caught on private beds. About six years in every decade, a good commercial "set" occurs in Willapa Bay, but Grays Harbor is too cold. Oyster populations in both bays are now maintained primarily by hatcheries. Populations are also limited by availability of high-quality feeding grounds. The best food supplies and other growing conditions that support the highest growth rates are found on grounds classified as Class I grounds. General oyster-growing areas are indicated on Figure 4.19.

Oyster beds are currently troubled by infestations of ghost shrimp (genera *Callianassa* and *Upogebia*). These animals burrow in the sediment under oyster beds and undermine the substrate, increasing siltation and competing with the oysters for food. The acreage of Willapa Bay infested with ghost shrimp has greatly increased since historical times, possibly because of reduced predation by sturgeon, which are their primary predator and are overfished,[18] or because of El Niño events.[14] Growers are seeking to continue to use the pesticide Sevin to control shrimp infestations, but testing is required to assure that this spraying does not have unacceptable impacts on the other major crustacean in the bay, Dungeness crab. Production in the bay has also been affected historically by siltation caused by forestry practices, and by natural changes in the sedimentary environment of the bay. Some additional problems are now occurring with invasion of the bay by the imported marsh grass *Spartina alterniflora*.

Harvest of oysters has increased 15 to 20 percent per year since the mid-1980s because of market conditions (reduced harvest of East and Gulf Coast oysters). Total coastal production increased from 5.18 million pounds in 1986 to 6.39 million in 1987 (Figure 4.21). There is potential for further expansion of production if there is demand. Restoration of historical production levels would partially depend on significant reduction of the extent of ghost shrimp infestation or on modification of current oyster culture practices.[18] A particular need is to reduce infestation on Class I grounds used for final fattening of the oysters before market.

Because good natural sets do not occur reliably, the state oyster industry until recently imported spat from Japan. Since the early 1970s, however, Washington growers have learned to produce spat, or "seed," artificially in hatcheries. The grower has a source of clean seawater and a reserve of adult oyster broodstock. The adults are temperature-conditioned to bring them to spawning condition. The larvae that result are maintained under controlled conditions and fed appropriate food, which is also grown in the laboratory. Hatcheries have also fostered breeding efforts to produce selected strains of oysters, and are experimenting with genetic control of these animals.

Commercial hatcheries sell to growers all over the West Coast, shipping oyster seed in the form of swimming larvae or as juveniles set on shell (called "cultched" seed).[23] The world's largest oyster hatchery, operated by Coast Oyster Co., is in Quilcene, Washington, on Hood Canal, and supplies seed to its growing operations on Willapa Bay and elsewhere, as well as selling the larvae or seed commercially to other growers. Coast Oyster also operates a hatchery on Willapa Bay. Hatcheries are expensive to run and produce tremendous quantities of seed, so most growers on the Washington coast purchase larvae from the hatcheries for setting on their own cultch or shell.[18] Growers have remote setting stations that permit setting to be performed at the desired location.

POTENTIAL IMPACTS OF OFFSHORE OIL AND GAS DEVELOPMENT ON WASHINGTON FISH AND SHELLFISH

Many studies have been conducted on toxic and sublethal impacts of oil on finfish and shellfish found in Washington waters.[120] It is difficult to interpret and compare the various results because experimental methods are not standardized and hydrocarbon concentrations have not always been monitored in the experimental media throughout the testing period. Standardized methods are needed for (1) holding and exposure of test animals, (2) preparation of test media, (3) determining type and frequency of analysis of test media, and (4) uniform assessment of results.[24,107] Test animals may be exposed for different lengths of time to whole crude oil, the water-soluble fraction of crude oil, or to individual hydrocarbon compounds. The oil may be weathered or unweathered, and from different sources such as Prudhoe Bay, Cook Inlet, or Saudi Arabia. Despite the lack of standardized methodology, ample data from laboratory and field studies provide convincing evidence that oil in the marine environment could alter the normal life processes of a variety of Washington finfish and shellfish.

SALMON AND PELAGIC FISH

Adults and juveniles

The concentrations of oil or specific oil constituents that kill half of the tested fish (LC50s) in laboratory studies on the acute toxicity of petroleum to adult and juvenile salmon and pelagic fish vary with the species, weight of the fish, type of oil tested, and exposure period. In general, larger fish are less vulnerable to oil than smaller fish.[24]

Oil effects on salmonids (salmon and trout) are variable, depending on the life stage affected and the duration of exposure. The fish at greatest risk from oil spills are found in intertidal and stream rearing areas, spawning areas, and rearing areas utilized by juvenile and adult migrants. There is evidence both for and against avoidance of oil-contaminated waters by salmon and trout. Pink salmon fry avoid the water-soluble fraction of Prudhoe Bay crude oil in freshwater and seawater at lethal concentrations but not at sublethal concentrations.[88,107] No data of any sort apparently are available for steelhead or cutthroat trout.

In addition to experimental data on acute toxicity of oil to Washington salmon and pelagic fish, there is also evidence of tissue, organ, and system damage from exposure to oil and its constituents. When coho salmon were exposed to No. 2 fuel oil, the color of the liver changed from the normal uniform dark brownish-red to a blotchy light brown; the color of the spleen changed from the normal black-red to light tan.[48] These changes probably reflected circulatory system damage. Pink salmon fry exposed to sublethal concentrations of the water-soluble fraction of Prudhoe Bay crude oil, Cook Inlet crude oil, and No. 2 fuel oil exhibited a cough response and increased oxygen consumption, reflecting irritation of the respiratory system.[88] The cough response diminished after three hours due to the evaporation of the irritant hydrocarbons from the water column.

Locomotor and activity patterns are also affected by exposure of pelagic fish to oil. When juvenile chinook, chum, and pink salmon were exposed to No. 2 diesel oil at concentrations of 100-3,000 ppm, the fish showed signs of narcosis, were unresponsive to fright stimuli, and swam at the surface of the water.[88] After 24 hours the fish had difficulty maintaining their position, began to swim vertically near the water surface, and finally lost their equilibrium completely.

Oil also affects salmon migration and spawning behavior. Field studies in Puget Sound showed that petroleum hydrocarbon concentrations greater than 0.7 ppm disrupted salmon upstream migration past a tidewater dam. Hydrocarbon concentrations of 2-3 ppm inhibited early upstream migration of coho salmon past the dam and reduced upstream movement of late migrating salmon by 50 percent. A delay in migration might reduce the reproductive success of salmon.[107]

Chinook salmon returning to the University of Washington hatchery were exposed to crude oil concentrations slightly higher than those in oil spills. The oil reduced the sensory ability of the salmon to distinguish between "home" from "non-home" fresh water in a test tank.[103] Spawning salmon use their sense of smell to return to their natal streams; apparently oil in the home water masks the normal odor of the water. If an oil spill occurred in an area where salmon were depending on odor cues for orientation, straying to other streams could occur. However, in field tests on chinook and coho, no impact of oiling on homing success was detected.[20,78,103]

Another impact of oil on Washington pelagic fish is tainting of the edible tissues. For example, adult Pacific herring take up and accumulate hydrocarbons rapidly in muscle, liver, and gonadal tissues. When placed in clean water, 50 percent of the hydrocarbons are lost during the first day, but 10 percent remain even after a week.[98] This retention is due to the high lipid (fat) levels in these tissues and to the suppression of hydrocarbon breakdown and excretion during the reproductive process. Even sublethal amounts of oil could impact herring fisheries if the rapid accumulation and persistent retention of oil hydrocarbons in the edible muscle and ovarian tissues made the herring unmarketable.

Eggs and Larvae

In laboratory studies on the acute toxicity of petroleum to eggs and larvae of salmon and other pelagic fish, the outer membranes of fish eggs provided some protection against exposure to oil, so larval stages were generally more sensitive than eggs. For example, pink salmon larvae grew more slowly when exposed to increasing concentrations of crude oil over 50 days.[88] Growth of later larval stages was reduced the most. Pink salmon eggs exposed to 25 ppm of crude oil had a hatching failure rate of 66 percent.[24]

Pacific herring eggs are deposited in intertidal and shallow subtidal regions, where they are susceptible to the direct physical effects of oil coating and to the toxic effects of specific oil constituents. Herring larvae are somewhat less exposed to smothering but are still vulnerable to the toxic effects of oil found in their nearshore habitat.[107] Direct exposure of herring larvae to oil is fatal. The LC50 drops from 1.85 ppm after seven days of exposure to 0.36 ppm after 21 days of exposure. Growth of herring larvae is reduced by exposure to 0.3 ppm of crude oil for seven days, or to 1 ppm for 12 hours. After 48 hours of exposure to 1 ppm, other developmental abnormalities were observed, including "broken back" flexures of the body. After six days of exposure, the larvae died. The larvae were most susceptible to toxic oil effects while absorbing their yolk sacs, where hydrocarbons tend to accumulate.[57,98]

Pacific herring and northern anchovy eggs and larvae exposed to benzene concentrations of 30-45 ppm experience developmental delays and abnormalities. Larvae were more sensitive than eggs.[88]

Weathered crude oil caused significant reductions in hatching success of fertilized surf smelt eggs at all but the lowest concentrations (30 ppb).[57] Survival rates for those that did hatch, even for the 30 ppb group, were less than 9 percent for all oil-treated groups compared with a normal 42 percent. Abnormalities found among oil-exposed surf smelt embryos included retarded eye development, pigment diffusion, arrested growth, and damage to eye and brain cells. Surf smelt spawning stocks are genetically distinct and thus vulnerable to localized extinction if their spawning beaches are oiled.[107]

Susceptibility of Salmon

Oil and gas development of the scale anticipated off the Washington coast is not considered to pose a high degree of space-use conflicts with ocean salmon or their fisheries. Salmonids probably do have preferred migration corridors and feeding grounds on the shelf, but it has not been possible in this report to document their existence or locations. Salmon would suffer localized displacement if oil or gas production commenced at such a site. Minor impacts also would be expected from routine discharges of produced water. Onshore facility construction also could cause impacts on salmon spawning habitat if conducted in a poorly controlled fashion near access routes to spawning streams, or if effluents from processing facilities were released to those regions.

One scenario for damage to adult salmonids from an oil spill along the Washington coast would involve the spill striking the coast at one or more river or bay mouths during the upstream migration period, in which case it might inhibit salmonids seeking their natal streams. This susceptible period is mainly in the late summer and fall, although some stocks migrate beginning in spring. The significance of the effect is uncertain but generally regarded as low. A spill that stayed offshore might disrupt the migration patterns of salmonids over the shelf but would probably not prevent most fish from locating their stream destinations.

A worst-case damage scenario might involve a major spill approaching shore, entering estuaries, and making landfall during the spring when juvenile salmonids are entering and adapting to salt water. This is a physiologically stressful period when food supplies are thought to be critical to survival. Spilled oil would surely cause significant mortality to juveniles from streams and estuaries it contacted, at least for some period that would again depend on volume spilled and duration of residence of the oil. Mortality would result from both direct toxicity and starvation. Both processes would also cause sublethal effects that could contribute to later additional mortalities.

The geographic scope of potential impacts on salmonids from oil and gas activities on the Washington shelf is not well defined. This report looks only at effects on coastal and Columbia River stocks. Impacts on adults could affect stocks from British Columbia to California, however, depending on the location, magnitude, transport, and volume of a spill. Impacts on nearshore and estuarine juveniles will be more more limited mainly to coastal and Columbia River stocks; these stocks, however, still originate from streams as far away as British Columbia and Idaho.

GROUNDFISH

Groundfish (especially flatfish) are particularly vulnerable to oil because they live on or near the sediments, where oil can concentrate. Although some mobile bottomfish can avoid petroleum exposure, flatfish do not show this behavior. In laboratory studies, juvenile flatfish given a choice of areas containing oil-contaminated or clean sediments did not show a preference.[107] English sole exposed to oil-contaminated sediments for four months accumulated substantial concentrations of petroleum hydrocarbons, developed liver abnormalities, and lost weight.

Flatfish eggs and larvae may be particularly vulnerable to floating oil and to the water-soluble fraction of oil associated with oil slicks, because the eggs and larvae are often found in the surface microlayer.[104] Abnormalities resulting from exposure of sand sole eggs and larvae to crude oil (64 ppb) include shorter body length; abnormal body shape, spine, and internal organs; reductions in yolk and pigmentation; and narcotization.[107]

Juvenile stages of most flatfish species are associated with the intertidal and shallow subtidal zones. These stages and the adult stages of nearshore and kelp-bed species are vulnerable to major oil spills at all times of the year. Most economically important groundfish species could be affected by a major oil spill in Washington marine waters. The most vulnerable areas would be the coast north of Destruction Island, Willapa Bay, and Grays Harbor. The two estuaries are major nursery areas for lingcod and many flatfish species. The northern coast is critical habitat for lingcod, rockfish, greenlings, and sculpins, species especially vulnerable to oiling.[107]

Field studies over a five-year period in Puget Sound found relationships between contaminated sediments and prevalences of liver cancers in bottomfish, especially English sole. Correlations were found between polycyclic aromatic hydrocarbons (PAHs) in the sediment, liver tumors, and hydrocarbon metabolites in the bile of English sole. Petroleum and its by-products are one source of PAHs. Fish collected from Eagle Harbor, where sediment hydrocarbon levels were highest, had the most liver tumors.[65,77] In another study, female English sole failed to mature sexually more frequently in Eagle Harbor and the Duwamish Waterway, two sites with high levels of petroleum hydrocarbons in the sediments, than in sites with cleaner sediments.[58] Although these studies were not directed specifically at oil pollution, the high incidence of abnormalities in English sole exposed to the types of hydrocarbons found in oil suggests a cause-effect relationship.

CRAB AND SHRIMP

Laboratory experiments on the acute toxicity of oil to crabs and shrimp show in general that larvae are more sensitive to oil than adults, No. 2 fuel oil is more toxic than crude oil, and the water-soluble fraction of crude oil is more toxic than oil-in-water dispersions. Naphthalene compounds are among the most toxic to first stage larvae.[21,24,57]

Crustaceans readily accumulate petroleum hydrocarbons from surrounding water when exposed for more than a few hours. Such hydrocarbons have been identified in the thorax and abdomen, gills, stomach, hepatopancreas, muscle, gonad, and blood of crabs and shrimp. Dungeness crab and pandalid shrimp are most vulnerable to oil spills at the egg and larval stages (which occur in winter and spring) and right after each molt.[107]

Dungeness crab larvae do not avoid oil slicks and can be killed by concentrations of crude oil less than 100 ppb. Larvae exposed to 1.1 ppm benzene experienced nearly 100 percent mortality at the time of first molt; however, neither benzene nor naphthalene affected the duration of larval stages or the size of surviving larvae.[21,57]

Sublethal effects of oil on these larvae include narcosis, abnormal development, reduced feeding and growth, and changes in behavioral response to light, gravity and pressure, and chemical cues. In response to seawater solutions of clam extract, Dungeness crab usually change the orientation of their antennules and increase the antennular flicking rate, a behavior analagous to sniffing for food in vertebrates. After 24 hours of exposure to 0.27 ppm crude oil, a significantly lower percentage of the crabs showed this behavior.[94] By impairing the chemosensory response, petroleum could cause crabs difficulty in finding food and thus ultimately reduce their survival.[56,57]

The presence of larval Dungeness crab near the ocean surface and in the surface microlayer makes them vulnerable to the effects of possible oil spills. Larvae concentrate in fronts and convergence zones, which could become accumulation sites for oil and toxins.[104]

The use of the intertidal and shallow subtidal zones as nursery habitat, especially in the Grays Harbor and Willapa Bay estuaries, also makes Dungeness crab highly vulnerable to oiling from surface slicks. This threat is particularly evident in estuaries, where oil can be trapped in fine sediments and may take years to be flushed out. Older juvenile crab reside in deeper channels in the estuaries, where they are vulnerable to disturbance and mortality caused by shipping and especially dredging. Large increases in such activities as a result of oil and gas development might impact crab yield.

Adult crab on the bottom in deeper water are susceptible to contamination from the negatively buoyant components of crude oil that sink to the bottom. Possible effects include direct effects of oil toxicity, uptake of contaminants through the food web, disruption of food supplies, and tainting of flesh. Localized impacts on adult crab also would occur where muds and cuttings were discharged near platforms.

Seismic exploration relies on high-intensity sound waves for sonar detection of subsurface rock and sediment layers. These sound waves have the potential for injuring or killing small, immature organisms within a few meters of the source. This hazard may exist for crab in the larval stage.[95] Studies on seismic effects on finfish, however, have concluded that any seismic-induced mortalities are localized within a very small range of the acoustic equipment and have negligible effects on the populations as a whole.[50] This conclusion would be expected to apply to crab larvae as well. Crab may also be vulnerable in the soft-shell stage just after molting.[112] This stage lasts about four to six weeks in an individual crab, and the molting season for crab on the coast lasts through the summer and fall.[9,10,11,12,13]

The shorter the maturation period of a fishery species, the more quickly its populations reflect environmental factors. In the case of pink shrimp, environmental effects are felt the following year. A corollary to this is that the longer the adult life span of a fishery species, the better able it is to maintain its population in spite of stresses, because there is a persistent adult population pool that can weather a series of poor year-classes and still maintain a viable spawning stock. This is not the case with the short-lived pink shrimp. Significant increases and decreases in shrimp catch are common because of the rapid changes in adult populations. Therefore, shrimp could be particularly vulnerable to environmental stresses that affect their year-class strength.

Since only two or three year-classes are present at any time, the fishery is vulnerable to collapse from overfishing or a series of poor year-classes.[85]

Shrimp larvae will be sensitive to surface layer contamination, such as by spilled oil, occurring during the April-July period they are in the plankton. The rest of the year, shrimp would be affected only by contaminants that sank to or near the bottom, such as heavy oil fractions, muds and cuttings, and construction/placement impacts. These will generally be localized except for the possible spillage of heavy oil. Such oil is expected to be transported northward in the general direction of productive shrimp grounds. If the oil moves shoreward along the bottom from an inshore spill site, it may not reach depths inhabited by adult commercial shrimp stocks.

CLAMS AND OYSTERS

Laboratory experiments on the acute toxicity of oil to clams and oysters show that exposure of sperm and eggs to 1 ppm of crude oil for one hour results in significant decreases in fertilization, normal embryonic development, and larval survival rates. Adults are less sensitive to the toxic effects of oil than eggs, larvae, and juveniles; 1,000 ppm crude oil exposure for 6 hours produced 26-31 percent mortality in oysters; 10 ppm produced 100 percent mortality in juvenile clams exposed for 20 days. No. 2 fuel oil is more toxic to littleneck clams than Cook Inlet crude oil; the 96-hour LC50s were about 2 ppm and 15 ppm, respectively.[24]

Clams and oysters inhabit intertidal and shallow subtidal areas, where spilled oil can concentrate. They accumulate hydrocarbons from surrounding water within a few hours and store them in gill, muscle, viscera, mantle, and foot tissue. Often several years will pass between successful sets of young clams or oysters; some are very long-lived. In such infrequently reproducing, long-lived species, a new generation may take many years to develop after an oil-spill-induced loss.[107] However, culture practices permit some restoration of localized losses.

Ventilation in clams and oysters serves the purposes of respiration, feeding, and waste and gamete discharge. Thus a pollutant which affects ventilation may have multiple physiological effects. Oysters show decreased ventilation and feeding with higher exposure to No. 2 fuel oil; at 0.9 ppm, their shells remained closed, a behavior that may affect metabolism.[55] Softshell clams from sediments exposed to No. 6 fuel oil grow at half the normal rate. In studies near an oil field discharge, oyster shell growth was reduced within 150 feet of the discharge point. Threshold concentrations of 3-6 percent oil in discharge water affected the clearance (filtration) rates of oysters; 10 percent oil in discharge waters affected pumping rates. On the other hand, other oyster studies have shown that 96-hour exposures to 1 percent oil-seawater dispersions of various crude and fuel oils have little effect on oyster growth. Several investigators have shown that oyster growth was unaffected even when the oysters were kept under a crude oil slick for more than one year.

Oil affects the early developmental stages of the Pacific oyster; exposure to about 1,000 ppm of crude oil produced abnormal development in 50 percent of the oyster larvae within 48 hours.[55] Threshold doses for inducement of abnormalities in oyster larvae by benzene, toluene, and xylene were 3.1-3.6 ppm. Benzene derivatives and naphthalene were the most toxic of the tested constituents.

Oyster larvae are used as a test organism in bioassays for water pollutants because of their demonstrated high sensitivity to contamination.[22] Mortalities or abnormalities may be caused by low levels of chemical contamination, or by fine particles in the water such as silt introduced by dredging or shore runoff. In nature, larval oysters rely on weak chemical cues in seawater to determine appropriate times and places to set, so petroleum hydrocarbons may disrupt their sensing systems. Furthermore, oyster grounds are by nature sheltered waters with poor flushing and fine-grained sediments. These kinds of waters are most sensitive to all kinds of contamination, but particularly to oil spills. Therefore, Willapa Bay oyster beds could be vulnerable to lower levels of contamination from oil and gas development than would occur from a massive spill. They could also be vulnerable to sedimentation caused by construction of pipelines and onshore facilities, or by increased dredging and vessel traffic.

The existence of the hatchery system mitigates these risks to an extent by supplanting the need to rely on natural spawning. However, hatcheries are still dependent on clean bay waters for growing adult broodstock and larvae. The waters of Willapa Bay are now considered quite pristine and free of chemical or bacterial contamination. Any alteration of that condition could affect the industry even before it would affect wild oyster populations. The greatest effects would occur from spill contamination of Class I beds.

Adult oysters would be sensitive to mortality or abnormalities caused by a massive spill. Toxicity of petroleum hydrocarbons, increased temperatures due to heating of a slick in summer, and suffocation by a slick are possible lethal or sublethal effects. Adult oysters are also vulnerable to low levels of contamination in the water because they filter huge volumes of water during feeding, so contaminants with an affinity for living tissue can accumulate in the oyster even if present at very low levels in the ambient water. This accumulation can be sufficient to produce toxic effects in the oyster; even at lower levels of contamination, the oyster may be unfit for commercial harvest and human consumption. Since oysters are not mobile like finfish, they are vulnerable year-round as long as oil contaminants remain in the sediments.

Another impact of oil on bivalves is decreased burrowing behavior. Littleneck clams burrow more slowly and less deeply into oiled sand. The result is increased vulnerability of clams to predators such as Dungeness crabs. In two field enclosure experiments lasting 13 and 29 days, Dungeness crabs consumed more littleneck clams from oiled than clean sand; the clams were shallower in the oiled sand.[94] This shows how a supposedly sublethal effect of oil (e.g., decreased burrowing in sand) actually causes a lethal effect.

The filtration rates of softshell clams increase in emulsions of 0.9 percent Bunker C fuel oil in seawater. Softshell clams in oiled intertidal sediments showed reduced growth and weight. Two years after the spill, clam weight had decreased by 20 percent in the contaminated sediments, but normal clams had grown 250 percent.[55] In several field experiments, growth of two Washington clam species was reduced significantly after four-month or six-month exposures to 2000 ppm total oil or 6 ppm naphthalenes and phenanthrenes in sediments.[5]

Toxicity of oil to razor clams has not been studied, but they are clearly highly vulnerable to any landfall of spilled oil on their beach habitat. Heavy oiling would probably cause serious mortality from direct toxicity, suffocation, and elimination of food supplies. Lighter contamination might cause physiological disturbances such as larval abnormalities and tumors. Tainting, at least temporarily, would result from light oiling. Siltation of the beach from dredging or from excavation for onshore facilities would need to be carefully contained when in the vicinity of razor clam beaches. Nearshore structures that would affect the sizes of waves or alongshore currents reaching beaches could affect their suitability as razor clam habitat; decreased surf could deprive some beds of sufficient oxygen but also could reduce storm mortality.

Razor clam populations are vulnerable to any increased environmental stress at the present time because of their depleted populations and parasite infestation. The significance of any potential oil and gas impacts would depend heavily on the condition of the populations. By the time oil and gas development occur, populations might have recovered substantially, might have suffered again, or might be in borderline condition as they are now. Mortality or stress due to contamination would likely be aggravated by the presence of the parasite, which still infests 100 percent of the population.

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5

Human Resources of the Washington Coast and Potential Socioeconomic Impacts of Offshore Oil and Gas Development

Coastal Economics

The Washington coast—Grays Harbor and Pacific counties, and Clallam and Jefferson counties west of the Olympic peaks—is an isolated area that has always depended heavily on natural resources. Westport styles itself "the salmon capital of the world." South Bend is "the oyster capital of the world." Forks is "the logging capital of the world." Raymond urges tourists to see its logger statue. Grays Harbor College calls its athletic teams "Chokers." People visit Westport, Ilwaco, La Push, and Neah Bay to catch salmon. They go to the ocean beaches to dig razor clams. Olympic National Park, with its mountains and rain forests and wild beaches, attracts more visitors than either of the state's other national parks.[84] The public beaches from the Columbia River north to Moclips, which are not state parks but are administered by the State Parks and Recreation Commission, logged 28 percent of the Parks Commission's visitor days for the entire state in calendar 1987.[85]

The native cultures depended on the resources they could harvest from the sea and from the rivers that ran into the sea. All the tribal groups harvested salmon, and they tended to live near the mouths of rivers to which salmon runs returned. The Makahs, at the mouth of the Strait of Juan de Fuca, also harvested halibut and whales.[30]

The European economy depended from the start on the forests, and the main population centers developed on rivermouth harbors in which ships could tie up to load logs or lumber. The whites, too, fished from the beginning, and commercial oyster harvesting began in Willapa Bay before Washington was a state, but the forest products industry has always been the mainstay of the economy.

That economy is the kind that is sometimes described as "colonial": a lot of natural resources that are shipped to faraway places, not much value added locally, a heavy reliance on outside capital. Its glory days passed a long time ago. In Grays Harbor County, the timber harvest peaked in 1929. The county's population declined with the timber harvest after 1930, and didn't surpass its early Depression level until the 1970s. Over the years, there has been a steady attrition of small mills all over the Northwest, and the Washington coastal region has been no exception. Indeed, as a center of cedar shake and shingle making, which tends to be done in extremely small operations, it has probably suffered more than other places from that historical attrition.

It has also suffered a loss of manufacturing jobs as the forest products industry has raised productivity by cutting more lumber with fewer workers. As the number of mills and the number of workers per mill have both declined, so has the percentage of the local work force that has worked in the woods and the mills. Take Grays Harbor County again: in 1970, the forest products industry provided 37.4 percent of total employment and 45 percent of total wages.[40,88,93] By September, 1988, the industry's share had dropped to 14.7 percent of nonagricultural employment. For 1987 as a whole, it contributed 21 percent of total wages—still impressive, but a big step down.[96]

In the early 1980s, the recession hit the forest products industry particularly hard, and the historical process of attrition turned into a sharp drop. Mills were closed and jobs disappeared all over the state. On the coast, the heavy reliance on forest products made the unemployment figures especially grim. An estimated 3,803 timber jobs—the kinds of basic jobs on which an economy is built—disappeared in coastal Washington between 1980 and 1985.[31] Unemployment figures went way up into double digits; at times, unemployment in Pacific County exceeded 20 percent.

And knowledgeable observers agreed that the statistics didn't tell the whole story: the actual number of people without jobs was almost certainly higher.[88,96]

There are no figures on the numbers of people who left the coast at that time to find work, although some certainly did. Others certainly would have if they hadn't owned houses that were impossible to sell and if they hadn't had deep roots in their communities. Actually, the coast was in some respects a relatively good place to subsist in hard times. There have been no studies, no statistics of any kind on the "underground economy," but doing work that didn't show up on the tax rolls clearly helped a good number of people get by. In good times as well as bad, a lot of people on the coast supplement their incomes by picking ferns or bark or mushrooms or beargrass, just as they help to fill their tables by raising produce and catching fish. (Many also work in family businesses, on farms, or in other jobs that never show up in state employment figures.) During the recession, they relied heavily on that income and subsistence. The abundance of natural resources and the closeness of the communities made it possible.[18,46,88]

The economic problems of the early 1980s went beyond the forest products industry, even beyond the overall recession that gripped the country at that time. The salmon catch declined precipitously, as the El Niño phenomenon, which increased water temperatures, compounded the long-term effects of overfishing and habitat loss. Commercial fishing and the sport charter fishing business both fell on hard times, deepening the effects of the recession. (To make things even worse, the state's razor clams were attacked by a deadly parasite, forcing both recreational and commercial harvesting to shut down for two years.) In 1974, salmon made up 58 percent of the value of the catch in coastal waters. By 1985, that figure had dropped to 18 percent. The poundage of the salmon catch dropped 85 percent over those years. The sport catch dropped, too. An estimated 3,852 jobs were lost in commercial fishing. In Westport, 278 charterboats operated in 1978, only 85 by 1984. In Ilwaco, the number of charterboats declined from 130 to 57. Between 1981 and 1984, hotel and motel tax receipts in Westport and Ilwaco dropped by more than half.[31]

Ever since World War II, unemployment in the coastal counties had been higher than Washington's average unemployment rate anyway.[88] The recession of the early 1980s just widened the gap. In 1979, the last really good year before the recession, Washington's state unemployment rate was 6.8 percent. Pacific County's was 8.5 percent, Grays Harbor County's 8.8 percent, Clallam County's 9.4 percent. In the worst full year of the recession, 1982, the state rate was 12.1 percent, but Grays Harbor's was 15.5, Pacific's 16.8, Clallam's 19.1. In December, 1984, with state unemployment back down to 9.3 percent, Pacific County's unemployment rate was 24.2 percent.[93,96]

The coast was simply falling further behind. In constant dollars, between 1977 and 1984, per capita personal income in Washington state rose a total of 5.5 percent. In Pacific County, it rose only 2.7 percent. In Grays Harbor County, it dropped 2 percent.[93]

A number of the mills that closed during the recession never reopened. Those that did are by and large doing well. (Some small mills that opened—or reopened—to take advantage of low log prices during the recession have suffered with the recent rise in log prices, though.) Prices are up, and the mills are processing a lot of wood. But because the industry streamlined itself during the recession, automating so that it could cut more wood with fewer workers—"restructuring" is the way it's usually described—the chances are it will never again employ as many people as it did in the late 1970s.

On the coast, unemployment figures have finally come down, but they remain well above the state average. In August, Pacific County still had a rate of unemployment 39 percent higher than the state as a whole. Grays Harbor County's unemployment rate was 53 percent above the state's.[96]

The old industries are still important there. Forest products provide some three-quarters of the manufacturing employment in Grays Harbor County. The industry provides nearly one-half the manufacturing jobs in Pacific County, more than two-thirds of the manufacturing jobs in Clallam County.[93,96]

Other traditional industries are important, too. When forest products employment is down, oyster raising is the largest single private source of employment in Pacific County; it is always at least a close second. Fishing and fish processing are still significant. The commercial salmon catch has gone down from its highs of the mid-1970s, but it is still worth $5 million a year. Actually, the salmon harvest has improved considerably from its nadir in the early 1980s. The commercial catch of chinook salmon, which hit a low of 1.26 million pounds in 1983, rose to 4.6 million pounds last year. The sport chinook catch rose from its 1984 low of 15,094 fish to

31,567 fish in 1986.[91] Commercial fishermen continue to catch shrimp and crab—which have recovered from a decline of their own—as well as rockfish and bottomfish. The charter boat operators have been building up a clientele for whale watching trips and for recreational bottomfishing.

The problem is that improvements from the levels of the early 1980s do not take the fisheries back to their historical averages or to high water marks that people in the charter business like to use as benchmarks. More people had jobs in Pacific and Grays Harbor counties in the summer of 1979 than in the summer of 1987. The counties also had more operating hotels and restaurants in 1979 than they did eight years later.[94,95]

Economic problems did not end with the recession. In 1987, officials of Pacific County talked publicly about declaring bankruptcy. A survey of voters in Grays Harbor County, done as part of a *Grays Harbor 2000* citizens' planning effort, found that "the top issue in Grays Harbor County is the economy, specifically the need for jobs and diversification of the economy." Asked about the biggest problems facing the area, 40 percent named unemployment and the need for more jobs, while another 30 percent named the need to bring in new industry and diversify.[6]

People who live on the coast don't want it to change in fundamental ways, but they do want it to be more prosperous. Some are evidently willing to see their neighbors go to considerable lengths to prosper individually. The same abundance of resources and community closeness that helped people weather the recession also made it tempting for some of them to steal large amounts of timber from federal land. As the timber theft scandal unfolded recently in the Seattle press, virtually no coastal residents quoted by the papers condemned the people who had been stealing federal logs. The log thieves were part of "us." The federal government was part of "them." Public resources belonged to the people who lived nearby.

As that episode illustrates, the coast is more than a little isolated from the culture of the Puget Sound metropolitan centers. Aberdeen, which is far and away the largest center of population, is only 46 miles from Olympia, but it is 106 miles from Seattle, 145 miles from Portland. (Those distances can, of course, be covered relatively easily by anyone who owns a car, and they are whenever circumstances warrant it. During a bitter strike of supermarket employees in Grays Harbor, many residents who didn't want to cross picket lines or get involved simply went to Olympia to buy groceries. A recent study of Pacific County oyster industry employees found that while they bought convenience grocery items close to home, they tended to go outside the county to buy clothing or staples).[15] Most economic and social statistics describe whole counties, but in fact, what is true of, say, Clallam or Jefferson County in general may not be true at all of the portions of those counties that lie along the coast. The eastern parts of the counties have most of the population, most of the jobs, the larger communities, the larger employers, much more convenient access to the cities.

The distance between the coast and the population centers of the state goes beyond mileage. Unemployment is chronically higher on the coast and personal income is lower. People tend to have a little less education and to be a little older. There is less economic growth and less population growth. The continuing reliance on natural resources puts the communities closer to the state's past, as seen from the metropolitan areas, than to its present or its future.

That perception may not be confined entirely to the metropolitan areas, either. "A stunning two-thirds of Grays Harbor County voters think their area is in worse shape than other areas of Washington State," the survey firm hired for *Grays Harbor 2000* reported. "We have rarely seen a public in the Northwest have such a sense of pessimism about current conditions."[6]

PROSPECTS FOR THE FUTURE: TOURISM

All the communities on the coast have to figure out where to go from here. The obvious problems are economic, but the ramifications go beyond dollars and cents. The firm that surveyed Grays Harbor County voters for the *Grays Harbor 2000* report noted that "when an area feels as negatively about itself as does Grays Harbor County at present, weak economic conditions are almost inevitably the reason." In its 1988 report on *Washington's Distressed Areas*, the Washington Economic Development Board noted that "the cost to Washington residents in lost revenues and added social services due to the permanent loss of just one primary job averaged $8,865 in 1986. . . . Added to that are the social costs of higher rates of alcoholism, wife and child abuse, serious illness and suicide."[6]

Jefferson was the only coastal county not classified on the basis of unemployment figures as "distressed." The Board estimated that if the others were to achieve 8 percent unemployment by the year 2000, Pacific County needed 228 new manufacturing jobs, Grays Harbor County needed 501, and Clallam County needed 833.[6]

No one expects the coastal economies to change drastically. Forest products will remain central. Hopes are that the industry will find ways to add more value to its products—to ship less raw material and more finished or semifinished items—and that other portions of the economy will grow. The prospects are limited. The high tech companies that some people saw, wishfully, as economic salvation a few years ago generally have no interest in an area such as the Washington coast. The distance from major markets and from major rail and highway routes excludes many other businesses. Aquaculture is one possibility. The shore-based tank farm on which a Norwegian company wants to raise salmon in Westport is a very encouraging development, although the project's long delay may have taken off a little of the bloom.[81]

Another potential focus of economic development, at least for Grays Harbor County, is the Port of Grays Harbor. What the port does primarily is export logs. In the depths of the recession, its log exports to the Far East were among the very few bright spots in the local economy. The U.S. Army Corps of Engineers wants to dredge the channel so that it can accommodate larger, more efficient log ships. Crab fishermen have opposed the dredging bitterly—it would, in fact, pose a threat to the crabs—but when Grays Harbor County voters were surveyed for the *Grays Harbor 2000* citizens' planning effort, 89 percent of them favored dredging. "Deepening the navigational channel" got more favorable responses than any other economic development proposal. Exactly what, beyond larger log ships, dredging would bring to Grays Harbor is mainly conjecture. In the past, there have been bursts of optimism about oil drilling platforms, coal slurry, and molybdenum, but so far, the port has attracted no major cargo except forest products.[6]

Perhaps the main economic hope of the coastal region—as it is the hope of economically distressed areas all over the state—is tourism. Seventy-six percent of the citizens surveyed for the *Grays Harbor 2000* study agreed that tourism was important for the county and "we need to do everything to expand it." The survey firm noted that "everyone wants to expand the tourist industry in Grays Harbor County."[6] All along the coast, tourism is an obvious way out. As a statewide prescription for economic salvation, even the most heroic efforts to increase tourism obviously have their limits: people from California or even Seattle simply won't flock to every distressed milltown in the state. But the Washington coast starts with major advantages: it is already a major tourist attraction; and it has the resources to attract even more visitors in the future.

Unfortunately, even as a tourist attraction, the coast has done relatively little to build on its natural resources. The resources are spectacular: there are miles of ocean beaches—25 miles on the Long Beach peninsula alone—game fish, razor clams, a magnificent national park. And people flock to the coast to take advantage of them. Last year, the Olympic National Park drew more visitors than any other national park in the state, 3.36 million. The state estimates that in 1986, travelers spent $11 million in Pacific County and generated 320 jobs. In Grays Harbor County, they spent $50 million and generated 1,200 jobs. In Clallam County, the estimates are $40 million and 960 jobs. In Jefferson, they are $12.8 million and 325 jobs.[86,87] (Those figures are all indirect measurements of tourist activity; they are derived from hotel and restaurant taxes and occupation codes for each county. They may be way off, but no one doubts that coastal tourism is economically significant.) No one is sure exactly where the visitors come from, although most seem to come from the I-5 corridor. If the coast follows the statewide pattern, most out-of-state visitors come from California.[84]

By and large, the biggest spenders seem to be the people who visit the coastal ports of Westport, Ilwaco, Neah Bay, and La Push for charter fishing. On the average, from 1982 to 1985, one person taking one charter boat trip in Washington state spent $115.70. Again on the average, 85.8 percent of that—$99.27—was spent at the destination. (People traveling for other kinds of activities often spend larger percentages of their total outlays before they arrive.)[50] The latest figures available show that 86,979 charter trips on the coast generated $9.72 million in direct expenditures and 496 jobs. The expenditures do not all represent money brought into the state. For recreational fishing in general, only about 28 percent of the total expenditures seem to represent money brought across the border.[50] But a great deal of the charter boat revenue does represent money brought into the coastal region. One hundred seventy-nine more coastal jobs depend on charter boats than depend on commercial fishing.[50]

The charter business hit its peak in the mid-1970s. Since then, declining fish stocks have pushed the catch way down, curtailed the fishing seasons, and cut the number of sport fishermen to a fraction of its former level: from half a million in 1977 to 40,000 in 1984; this year, the estimate is 60,000. Not surprisingly, the number of charter boats has plummeted, from 228 at the high point to 60 today. In 1984 and 1985, possibly half the charter boat operators went bankrupt.[79]

The survivors, unable to do anything about the number of available salmon, have been trying to build up clientele for other kinds of excursions. They now take sportsmen out to catch bottomfish. (The peak seasons have been roughly the same: July and August for salmon fishing, August for bottomfishing. Black rockfish and lingcod are the main targets of the new sport fishery, but other species are taken, too.) And Westport has become a center for whale-watching trips.

The coast still attracts thousands of people to dig razor clams. (Razor clams used to be harvested commercially, but the last major public beach was closed to commercial harvesting in 1968. Now, except for offshore spits on the Quinault Indian reservation and in Willapa Bay, razor clams are no longer a commercial species.) The clam harvest is only about one-third of what it was in the 1970s—it has dropped from an average of about 7.5 million to an average of about 2.5 million—and the season has shrunk, but people still pack the beaches whenever digging is allowed.[92] In 1983, the Grays Harbor Regional Planning Commission estimated that razor clamming was worth $30 million a year to the region. That figure was almost certainly much too high. After clamming was banned for a couple of years in the mid-1980s—because a parasite had devastated the clam population—short seasons were permitted again, with people allowed to dig only every other day. Tourism officials assumed that the every-other-day regime would bring an economic boom, as diggers would have to stay some place and to eat between digging days. The boom never materialized. It turned out that the razor clam diggers who stayed more than one day by and large traveled in RVs. They didn't rent motel rooms. They didn't eat in restaurants. They didn't even buy much of their food locally. The RV parks did a good business, and gift shops near the RV parks did all right, too, but the rest of the economy received a very limited boost.[97] (It may be significant that while Grays Harbor County's percentage of state gas station sales rose from 0.2 to 1 between 1977 and 1984, its percentage of state hotel and motel receipts fell from 3 to 1.8.)[39]

The fact is that, like the traditional resource industries of the coast, the tourist industry has added relatively little to what nature has put there. (Some communities have started trying to make themselves more attractive to visitors—murals in Ilwaco and the Long Beach peninsula and a passenger ferry across the mouth of Grays Harbor are among the new attractions—but there is still nothing that competes with and relatively little that complements the region's natural assets.) While many people visit the area each year to take advantage of the fishing and the clamming, the wide beaches and the national park, both the number and the quality of accommodations leave something to be desired. As the state Department of Community Development's Coastal Readjustment Strategy noted in 1985, "throughout the coastal region, there exists an extreme shortage of first-class, resort quality lodgings. . . . The lodgings that exist on the coast primarily have been oriented toward the budget travelers and toward special interest groups such as fishermen travelling without families and requiring only basic accommodations. Travellers accustomed to higher quality standards, however, or seeking a unique destination experience, are not easily accommodated on the coast at the present time. Coincident with the shortage of higher quality tourist accommodations on the coast is a shortage of quality dining establishments." Beyond the basics of lodging and dining, the report noted that "in contrast to the majority of tourist centers in areas such as coastal New England and California, the Washington coast lacks interesting shopping and entertainment experiences."[31]

One assumes that "travellers accustomed to higher quality standards" will also not flock to beaches that by law and custom are used as public highways, with some cars and trucks parked virtually at the water's edge and others cruising endlessly back and forth. That is not the kind of ambience that draws people to, say, the beaches of Cape Cod. (Traffic on some beaches should get lighter in 1990; a law passed by the 1988 legislature requires that after that date at least 40 percent of the beaches must be reserved for pedestrians during the summer.)

If the presence of cars along the beaches is, perhaps, a handicap, so is the absence of a way for cars to drive all the way down the coast. Route 101 jogs inland, around the Quinault reservation. For years, the Quinaults did not want a road through their land. Recently, they have changed their minds, and eventually it should be possible for visitors to avoid the long inland detour.

The only real new attraction being developed for the coast is the Tall Ships project in Grays Harbor. There, a tall sailing ship is being built—and another is planned—as a tourist attraction. State economic development money has made the Tall Ships project possible; a local bond issue to finance the project failed.[40] Some people speculate that when the tall ships are completed, motels will be built to accommodate the people who visit them, and the area's shortage of attractive lodgings may be somewhat reduced.

Overall, though, the area remains heavily dependent on sport fishing and clamming, and at the mercy of the same fluctuations of natural fish and clam populations that buffet commercial harvesters. With the exception of the Tall Ships project, there is still little being added. The shift of Westport charter operators toward whale watching seems a promising development. There is still relatively little effort made, though, to accommodate people who come to watch and study nature rather than harvest it. (A U.S. Fish and Wildlife Service visitors center at Bowerman Basin—which has just become a national wildlife refuge—may be a step in the right direction, although it is not a step taken on local initiative.) And the shortage of attractive restaurants and accommodations will not be overcome any time soon.

TOURISM CONFLICTS

On one hand, it is obvious that people do not visit the coast to enjoy an industrial atmosphere. On the other, it is also obvious that tourism has survived and even flourished in places that have oil platforms offshore. The petroleum industry likes to point out that platforms can act as artificial reefs, and that the fishing around their bases can actually be better than the fishing in surrounding waters. This is small consolation to commercial fishermen, who cannot take their gear in close to the platforms, but it may be an advantage to sportsmen, who can get in close. In general, people whose use of the coast is basically extractive—who come to fish or clam—will probably be bothered less by the petroleum industry's visible presence than people who come primarily for the look and feel and tranquility of the shore. It isn't clear at what level of development the presence of the petroleum industry would be felt as intrusive. Along the wilderness beaches, any visible presence would obviously alter and detract from the experience visitors go there to find. Along the more accessible beaches, it might seem discordant, too, but low levels of development might have little effect on visitors. Larry Wilder, vice-president of the Region VIII tourism area, suggests that visitors probably wouldn't notice a lone offshore platform. A group of platforms, on the other hand, would be noticed.[97]

The draft environmental impact statement for lease sale 91 off the coast of northern California notes "some evidence of a negative association between offshore platforms and beach attendance" but says that finding is "inconclusive." "The search for a link between offshore structures and beach attractiveness is on the frontier of recreational analysis," the DEIS says. "We have no knowledge of previous research designed to quantify the effects of OCS development on recreation participation and tourism spending. . . . In addition, the concept of beach attractiveness is very subjective. Each individual has his or her own perception of what makes a beach appealing and of how OCS development may affect that appeal. We also have no knowledge of any actual reduction in tourism because of the presence of offshore structures."[70]

"There is no evidence that offshore petroleum activities have discouraged tourism anywhere in the United States," says the American Petroleum Institute. "Even in those few areas, such as Santa Barbara, where drilling and production operations can be seen from land, the same is true."[3] In fact, tourism and recreation in the Santa Barbara area have continued to climb despite the presence of offshore platforms. In the three years after a moratorium on drilling in the Santa Barbara channel was lifted, in 1979, tourism revenue in the Santa Barbara area increased 25 percent.[3] But commenting on the DEIS for northern California, the California Legislature's Joint Committee on Fisheries and Aquaculture suggested it was wrong to assume that just because offshore development seems to have had little or no impact on southern California beach use it would make no difference to the people who visit the northern coast. "People are primarily drawn to this area to view its unspoiled coastline and uncluttered ocean vistas," the legislators observed. "Yet the DEIS uses what it believes to be comparable data from southern Californian beaches, in which the primary activity is 'active' ocean recreation such as swimming, diving, surfing and sunbathing, to address the impacts from oil development on beach usage. We find this data completely inappropriate for assessing beach usage along the North Coast."[20]

Commenting on the proposed lease sale off northern California, where the subject had become highly politicized, supervisors of both Mendocino and Sonoma counties said anything that diminished the visual attractiveness of the coast would have a negative effect on tourism.[69] No research has established the percentage of visitors to the Washington coast that use the beach for water-contact activities, but water temperatures and casual observation suggest that, at the very least, it is probably no greater than the percentage for northern California.

"It is apparent that introducing an industrial structure in a natural environment may reduce some people's enjoyment of that environment," D.M. Dornbush & Co. observe in a study entitled *Impacts of OCS Development on Recreation and Tourism.* "The question is how many people, if any, would consequently divert their recreation to elsewhere."[29] That is indeed the question. D.M. Dornbush & Co. do not attempt to answer.

Platforms would not be the only structures that could have either temporary or lasting effects on tourism. Laying a pipeline would inevitably close a corridor of beach during the construction period. The actual physical corridor required by a pipeline is only about 40 feet wide.[29] The construction process would obviously take up more room than that. And the noise of construction would exclude visitors from a much wider area. Primarily because of noise, the corridor of beach closed during construction might be 1600 feet wide. The effects of pipeline construction could be mitigated at least somewhat by scheduling construction during winter months and erecting barriers to reduce noise and visual intrusiveness.

After construction, the pipeline could be covered so that it would constitute neither a physical barrier nor an aesthetic eyesore. Beaches and dunes could be recontoured and vegetation replanted. If that weren't done, use of the beach might be permanently altered.

Onshore buildings would be harder to hide than a pipeline, although judicious placement and landscaping could make them relatively inconspicuous.

The big wild card—the event that would have the greatest impact but the lowest probability of happening—for tourism as well as fishing would be, of course, an oil spill. In southern California, periodic small spills and oil washing ashore from natural seeps have extremely localized and extremely short-lived impacts: when oil is there, people tend to stay away, but as soon as it's gone, they return.[66] Whether or not they would be so quick to return on the Washington coast is an open question.

A major spill would clearly have longer lasting affects. Larry Wilder figures that a significant oil spill would be noticed for a long time. If a spill hit the region in the summer, there would be 150,000 to 200,000 people on the beaches. The big question, Wilder says, is how they would spread the word. It might take a long time indeed for the affected beaches' negative image to fade.[97] People stayed away from the beaches even after the oil from the big Santa Barbara spill of 1969 was cleaned up. They stayed away after the *Amoco Cadiz* and *Ixtoc* I spills, too.[67]

The experience of Brittany after the *Amoco Cadiz* spill of 1978 may be instructive. The Brittany coast had become the second leading tourist region in France. It drew the French in July and August, the Germans, Swiss, and British in the other spring and summer months. The spill hit in March. For April, May, and June, the number of tourists in Finisterre, the department at the scenic tip of Brittany, was only one-half what it had been the year before. Tourism remained 36 percent below the previous year's level in July, 15 to 20 percent below it in August. All in all, it was the worst year the Finisterre hotel industry had ever experienced. Lost profit and wages in the Breton tourist industry were estimated, in 1988 dollars, at $44.3 million to $107.6 million. David Fairhall and Philip Jordan in their book, *The Wreck of the Amoco Cadiz*, refer to a "'consumer psychosis' [that] particularly affected the holiday industry and was noticeable for the numbers of foreign tourists who failed to arrive."[36,70]

FISHERIES

Fishing is an important economic activity for both white and Indian communities along the coast, but it is hard to separate fishing as straight economics from fishing as a cultural pursuit. Fishing is, of course, inseparable from the cultural heritage of the tribal groups.

A reliance on fish and marine mammals was the main thing that tied together all the native cultures of the coast. Their economies were all based on the sea. Their religions were all inextricably tied to it; for example, all the native groups had some version of a first salmon ceremony, ritually welcoming the salmon runs each year so they would continue to come in the future.

The dependence on fish and fishing has diminished over the years as natives have gone into logging, teaching, and other professions. A 1980 Makah comprehensive plan attributed 37 percent of reservation employment to local government and another 18 percent to education. Only 10 percent was in fishing.[62] And yet a recent survey on the Makah reservation found that 85 percent of tribal members had some economic connection to fishing.[82] In general, the continuing importance of fishing to tribal economies and cultures is assumed. There have been no detailed studies.

Both the Makahs and the Quinaults have made significant long-term tribal commitments to fishing. Both maintain tribal fish hatcheries (there are also Quileute and Hoh hatcheries), and both enforce their own fishing regulations. The Quinaults, in fact, have enforced fishing regulations on the rivers that flow through their reservations ever since 1916.[13]

All the coastal tribes that signed treaties with the U.S. government in the 1850s—the Makahs, the Quinaults, the Quileutes, the Ozettes and the Hohs—have more than an emotional or economic dependence on fishing: they have a special legal right to catch fish. A 1974 court decision in the case of U.S. v. Washington determined that the treaty tribes had rights to take half the fish that could be caught at their traditional fishing spots without endangering the resource. Those fishing rights do not depend in any way on the laws or actions of the state. They are recognized by federal treaty. While they could be extinguished by an explicit act of Congress, they cannot simply be disregarded if federal laws or actions conflict with them.

The findings of fact in U.S. v. Washington observed that "fish continues to provide a vital component of many Indians' diet. For others it may remain an important food in a symbolic sense—analogous to Thanksgiving turkey. Few habits are stronger than dietary habits and their persistence is usually a matter of emotional preference rather than a nutritional need. . . . The Indian cultural identification with fishing is primarily dietary, related to the subsistence fishery, and secondarily associated with religious ceremonies and commercial fishing. Indian commercial fishermen share the same economic motivation as non-Indian commercial fishermen."[13]

Presumably, they share the same noneconomic motivations, too. While there are certainly people, both Indian and non-Indian, who really do depend on commercial salmon fishing and some who make a good deal of money from it, fishing may also be, for many of its practitioners, a matter of lifestyle and identity. For some, it seems to be primarily a matter of lifestyle and identity. In 1985, 80 percent of the salmon fishing boats brought in less than $10,000 worth of fish. At Westport, 78 percent of the boats brought in less than $5,000 worth. At Neah Bay, 87 percent brought in less than $5,000 worth.[50] Nobody makes a living catching less than $5,000 worth of salmon. Some, of course, fish for other species in other seasons. But some do not. A report prepared for the state Department of Community Development in March, 1988, estimated that the net economic value of non-Indian commercial salmon fishing on the coast and in the Strait of Juan de Fuca was negative. The net value of gillnetting in Grays Harbor and Willapa Bay was positive, but it was more than offset by the negative value of coastal trolling. Troll boats, which drag baited hooks or lures behind them through the water, make up half the fleet but take no more than 12 percent of the catch.[50]

This is arguably bad for the state but good for the economy of the coast. The DCD report noted that "spending by commercial fishermen in excess of what is required to take the allowable harvest [results] in a redistribution of spending toward fisheries and fishery-dependent regions of the state."[50]

The dismal numbers racked up by the non-Indian troll fleet do not apply to the treaty fishermen. The tribes have far fewer boats catching an equal number of fish. It seems safe to say that their average returns are very healthy indeed—although the tribes are sensitive about the figures and will not make them public.

It has always been hard to figure out how many of the people engaged in fishing are really full-time fishermen who depend on it for a living. No one knows how many of the others do it for supplementary income, how many do it primarily as a matter of lifestyle. (The DCD report observes, "there are many benefits that accrue to commercial salmon . . . fishermen which are . . . not reflected in the market value of fish or the dollar incomes they get from fishing.")[50]

It would seem that shellfish aquaculture has a lifestyle component, too. At least, when shellfish growers in Willapa Bay were asked how much their most productive oyster lands were worth, they replied they simply would not sell those lands.[14]

Not that the shellfish industry in Willapa Bay—or the smaller one in Grays Harbor near Westport—is by any means a hobby. Willapa Bay produced $4.8 million worth of oysters in 1986. Grays Harbor produced another $1.8 million worth.[91] Concern over the harvestability of oysters in Puget Sound was the main motivation for an attack on non-point source pollution that cost public agencies some $5 million in fiscal 1988 and nearly $7 million in fiscal 1989.[76] And yet, Puget Sound's 1986 oyster harvest was worth $1.9 million less than the coast's.[91]

Some active oyster farms in Willapa Bay have been operating for 140 years.[14]

While Willapa Bay is extremely productive, its recent average has been only about 3 million pounds per year, compared with 11 million pounds in the 1940s.[14] Growers say that oysters, which now require three and one-half years to mature, were ready in two years then. Current problems include invasion of the oyster beds by ghost shrimp, which basically undermine the beds and cause oysters to be covered by silt. The recent appearance of *spartina* grass, which simply covers ground that might otherwise be occupied by oysters, is a potential problem. The main barrier to increased production is the infestation by ghost shrimp of Class I grounds, the intertidal areas with the best natural food supplies and growing conditions that are used to fatten oysters before market.[14]

Despite the problems, Willapa Bay production has have been expanding at a rate of around 10 percent a year. As the Chesapeake Bay oyster industry suffers a decline, Willapa Bay growers are stepping into the gap in the market. Most of the growers operate their own hatcheries. Seventy-nine percent of the growers in a recent survey use ground culture. Others use racks or longline methods. At any given time, growers have perhaps $8 million or more tied up in production costs. They employ an estimated 470 year-around workers and 440 temporary workers, making oyster production the largest or second-largest employer in Pacific County. Ten to twelve percent of the jobs in the county are tied up with the oyster industry.[14,16]

Oysters make up only a relatively small percentage, by value, of all the seafood harvested on the coast, though. Traditionally, salmon were worth more than all other species put together. In 1974, for example, they were 58.4 percent of the total. Declines in the salmon runs, the warming water brought by El Niño in the early 1980s, passage of the Fisheries Conservation and Management Act of 1976, and a variety of other factors have altered the percentages beyond recognition. In 1985, salmon produced only 18 percent of the value of the Washington coastal catch. The high water mark for the ocean troll fishery was 1976, when trollers landed $13.824 million worth of chinook and coho. The low point was 1983, when the value of the catch dropped to $1.465 million. In constant dollars, the difference is even greater: troll catch in 1983 was worth only 6 percent of the catch in 1976.[31,40,91]

Long-term prospects for the salmon fishery may be reasonably good. Catches have already climbed well above their nadir of the early 1980s. If runs can be rebuilt and if Canadians can be persuaded to take fewer of the coho that would otherwise be caught off the Washington coast, figures may continue to rise. The prospects for the commercial troll fishery may not be so bright, though. A salmon caught by a sport fisherman is worth a lot more to the state's economy than a salmon caught by a commercial troller. The report done for the Department of Community Development estimates that a 10 percent increase in coastal recreational fishing would directly and indirectly increase household incomes by $1.299 million. It says a 10 percent increase in coastal commercial fishing would increase household income by only $0.634 million. For the Strait, the projected difference is even more dramatic: $0.94 million against $0.3 million. Because of numbers like that, some people figure commercial trolling may eventually be curtailed drastically or even eliminated in order to provide more fish for sportsmen.[50]

For the time being, as the relative importance of the salmon fishery has declined, the relative importance of other fisheries has grown. Groundfish (which include halibut, cod, black cod, ling cod, English sole, Dover sole, and more than 20 species of rockfish) were responsible for 33.8 percent of the value of the coastal catch in 1985, up from only 8.6 percent in 1974. Crab made up 22.9 percent of the catch value—more than salmon—up from 13.2 percent in 1974.[40] (It is not clear whether some of the fisheries that have grown rapidly in recent years can be sustained over the long haul. The black cod fishery, for example, has prospered in the 1980s, but black cod fishermen say that there seem to be fewer fish than there were a few years ago, and that large fish have become scarce.)

Shrimp landed in Grays Harbor, Willapa Bay, and the Columbia River in 1986 were worth more than crabs or oysters or, for that matter, the entire coastal salmon catch. The shrimp harvest delivered in Grays Harbor was worth $7.1 million, the harvest landed in Willapa Bay, $2.7 million. Columbia River landings contributed another $4.6 million worth of shrimp.[91]

Catch values vary dramatically from year to year, responding to variations in both fishery populations and prices. Different agencies consistently calculate the values differently. The value of coastal and Columbia River fisheries is a moving target. According to one estimate, though, the total 1987 ex-vessel value of coastal salmon, groundfish, halibut, and shrimp catches in Washington, including tribal and joint venture catches, was about $58 million.[72] Washington and Oregon coastal fisheries together were worth roughly $122 million. Washington crab and oyster harvests were worth about an additional $25 million.

Sport fishing can be considered as part of "fisheries" in general or as part of "tourism." Obviously, it depends on the same stocks of fish that commercial fishermen depend on, and those stocks are subject to the same vagaries of environmental influences, harvesting pressure, and regulation. Unlike commercial fishing, though, its economic value rests not on the pounds of fish caught or the price per pound but on the amount that visitors are willing to pay for a certain kind of coastal experience. Part of its value shows up in the same kinds of hotel, motel, and restaurant receipts to which beach visitors, recreational clammers, and other kinds of tourists contribute. Its noneconomic values do not add up to the kind of lifestyle or personal identity that even commercial fishermen who can't make a living fishing find in the activity. For all those reasons, we shall consider sport fishing a part of "tourism." Nevertheless, the environmental factors that affect the profitability and long-term viability of the commercial fisheries can affect the profitability and long-term viability of the sport fishery, too.

It is hard to pinpoint the areas off the coast that are most important to the commercial fisheries. Trollers will follow depth lines—say, 80 fathoms—all along the coast, although certain areas may tend to yield particularly rich harvests; tribal fishermen have done particularly well, for example, in areas of the ocean known as "the prairie" and "blue dot" that lie basically west southwest of Cape Flattery. The non-Indian troll fishery tends to concentrate farther south, in the waters off Grays Harbor. (The non-Indian troll fishery takes places between May and September, with a clear peak in July and August; tribal efforts tend to be spread more evenly over a larger portion of the year.) A small Makah ocean gillnet fishery operates close to shore just south of Cape Flattery. Bottom trawlers after lingcod, Dover sole, and other species tend to work the edges of the offshore canyons. So do longliners in pursuit of halibut and rockfish. Shrimp trawlers, who use midwater nets, tend to work just inside the canyons. (In the late 1970s, the fishery concentrated on true cod and English and petrale sole in relatively shallow water. The trend is to go ever deeper, with a lot of bottom fishing now at depths of more than 300 fathoms.) Crab fishermen will start in the winter by setting their pots at 60 fathoms, then move most of the pots in to 30 fathoms in March and to 20 fathoms in May. (The season goes until September, but most of the catch is taken before summer.) Bottomfishermen will have to follow the fish up to 60 or 70 miles. The hake fishery—a joint venture fishery (not counted in Washington state statistics) in which American fishermen deliver their catch to Russian processing ships—follows the hake all up and down the coast.[32]

FISHERIES CONFLICTS

Commercial fishing and offshore oil development coexist in a number of places, including southern California, Cook Inlet, the Gulf of Mexico, and the North Sea. Fishermen do not tend to be enthusiastic about oil operations, or about any other competing uses of the seas. Many complain about inconvenience, damaged gear, and slow payment of compensation, and some allege that oil development has diminished the commercial fishery. One 1987 study found that offshore oil development had had moderate to large negative impacts on nearly 70 percent of Santa Barbara fishermen.[58] Fishermen claim that 40 percent of the trawl grounds in the Santa Barbara Channel has been lost to the oil industry.[38,59] The tight quarters of the channel and the large scale of oil development there intensify the conflicts. In a survey taken by Santa Barbara County, 51 percent of the fishermen claimed they had to spend extra time and money traveling to fishing grounds because of offshore oil development.[59] "Based on the experience of California fishermen thus far with offshore oil, we would be better off having none," Zeke Grader, executive director of the Pacific Coast Federation of Fishermen's Associations, told a Seattle audience in 1987. "No mitigation measure is likely to make up for the loss of grounds, the loss of gear, the loss of resource, the hassles fishermen are faced with from offshore oil."[38]

The statistics do not indicate any overall negative effects on the fisheries around Santa Barbara or anyplace else, though. This is not to say that negative effects do not exist—just that they are not visible in the larger statistical trends. In the Santa Barbara area, for example, despite continuing offshore operations and the major oil spill of 1969, the total catch in 1982 was 4 times the catch in 1968.[45] Last year in Cook Inlet, there was an oil spill just as the salmon runs were appearing; despite the spill, Cook Inlet fishermen had their best year ever.[37,54]

While no one has managed to eliminate conflicts or the feeling of conflict, representatives of the fishing and oil industries have worked together successfully to reduce friction between the industries and to mitigate the effects on fisheries of oil development. There is, for example a Joint Oil/Fisheries Committee and a Joint Oil/Fisheries Liaison Office of South/Central California.[25,57,78]

Those efforts have helped to ease the tension, but fishermen in the Santa Barbara area still tend to be hostile toward the oil industry.[57,83] That doesn't seem likely to change. Clearly, the mitigation measures might have done more good if they had been in place before the conflicts erupted. As it happened, though, they were put into place after the fact, and they have not been able to undo completely the problems or the emotions that developed before they came along, though much has been accomplished.

One thing the joint office and joint committee have produced is a manual for reducing the conflicts caused by geophysical operations. There is no question that seismic surveys can make trouble for fishermen, if not for fish. The technique used for seismic exploration involves firing underwater bursts of sound from air guns towed short distances behind a vessel and recording the reflected sounds on sensing devices towed behind the vessel on a long cable. The cable stretches up to two miles behind the vessel. It can damage or carry off any fixed fishing gear in its path. However, since the cables are worth $1 million, are very fragile, and are uninsurable, operators are careful to avoid contact with fishing gear.[35]

In 1980, the exploration vessel *Geco Alpha* destroyed an estimated two to three percent of the crab pots off the Washington coast. The vessel's cable caught the lines between crab pots and their marking bouys, pulling the buoys underwater and carrying the pots off into deeper water. Crab fishermen filed claims for 1,038 pots. The lost pots can remain on the ocean floor, catching and potentially killing crabs for months.[57] Since then, the geophysical industry is active in avoiding these problems. Vessel operators now are briefed on how to prevent fishery conflicts.[35]

(The compensation of fishermen for losses can have negative side effects. Santa Barbara County found that local fishermen thought a major effect of offshore oil development was a "division of the fishing community as a result of oil company money payments." It has also turned out that some fishermen who got paid for not fishing don't fish, which can have an impact on fish processors. One processor is leaving Santa Barbara partly, he says, because payments to fishermen from oil companies have reduced the number of fishermen delivering to him.)[34,59]

If crab pots and seismic exploration vessels are in the same water at the same time, there will inevitably be conflicts. At a cost of $90 to $150 per pot—and an estimated 35,000-45,000 pots in use at peak times off the Washington coast—that is no trivial consideration to the fishermen. Conflicts, however, can be reduced or avoided. In the Santa Barbara area, for example, oil industry and fishing industry representatives agreed to remove fishing gear from the Santa Barbara Channel during seismic exploration and to compensate fishermen for their lost fishing opportunity. In northern California, seismic explorations were simply scheduled around fishing seasons.

In addition to the effects of seismic exploration on fixed fishing gear, fishermen have worried about the effect of air gun blasts on the welfare and catchability of fish. A 1987 Battelle experiment on the effects of air gun blasts on rockfish found that catch per unit effort declined 52.4 percent and the cash value of the catch declined 49.8 percent.[74] That experiment is controversial. It was not designed to duplicate the actual conditions under which seismic surveying and fishing take place. Those conditions, and the spatial extent and the duration of the effect, will be the subject of additional studies. But the experiment did demonstrate that some rockfish species can be startled by compressed air. And it does square with fishermen's observation that air gun blasts tend to scatter fish, which may take several days to regroup.

At the stage of seismic testing, the inevitable conflict is between moving seismic survey vessels and fixed fishing gear. At the exploration, development, and production stages, the inevitable conflict is between fixed oil drilling platforms and their anchor cables—and possibly debris and capped wells on the ocean floor—and moving fishing vessels and gear. The problem isn't that the boats and gear are damaged (except by the unseen obstructions on the bottom, which clearly do damage nets); it is that they are excluded from the areas in which the platforms operate. In addition, trawlers may have to shorten their runs and trollers alter their normal patterns to avoid the platform area. Humboldt County, California, looking at the possible effects of offshore oil development, found that in shallow water, a cost-effective trawl run was at least four miles long; in water over 100 meters deep, the length was seven to ten miles. Under those circumstances, the county found that two oil platforms and their associated pipelines could have a moderate to high impact on trawlers.[57]

Boats will normally be kept out of a four-square-mile buffer zone during the six months or so it takes to install a platform. After the platform has been installed, fishing vessels can often fish within one-half mile or even one-quarter mile of it, depending on the type of fishing gear used and the sea conditions. When a platform is actually operating, trawlers may be excluded from 0.785 squares mile of ocean, trollers from only 0.196 square miles. (A drift gillnetter would be excluded from 64 square miles—an impressive figure but largely irrelevant to the Washington coast, where no drift gillnetters operated until a thresher shark fishery began in 1986. The thresher shark fishermen have been using drift gillnets between 19 and 148 kilometers offshore.) The area of exclusion depends partly on the type of rig; it is larger for a semisubmersible platform that is tethered by anchor lines, for example, than for a jack-up rig that occupies a smaller "footprint" on the ocean floor.[37,70]

A 1985 study of the potential impact of one or more oil platforms in the northern Santa Maria basin off California found that during installation of the platform, the average groundfish trawler would lose \$388, the average shrimp trawler \$1,396, the average troller only \$4. Once the platform was operating, trollers would lose nothing. Groundfish trawlers would lose \$121 a year, and shrimp trawlers would lose \$458 a year.[33] (These figures do not include any effects of seismic exploration, exploratory well drilling, or sea floor debris.)

If the area were totally "built out" with platforms, something that isn't likely to happen in Washington, trollers would still lose only \$3 a year, but groundfish trawlers would lose \$892 and shrimp trawlers \$3,210.[33]

Exploratory drilling rigs can interfere with fishing, too, and the thresher shark case in California suggests that their use may have to be modified to protect a fishery. The thresher shark case arose when two major oil companies, Exxon and Sun, wanted to drill in an area off Santa Barbara known as "the Finger." "The Finger" was an important shark fishing ground, and fishermen did not want exploratory oil rigs there interfering with their drift gillnetting during the fishing season. (The fishermen were not intrinsically interested in thresher sharks. Their real interest was swordfish, but state regulations required them to balance their swordfish catch with a catch of thresher shark.) Sun negotiated with fishermen and the California Coastal Commission, agreeing to drill only between Thanksgiving and Mayday, when the fishery was closed, and receiving permission to drill in part of the area. (Sun drilled three wells. When drilling ran into the fishing season, the oil company agreed with fishermen to pay for a scout boat that could inform them about currents, help them retrieve nets, and perform other services while the drilling rig was there.) Exxon would not accept a seasonal restriction on its right to drill in the Finger, and the California Coastal Commission consequently refused to say that Exxon's drilling plans were consistent with the state's coastal zone management act. Exxon appealed to the Secretary of Commerce. The Secretary said the Coastal Commission had a right to require mitigation. Exxon sued in federal court. A federal district court said the Commission could not take economic impacts into account in applying the state's coastal zone management act. But a federal appeals court ruled in the Commission's favor. Ironically, the Finger is a less important thresher shark area than it was when the case began—the shark population has been depleted there, and the fishery has developed in other areas—but the case may have established an important principle.[56,57]

Space conflicts can extend to fishing ports as well as fishing grounds. "There may be some limited congestion at first with geophysical vessels," the American Petroleum Institute concedes. However, it says, "the long lead time needed for any large buildup of oil company boats gives plenty of time to prepare for expanded development of port facilities."[45] In Aberdeen and Peterhead, Scotland, boats serving the North Sea oil fields did create space problems for fishing vessels in the early years of oil development, but revenues from the oil boats were used for port improvements, and the fishing fleets now have much better ports.[49]

The laying of pipelines to take oil or gas to shore sets up yet another potential space conflict. Fishermen will not be able to operate in the pipeline corridor during construction. The anchors of the pipelaying barge will leave lasting scars on the bottom. These scars can damage trawl nets. The scarring will create a permanent buffer zone perhaps one mile across that extends the full length of the pipeline.[70] (If a pipeline were laid through enclosed waters in which oysters were grown, the construction process could physically damage oyster beds, and the pipeline itself might alter currents in ways that encouraged a buildup of silt on the beds. These problems have actually arisen in Louisiana.)[60,65]

The fear that lurks in the minds of many fishermen and oyster growers is, of course, not just one of nets caught on anchor scars or fish scared off by air guns; it is of an oil spill. An oil spill could affect fisheries in a number of ways: by damaging fish or shellfish populations directly; by tainting them with oil so that they could not be sold; by keeping boats in the harbor; by fouling boats or nets; by creating a public image that would affect the marketability or price of locally harvested seafood long after the physical effects had passed.

During the Santa Barbara spill, booms to contain the oil were stretched across the harbor mouth so that boats couldn't get out.

During the Cook Inlet spill in 1987, the state had fishermen stay ahead of the oil as it moved. Sometimes, they did get oil on their nets, an accident that might require cutting out a portion of the net. If fish were tainted with oil from a contaminated net, state inspectors would reject the whole batch. The fear was that if any oil-tainted Cook Inlet fish reached market, it might create a negative public image that would diminish the value or marketability of all Cook Inlet salmon.[37,54]

During the *Amoco Cadiz* spill off Brittany, the oyster beds were particularly hard hit. Floating booms failed to keep the oil out. Other fisheries recovered relatively quickly. Much of the oyster industry—which produced 10 to 12 percent of all French oysters—was basically wiped out. When oysters remained contaminated for months after the spill, many of the stocks were simply destroyed. Before the stocks could be rebuilt, it was necessary to get the oil out of the sediments. In the Brest area, the oyster catch dropped by 80 percent, and its value declined by two-thirds. Over a year later, oysters raised in clean water and placed on the contaminated sediments soon displayed hydrocarbon contents many times normal.[21,36]

Breton seafood—and other products—suffered as much from public perception as from the physical effects of oil. "So extensive had been the publicity over the spill that consumers had come to believe that anything and everything from Brittany was covered in oil," wrote David Fairhall and Philip Jordan in *The Wreck of the Amoco Cadiz*. "Not only would they not buy fish from the waters off the affected coast, they began to turn against fish from any part of Brittany. They refused even to eat lobsters which had been fished off the coast of Africa because they had been caught by Breton boats."[36]

Statistically, a spill on the scale of the *Amoco Cadiz* disaster is not likely to take place as a result of oil production off the Washington coast. But oystermen in Willapa Bay and Grays Harbor know what happened to the oystermen in Brittany. They know that the water in Willapa Bay changes completely every two weeks, so that it would be hard to keep oil out. They know that a very small portion of the oyster beds, the nursery lands, are critical to the whole industry, and that damage to that small portion would be a long-lasting disaster for the industry. They know that they market their oysters as the products of clean water, and a spill or even an image of industrialization would erode their market position. They know that even if they were compensated in full for any oysters damaged by a spill, it might take them a long time and a lot of price-cutting to regain their share of the market. For all those reasons, they are not eager to see offshore oil development come to the Washington coast.[98]

Neither are the commercial fishermen. It may be that some fishermen harbor memories of seismic exploration in the old days when the survey boats used dynamite instead of air guns, and one could literally see dead fish floating on the surface—memories that in fact are out of date—but fishermen who have actually worked in offshore drilling areas do not become reconciled to the oil industry's presence. When representatives of the oil industry and the fishing industry sit down together, they do seem able to work out many of the problems. The two industries can coexist. But by and large the oil industry creates annoyances for the fishermen at the very least, the fishermen receive no direct benefits from the industry's presence (even though their boats do run on petroleum products), and they don't like having it around.

Louisiana offers a case in point: a massive offshore petroleum industry coexists there with very significant finfish and shellfish industries, but there are continual conflicts. As one

Louisiana Sea Grant marine advisor puts it, "I think every oyster farmer has a lawyer, and just about every one of them has used his lawyer against the oil industry."[65]

COASTAL AESTHETICS

Virtually everyone agrees that the coast has aesthetic value—and the experience of being on the coast has spiritual value—for a great many people. But discussions of aesthetics do not lend themselves to the precision—in some cases, the pseudo-precision—with which economic values are discussed. As a result, in conventional calculations of risk and benefit, they tend to get short shrift. As Georgiana Dix Blomberg observed in the *Coastal Zone Management Journal*, "The reigning idea seems to be that while economic values are concrete and easily represented both verbally and monetarily, noneconomic values are highly individualized, vague, and diffuse, thus impossible to identify. Explicit consideration of these values, therefore, is usually deemed impossible."[12]

Federal law does make at least a cursory attempt to bring aesthetics into the equation. The National Environmental Policy Act says that "esthetically and culturally pleasing surroundings" must receive "adequate consideration in decision-making," and the Coastal Zone Management Act says that "esthetic values in the coastal zone . . . are essential to the well-being of all citizens."[12]

California's Coastal Plan refers to the aesthetics of the coastline, too. The plan says that "for the most part, the California coastline is an outstanding visual resource of great variety, grandeur, contrast, and beauty that can be enjoyed by all the people of the state." It says that the coast's visual aesthetics "add to the quality of life for coastal residents, visitors, and workers, and contribute to the economic success of the tourist industry by attracting many vacationers to the coastline."[12]

The Granville Corporation, with money from the Bureau of Land Management's Pacific Outer Continental Shelf Office, actually made a systematic "inventory and evaluation of California coastal recreation and aesthetic resources." Granville concluded that:

> coastal aesthetic resources include both visual and non-visual factors. A visual aesthetic resource is any aspect of the visual environment that exhibits 'imageability'—the ability to evoke a strong, memorable visual image—or contributes to a sense of scenic harmony within a setting. A visual aesthetic resource may be a focal point in the landscape, a landmark, a vista point, a scenic drive, a particular visual composition (scene), or a continuum of visual experiences as seen in sequence.
>
> Non-visual aesthetic resources include sounds, smells, and ephemeral characteristic of a particular landscape unit. [Important nonvisual resources include] the sounds of water movement (streams, rivers, the ocean), wind, wildlife and foghorns. Important smells include the sea itself, marine life, and coastal vegetation. . . . Of particular importance to coastal aesthetics is the intermittent presence of livestock and wildlife (e.g., marine mammals, seabirds, terrestrial wildlife) and such human activities as fishing, boating surfing and sightseeing.[39]

Granville divided the California coast into 166 distinct units and gave each an aesthetic value. The criteria on which the units were rated included "distinctiveness: a measure of the unique, bold, dramatic and memorable qualities of the visual landscape"; and "harmony: a measure of the agreement of elements brought together within the visual landscape; a pleasing congruent arrangement of the parts."[39]

No one has evaluated the Washington coast that way, but the importance of its aesthetic and other noneconomic values are widely recognized. Larry Wilder, vice-president of the state's tourism Region VIII, took a post card survey of visitors to the coast and found that, overwhelmingly, "the reason they came to the ocean was for the peace and the quiet . . . the sand and the ocean."[97]

Darryll Johnson of the University of Washington made informal observations of the people using Fourth Beach near Kalaloch, the last bit of coast below the wilderness beaches that is easily accessible from the road. He found that their use of the place was mainly extractive: when the tide was out, they got tube worms from the rocks. When the tide came in, they used the worms as bait to catch perch. They also took crabs and other species from the shallow water. Although they hadn't come to Fourth Beach for contemplation, Johnson surmised, they were attached to the look and feel of the place. Indeed, he found that in many cases, their families had been visiting it for generations. People whose parents or grandparents had gone there were taking their own children or grandchildren. Not all of the visitors lived on the coast, but most had lived there at one time. "If they weren't white and Caucasian," Johnson observed, "you'd say it was a cultural thing."[51]

Visitors obviously approach the wilderness beaches farther north in a somewhat different spirit. A ranger for the Ozette district, Kevin McCartney, says that in talking with visitors informally it is clear that "the primary reason why people come here is the wilderness experience: scenic beauty untrammeled by man."[63] Blomberg theorizes that part of the appeal of any coast is similar to the appeal of wilderness; a beach that actually is wilderness presumably intensifies that appeal.[12]

The Granville Corporation, in its study of the California coast, suggested that wilderness contributed significantly to the aesthetic values of coastal segments to which it gave particularly high aesthetic ratings. For the area from Devils Gate to Kings Range North, it observed that "the primary aesthetic considerations are the segment's wilderness qualities." For the segment from Kings Range North to Kings Range South, it said, "The chief aesthetic resources of the unit are its wilderness values to the north and its remote qualities, bordering on wilderness, to the south."

"The 50 miles of rugged wilderness coastline from Cape Alava to Kalaloch is one of the principal resources of the Olympic National Park," states the Park's official Master Plan. The plan observes that "this picturesque coast, with its expanse of driftwood, eroded cliffs and sculptured rocky islets, provides one of the last remaining opportunities for preservation of an undisturbed coastal ecosystem in the conterminous United States. . . . In addition to having considerable aesthetic appeal, this coast has biological values that are impossible to quantify. . . . The progressive disturbance of areal habitat elsewhere along the Pacific Coast will inevitably increase the use of this valuable resource by wildlife."[4]

The coast is an integral part of the wide range of unspoiled ecosystems from seashore to mountain peaks that have led to the designation of Olympic National Park as both a world heritage site and an international biosphere reserve. Park official Paul Crawford says that those international designations probably don't draw many casual visitors to the park, but they do draw serious scientific researchers.[27]

The number of visitors is a poor way to establish a value for wilderness, anyway. By its nature, wilderness will draw fewer people than more accessible places. But that does not mean that it is less valuable, either intrinsically or to many people who will never see it. "Because wilderness . . . satisf[ies] a want and is scarce, it [has] economic value," Lawrence G. Hines, a former chairman of the Dartmouth economics department, told a 1969 Sierra Club conference on Wilderness and the Quality of Life. "It is not the absence of economic value that distinguishes between wilderness and other resources; it is the measurability of that economic value. Because the value of wilderness is not easily expressed in dollar units, its economic value is intangible in contrast with the economic values of most resources, which are expressed in dollar units. Therefore, it is frequently erroneously assumed that because of the absence of a market economic value, wilderness has no economic value."[64]

In addition, wilderness clearly has values that transcend most notions of economics. It is said to have "existence value," which means people value the fact that it is there, whether they ever see it or not; "option value," which means they value having the possibility of using it; and "bequest value," which means they value the opportunity to pass it on to their children.[43]

"Wilderness allocation and management is truly a cultural contribution of the United States to the world," Roderick Nash, professor of history and environmental studies at the University of California at Santa Barbara, suggests in the U.S. Forest Service's book on wilderness management. "Despite the continuing ambivalence of American society towards wilderness, the reserves should be regarded as one of the Nation's most significant contributions."[47]

A wilderness such as the coastal beaches that is part of a national park may have an additional significance, too. Crawford notes that the national parks are the country's national jewels—just as Americans visit Europe to see the cathedrals and art museums, Europeans visit

America to see the parks. He suggests that they are a resource that America holds in trust for the whole world.[27]

AESTHETIC CONFLICTS

The occurrence and effects of an oil spill or spills are pure conjecture. It is not conjecture at all, though, to say that if drilling occurs off the coast, large steel structures will be visible offshore. Their visibility from the shore will depend on a number of factors: their distance from shore; the elevation from which they are seen; the height of the waves; and atmospheric conditions. The closer they are, the easier they are to see, and the larger they appear. Beyond 15 miles, they are for all intents and purposes invisible.

What effect would these steel structures have on the aesthetics of the coast and the overall experience of being there? The environmental impact statement for the Minerals Management Service's proposed five-year outer continental shelf oil and gas leasing program states flatly that "visual resources will suffer unavoidable adverse impacts due to platform construction. . . . [These] impacts will last the lifetime of the projected OCS oil and gas activities."[69]

Larry Wilder believes that a single platform wouldn't interfere at all with most beach visitors' enjoyment of the place. A group of platforms might begin to interfere.[97] Dix suggests that an apparent "imperviousness to man and the works of man" constitutes an important part of the coast's appeal. "Even though the ocean and its shores are touched and affected by man," she writes, "it covers and removes these intrusions quite effectively, and retains at least an image of its primal, untrammeled state. Breaking waves erase footprints and wash away the traces and litter of human trespass; and refuse thrown into the ocean usually remains unseen by people on the coast."[12] Drilling rigs would seem to undercut this perception of a place in which the marks of man do not endure. Obviously, a major oil spill would undercut it a great deal more.

While the effects of oil or gas development on aesthetics of the heavily visited beaches to the south may or may not be severe, there seems little doubt that they would significantly alter people's perceptions of the wilderness beach to the north. The Forest Service's book on wilderness management states unequivocally that, "simply put, wilderness does not exist in a vacuum—what goes on outside of, but adjacent to, a wilderness can have substantial impacts inside the boundary."[47]

When the Interior Department proposed wilderness designation—later granted—for Washington's offshore rocks and islands, it observed that "currently, there is no restriction on placement of oil and gas rigs in the ocean close beside refuge rocks. Such occurrence would, of course, detract considerably from the wilderness character of the area."[89]

In a wilderness study report, the Interior Department observed that the remaining wilderness coastline "could be changed by oil and gas operations."[90]

A major oil spill that struck the wilderness beaches would, of course, be considered a desecration.

THE SATSOP EXPERIENCE

The project that in its socioeconomic impact on coastal counties probably came closest to the impact of a major oil development was the abortive construction of the two Satsop nuclear plants near Elma in Grays Harbor County. Satsop was not an oil project, of course (although it was an energy project), but it did bring a lot of workers into a coastal county to build something. Although construction did not take place on the shore and the work force was much larger than anything offshore oil is likely to require, Satsop provides the closest analogy in a Washington coastal setting.

Work on the nuclear project began in 1977 and was expected to peak in 1983. By that time, though, one of the reactors had been "terminated" and the other indefinitely "mothballed." The actual peak was reached in 1981, before construction of either plant was shut down.[42]

The Grays Harbor Regional Planning Commission tried to track the Satsop project's impact during the construction process. No one kept track of what happened after construction shut down.[88]

Even the effects of construction were hard to separate from the effects of other things that were happening in the economy. Construction was still going on after the recession started. It seemed clear that, at the very least, the Satsop project temporarily cushioned part of Grays Harbor from the worst effects of the recession.[88]

In June, 1981, 5,388 people were working at Satsop. In April, the Planning Commission had reported that since the start of the project, Satsop hiring had accounted for 90 percent of the county's net increase in employment. By June, 1980, Satsop provided 9 percent of the county's total employment.[88]

The people who worked directly on the Satsop project also supported secondary jobs in nearby communities. The Grays Harbor Regional Planning Commission calculated in 1982 that overall, from the start of the Satsop project, each new basic job in the economy had created 1.28 other jobs.[41]

Before the project started, there had been fears that it would attract a lot of would-be workers who would be unable to find jobs but would stay, swelling the unemployment rolls. That did not seem to happen. The Planning Commission reported in 1981 that "earlier analysis could not detect such an effect occurring. Except for the rise in average construction unemployment, [the record] still does not clearly identify this effect. The rise in average construction unemployment could indicate that this effect may be occurring, but other factors such as the depressed housing market were probably more significant. Also, employment on the project has a high turnover, and this turnover is affected by the weather and the actual construction activities. Between jobs, construction workers may file for unemployment compensation. . . . This measure of idle construction workers is associated with any construction project, and is not the same as attracting unemployed workers who do not obtain employment."[42]

People did move to the Satsop area to take jobs, although not all or even most of the workers employed there settled in Grays Harbor County. Roughly two-thirds commuted from other places. ("A commute of greater than 60 miles is not considered unusual for construction workers," the Planning Commission observed. "Such a commuting distance reaches beyond the Tacoma area where a large construction labor force is present. . . . The second year report estimated that over 15 percent of the workers resided outside of the 60 mile driving distance.") Of the people working at Satsop in June, 1981, only 32 percent lived in Grays Harbor County. Of those, roughly one-quarter had lived there before, one-quarter were clearly transient, and one-half were apparently permanent new residents. The community with the largest number of workers was the small town of Elma, closest to the project. Aberdeen, the largest city, had the second largest number.[41]

No one had expected such an influx. "The peak of the impact of the project on Grays Harbor County growth patterns greatly exceeded expectations in both numbers of people and distribution of impact," the Planning Commission observed. The total amount of growth was approximately three times the original projection. While the impact exceeded expectations in all areas, the impact was more focussed and concentrated on the Elma area than was originally expected." No more than 177 workers were expected to move into Elma at the peak of construction. The actual number was 635.[41]

The Planning Commission wrote in 1982 that "the stimulus of the Satsop Project can account for all of the net growth of the county that has occurred since it started construction in 1977." However, it noted, the project's impact was not distributed uniformly across the county. Instead, it "varies between areas where the stimulus of the Satsop Project could account for more than all the growth that has occurred to areas where it may account for only a small share of the growth."[41]

Inevitably, there was a boom in housing construction to accommodate the new workers. For years, housing construction in Grays Harbor County had not met the targets planners considered necessary to accommodate even a low rate of economic growth. Construction surged at the start of the project, though, and while it fell back to a slower pace after the first couple of years, it stayed well above earlier rates—and above the planners' targets. The lack of existing housing had been considered especially severe in the eastern portion of the county. The Satsop project helped, at least temporarily, to turn that around. Even though there were more people to house, the Planning Commission noted, the net effect was more housing available. And, it pointed out, "this housing supply will remain available after the project is completed."

The price of houses in the Satsop area shot up. The average two-bedroom house sold around Elma in 1974 cost $16,563. In 1979, it cost $32,028. Between 1976 and 1979, rents in eastern Grays Harbor County roughly doubled.[42] But it would be hard to attribute the entire rise in the housing costs to the Satsop project. They were shooting up everywhere during that period. Between December, 1975, and December, 1979, the U.S. average rose 46 percent.[24]

Housing aside, the social impact of the Satsop project was hard to gauge. The work load on social service agencies rose dramatically, but very little of the increase was directly attributable to the project. How much should have been attributed to it indirectly, no one knew. It was difficult to tell how much of the eastern county's increased school enrollment was caused by the project; in the closest district, 12 percent of the children were definitely there because of Satsop.[42]

Some of the increases in crime were downright startling, although no one knew exactly what they meant. As the Planning Commission observed, "the percentage of total offenses and arrests [in Elma and nearby McCleary] that are known to be related to the Satsop Project is considerable. This involvement appears to almost double each year in McCleary and increased in Elma approximately 38 percent [from 1978 to 1980]." In Elma, 66.7 percent of the 1980 arrests for aggravated assault were known to be related to the Satsop project. (For what it's worth, aggravated assaults shot up in Fairbanks during construction of the Trans Alaska Pipeline, as did robberies and acts of larceny.)[42]

Grays Harbor County was not exactly a crime-free area to begin with. The urban areas had a crime rate 20 percent higher than the U.S. average for cities that size in 1975, and Elma had a crime rate 73 percent higher than the U.S. average for communities in its size range. Four years later, the offense rate in urban Grays Harbor County was still 20 percent above the national average. The offense rate in Elma had soared to a level 149 percent above the national average. There was no clear link to the Satsop project, but it seems reasonable to suppose that the project had something to do with the astronomical number.[42] (The cities weren't left to bear the full cost of increased police work by themselves. An increased police load was no surprise, and the affected cities had worked out an agreement with the Washington Public Power Supply System under which WPPSS committed itself to providing $1,543,000 during the life of the project to cover the costs. WPPSS also provided money to the city of Elma to cover the effect of gravel truck traffic on the city's roads, and it agreed with Grays Harbor County and the state to provide money for new road construction.)[42]

All in all, the Planning Commission reported, "social change seems to be occurring in certain areas. . . . The project seems to be a contributor to this change, and if the secondary impact of the project is considered, the full impact of the project on the social character of Grays Harbor County could be considerable."

No one has even tried to gauge the lasting social affects.[88] Some of the lasting physical effects are easy to see. One is the proliferation of gravel pits in agricultural areas around the site. Another is the proliferation of substandard mobile homes. Many of the new housing units created during during construction were mobile homes built in the 1960s. They do not meet federal standards for mobile homes established in 1976. They do not meet county housing codes. But they are there. So is the new high school that the people of Elma decided to build because there was an influx of new residents and because the very high assessed valuation of the Satsop plants would keep individual taxpayers from having to pay large sums to retire the bonds. Since construction of the reactors shut down, the assessed valuation of the site has dropped dramatically, and individual property taxes in Elma subsequently doubled.[53] If the citizens of Elma are paying a financial price, Grays Harbor County in general is much better off financially than it would have been without Satsop; its tax revenues rose sharply during the construction years, and since the county chose to hoard a lot of the new revenues instead of launching new public works projects, it came through the lean years of the 1980s in much better shape than its neighbors.

THE NORTH SEA EXPERIENCE

The Washington coast has more in common with the coast of Scotland than it does with most other areas adjacent to outer continental shelf oil development, so the effects of North Sea oil on the Scottish mainland and the Shetland Islands to the north offer an attractive analogy. When Newfoundland considered offshore oil development, people took the Scottish experiences as a kind of model. Often, they did so with very little idea of what that experience had been. J.D. House of the Memorial University of Newfoundland has written that "some local people have been heard to exclaim . . .'We don't want to happen here what happened in Aberdeen,' without any clear idea of what did in fact happen in Aberdeen . . . What I call the 'negative myth' of North Sea oil . . . holds that oil activities have wrought all sorts of havoc with the traditional lifestyles of Northern Scots.

Aberdeen is portrayed as the 'sin city of the north,' abounding with drunks, prostitutes, battered wives and neglected children. Nothing could be further from the truth, although there have indeed been problems. There has also emerged . . . the positive myth of North Sea oil. This holds that oil and gas have brought instant prosperity to Northern Scotland."[49] House concedes that he has caricatured both points of view but says that elements of them persist. If Washington chooses to look at the Scottish experience, it should do so with a clearer view.

It should start by recognizing that the differences between Aberdeen, Scotland, the city on Scotland's east coast that became the headquarters for North Sea oil development, and Aberdeen, Washington, are profound. The scale of offshore development in the North Sea far exceeds even the outside range of projections for the Washington coast. Beyond that, Aberdeen became a headquarters for offshore development during a time at which the offshore oil industry was much less mature than it is now. Engineering and construction that were done from Aberdeen in the early 1970s would now be done from cities around the world. The net result is that the number of jobs and residents added to Aberdeen, Scotland, is many times the number that the Washington coast could reasonably expect.

Cultural and political differences also complicate the task of finding valid lessons in the Scottish experience. Government controls land use much more rigidly in Scotland that it does in the United States, so that zoning can artificially hold down the supply and drive up the price of commercial land. Government is also the leading builder of houses, so that politics can create bottlenecks in the housing supply.

Still, it is tempting to look for lessons in the Scottish experience, and even if there are huge differences in scale, what has happened in Scottish communities may very well indicate the kinds, if not the magnitudes, of changes that oil development would bring to the Washington coast.

Oil development had tremendous impact on Scotland, both on the Shetland Islands, north of the Scottish mainland, and on the mainland's Grampian region. The effects have been mixed. "On balance," T.F. Sprott of the Grampian Regional Council's Department of Physical Planning told an International Conference on Oil and the Environment in 1980, "the advent of the North Sea oil and gas industry has been good for the Grampian Region, helping the area to recover from a long period of post-war stagnation during which its geographical location in the UK and in relation to overseas markets and its small manufacturing base provided an inadequate foundation for major economic expansion."[19]

One of the most noticeable things North Sea oil development has brought to parts of Scotland is jobs. The city of Aberdeen, on Scotland's eastern coast, which has become the headquarters for North Sea oil development, had lower unemployment than the Scottish average at the end of the 1960s, but the figure was edging up; in 1968, Aberdeen's unemployment rate was 62 percent of the Scottish average, and two years later it was 73 percent. By 1980, that had changed. Scotland's unemployment rate stood at 10.7 percent in September, 1980. Great Britain's average was 8.3 percent. Aberdeen's was only 4.6 percent. And in the Shetland Islands, north of the Scottish mainland, where the big Sullom Voe oil terminal was being built, unemployment was only 2.9 percent.[61] (Jobs were not spread around evenly. The oil companies were looking for experienced help, for example, so youth unemployment stayed high. This was not quite the experience Fairbanks had during construction of the Trans Alaska Pipeline. There, double-shifting in the schools gave kids more time, and a movement of adults into pipeline work gave them local job openings, so many young people found work that paid more than minimum wages.)[99]

Not all the oil jobs, by a long shot, went to residents, but those local people who did get jobs in the oil industry had opportunities to make more money than they ever had before. (Jobs in the oil industry and the various support industries went to a wide variety of local people, but by and large they did not go to the unemployed. As Robert Moore observed in *The Social Impact of Oil*, "incoming firms seemed reluctant to employ the unemployed on the grounds that there must have been a good reason for their being unemployed.")[71] Wage rates weren't necessarily higher, but with overtime, workers took home a lot of money. Some local companies complained that they were losing skilled labor to the oil industry, and government policy did not allow them to raise wages high enough to compete. In one survey, 84 Aberdeen firms were asked, "have you experienced any problems as a consequence of the oil industry in Aberdeen?" Sixty-two of the firms said higher labor costs were a problem.[61]

Actually, the Aberdeen firms' responses notwithstanding, the effects on local wage rates were hard to gauge. "It is true that earnings in the oil industry are very high—although per hour the rates are not greatly above those of the construction industry," wrote G.A. Mackay and Anne C. Moir in *North Sea Oil and the Aberdeen Economy*, "but . . . this has not permeated through to the rest of the local economy as much as might have been expected. . . . The increased competition for labour [may have] resulted in increases in overtime working but . . . the basic structure of wage levels . . . has not been substantially affected." The big exception, they said, was the construction industry, where wages had, in fact, gone up.[61]

Wages may not really have been all that much higher in and around the the oil industry, but people certainly thought that workers were leaving longer-established industries to try their luck. Forty-nine of those 84 Aberdeen firms complained that they had lost workers.[61]

At the Crosse and Blackwell food processing plant in Peterhead, Moore wrote, "the problem created by oil was the loss of male workers: 'a lot' left to go into construction and technically qualified men left for the bases. . . . Less-skilled jobs, like driving fork-lift trucks have been taken over by women. . . . two 8-hour shifts were needed to cope with demand for canned foods but only one could be manned because there were not enough women available." At the General Motors plant in town, there was very high turnover for a couple of years while oil-related construction was booming nearby, but the high turnover didn't last, and in a few years the men who had left to take oil jobs started coming back.[71]

In the Shetland Islands, where people still depended heavily on fishing, knitting and other traditional industries that couldn't possibly raise wage rates to compete with oil, the petroleum companies tried not to pay so much that they drew labor away from the indigenous firms. Just the presence of hundreds of extra jobs seemed to exert some pressure on wages, though, Iain McNicoll suggested in *The Shetland Way of Oil*. When the traditional industries slumped, some workers went to oil. When the traditional industries recovered, they didn't necessarily go back. McNicoll feared there might be a "ratchet" effect that gradually drew workers from the traditional industries. Already, he said, there had been shortages of bakery and milk delivery workers. And it wasn't hard to see why people might be attracted to oil jobs. A woman who knitted sweaters at home on a piecework basis might suddenly be able to make $275 a week as a maid.[18]

There was no question that oil development brought a lot of new people to the Shetlands and to Aberdeen, and housing was consequently scarce. The local authorities in Aberdeen built much of the city's new housing, and they built fewer houses per year in the 1970s, when the oil boom was going on, than they had in the 1960s. Partly, the problems were political (and held no useful lessons for Washington state). Partly, public like private construction suffered from the fact that many construction workers—and whole firms—shifted from residential construction to the oil industry. During the oil boom in East Ross, a housing contractor asked, "How can we build houses for the folk working at Nigg [a platform fabrication yard] when all our men are down working at Nigg? We can't afford to pay them the kind of money they are getting there. And even if we had the men, we can hardly get the materials." Suitable land grew harder to find, too. And it grew more expensive: by 1975, the price of residential land in Aberdeen had increased to almost five times its 1973 value.[5,61,71]

The cost of housing grew more rapidly in Aberdeen than it did in the rest of Scotland. From 1970 to 1974, Scotland's average housing price rose 90 percent; Aberdeen's rose 170 percent. Teachers, planners, and others whose services were needed in the city wouldn't take jobs there because they couldn't find affordable housing. In Shetland by the early 1980s, an unexceptional three-bedroom home went for $120,000. As *The New York Times* reported, the rise in prices had created "substantial wealth for owners and substantial difficulty for buyers."[5,77]

Cost aside, there simply weren't enough units to go around. Much of the growth was consequently channeled into suburbs that weren't well equipped to handle it. With new homes in the suburbs and virtually all the new jobs in the city, Aberdeen experienced a rapid increase in commuting. [61]

The price of land rose more even rapidly than the price of housing. Michelin paid under $3,000 an acre when it built a tire factory in Aberdeen in 1969. Five years later, land across the street sold for $100,000 an acre. Local government paid 450,000 pounds for land in Peterhead on which to build public housing; two years before, the property developer had bought the same land for 210,000 pounds. The Shetland Island Council paid 2.3 million pounds for land it could have bought a few months earlier for one-tenth the price.[5]

Not only did the price go sky high, but the land itself, in many cases, was bought up by investors living outside northeastern Scotland. The buyer might be a corporation with a local address, but the actual owners were often located far away.

In Shetland, outsiders also bought up many of the local businesses.

Some effects of oil development were immediately visible. One was increased truck traffic and the resulting deterioration of local roads. Another was the presence of large numbers of people who had never been seen in the small towns before. "Shetlanders are for the first time ever meeting in Shetland large numbers of people who do not like the place," Jim Nicolson wrote in *The Shetland Way of Oil*. "It is not surprising that there is considerable anti-incomer feeling in the isles, for Shetlanders are used to hearing from summer visitors and 'white settlers' alike how splendid they and their archipelago are."[18]

Shetland had had the highest proportion of residents over 50 in all of Britain. Suddenly it had the highest proportion of residents under 30. Suddenly it also had crime and a rise in auto accidents. Writing in *The Scotsman*, Martin Dowle called the new economy a "materialist nirvana" that was glaringly out of step with local tradition.[44]

"Shetland was a very friendly place, and now everybody treats you with caution," a Scalloway fish factory worker complained to *The New York Times*.[77]

"For the Peterheadian," wrote Robert Moore, "it is a question about the quality of his or her life. Quite dramatic and visible changes that they did not ask for have been thrust upon them. The streets seemed to fill with Italians and Spaniards, and then empty again. The prices of houses seemed to rise suddenly. There were more jobs and rising wages. The streets became littered, the pavements broken and heavy traffic made it dangerous to cross the road. . . . marriages seemed to be breaking up, there were more serious crimes before the courts, the schools were overcrowded. . . anxieties were backed by a feeling that the local people could do very little about the events which were willed by powerful economic and political forces far beyond their control." (Not all the social disruption could legitimately be attributed to oil, Moore wrote. A boom in the fishing industry that had given young men extra spending money had led to increased drinking. New employment opportunities had given women a chance to leave marriages that had already gone bad.)[71]

Oil development did not affect all communities equally. Some fared much better than others. "Overall, Aberdeen has done well from the offshore developments," concluded G.A. Mackay and Anne C. Moir. "On balance we certainly believe that the benefits exceed the costs, which we do not think is the case for certain other oil-related areas in Scotland."[61]

They made it clear, though, that even within Aberdeen, the costs and benefits were not distributed equally: "although most locals would probably agree that, overall, Aberdeen has benefitted from oil, there are significant minorities—people and companies—who have not and the benefits have certainly not been spread uniformly. Social problems have arisen because of the shortage of housing in the area and there has been a tendency for the provision of social facilities to lag behind the growth in employment and population."[61]

The fishing industry was one of the nonbeneficiaries. Debris on the bottom was a major problem during the early years of North Sea development. Claims for debris damage to nets declined after that, but not because the debris was gone; skippers just avoided areas in which they knew debris still existed. This added to the substantial area from which fishing boats were excluded by oil development.

Norwegian data suggest that most of the trawlers operating in the North Sea had gear damaged by debris more than once during the 1970s. A Norwegian government survey indicated that because of debris damage and reduced access to the fishing grounds, the catch was reduced by 25 percent between 1974 and 1976. The Norwegian trawl catch picked up substantially in 1980, though, suggesting that the effects may not have been long-lasting.[48]

In Scotland, estimates of the fishing area lost to oil development range from 190 to 830 square nautical miles. For the year 1976, fishing losses were estimated from 235 to 2,000 tons, worth between 50,000 and 460,000 pounds. The losses were spread evenly across the fishing grounds. Most took place in just two areas, the Moray Firth and the East Shetland Basin. In 1985, John Goodlad of the Shetland Fishermen's Association claimed that his association had lost 5.5 million pounds since 1975, and the overall loss to fishermen may have been 60 million pounds.[38]

In some places, pipeline construction from the oil fields to shore has destroyed rich fishing grounds. "The laying of the pipelines marked the lowest ebb in the fishermen's relations with the oil companies," according to *The Shetland Way of Oil*.[18] "Much of the inconvenience caused to fishermen could have been avoided by common sense and stricter control over the contractors engaged to lay the pipelines. The oil companies were always eager to let the fishermen know what they were doing, but it seemed that they were less willing to find out where the fishermen were operating at each season or even what was involved in their fishing techniques. All sorts of debris from safety helmets to broken hawsers were dumped on the fishing grounds."[18]

In addition to placing physical obstacles in the paths of the fishermen, oil development has created competition for labor and for harbor space. The seafood processing industry has felt the labor squeeze. In Shetland, a few processing firms were squeezed so hard they had to close. Fishermen in both Aberdeen and Peterhead were crowded out of harbor space during the early years of North Sea development by oil industry supply boats. Revenue from the supply boats paid for substantial harbor improvements in both places, though, so that in the long run, fishermen are probably better off. At least, they have better facilities. On the negative side, they no longer have access to some of the small repair yards, which have been permanently crowded out by the supply operations.[48]

Trying to find lessons for Atlantic Canada in the North Sea experience, J.D. House has written that the oil industry's "stronger bargaining power both with governments and in various labour and commodity markets gives [it] a competitive advantage over the fishing industry. The latter suffers not only directly from several nuisance problems; but also more fundamentally from the way in which the oil industry comes to dominate the regional economy and society, incorporating people and other resources into serving its interests. While nuisance problems can be mitigated . . . the fundamental problems are more difficult to deal with."[48]

Fundamentally, oil has changed life for Shetland Islanders in ways many of them did not want or anticipate. At first, it seemed that they were on top of things. As Peter Koenig wrote in "*Audubon*", in 1976, people in Shetland, Edinburgh, and London believed the islanders had negotiated a canny deal for themselves. Shetland was cast by the European media as "a David battling the oil industry Goliath." The Shetlanders kept ownership of the land beneath the oil facilities. They owned the docks and leased them to the oil companies. They got 90 percent of their property taxes from oil.[55]

But oil proved a mixed blessing nonetheless. "While the mood then was one of victory, now it was one of defeat," Koenig wrote in 1982. "Instead of being flush with oil revenues, the local government had gone $300 million into debt. . . . Off the record, oilmen pointed to local government's financial incompetence. Off the record, local politicians pointed to the oil industry's sharp dealing." The traditional industries were declining, contrary to some people's expectations, and there had been a well-publicized oil spill that contaminated seaweed, ultimately killing the local sheep that fed on the seaweed. Quite apart from such things, Koenig theorized, the main change in Shetland "has nothing to do with environmental degradation or with economic boom or bust. It has to do with the marginalization of the Shetlanders. In 1976, the Shetlanders I met were living in almost total harmony with the harsh, beautiful nature around them. They felt and seemed at the center of their universe. On my return, most Shetlanders were still living in harmony with nature. But they felt and seemed more on the periphery of what was happening on their islands."[55]

IMPACTS ON COMMUNITIES

The lion's share of oil revenue flows to whoever owns the well and/or whoever owns the land in which the well is drilled. If the oil is located on the outer continental shelf, that leaves out the communities and counties closest to the drilling. If oil is produced on leases adjacent to state water, the federal government will give 27 percent of its revenue from those leases to the state. The state can choose to give part or all—or none—of that money to the nearby communities. (If no oil is produced on leases adjacent to state lands, no money will flow to the state, and the formula for distributing it will be irrelevant.) Those communities may also get extra tax revenue. But they won't get money directly and they won't get the lion's share. "The economic benefits of the development are spread across the entire country," explained John W. Devanney III in *Technology Review*, "the environmental disbenefits highly localized." Devanney concluded that "it becomes quite rational for those in the immediate vicinity of a development . . . to oppose it, for they see only a minute proportion of the economic benefit but all the environmental disbenefit."[28]

Biliana Cicin-Sain expands the idea of "disbenefits" beyond the environmental. In the *Public Affairs Report of the Institute of Governmental Studies* at Berkeley, she states flatly that, "the crux of the policy dilemma posed by increased offshore oil development is that the benefits from oil production tend to be distributed nationally, while the costs tend to be concentrated locally."[23]

If oil development doesn't progress past the exploration stage, there will be very few national benefits and very few local costs. If commercial quantities of oil or gas are found, both the costs and the benefits increase. The overriding national interest is a continuing supply of petroleum. Actually, MMS estimates that the continental shelf off the Washington and Oregon coasts contains only enough economically recoverable petroleum to run the United States for about three days. This is of limited value. MMS argues, though, that it should be seen in broader context. "Suggestions are sometimes made that the relative importance of developing a prospect can be gauged in terms of the number of days it alone could satisfy national petroleum needs," MMS says. "However, if the test for proceeding with oil and gas development in a prospect were whether it contained more that several days' supply for the nation, little energy would be developed domestically. . . . Over 80 percent of all known OCS oil and gas reserves are in fields containing 1 day's supply of oil or less. Only 6 percent of all known OCS oil and gas reserves in the Gulf of Mexico and Pacific OCS is in fields containing more than 3 days' supply of oil. It is the cumulative contribution of all the small fields, along with the few really large ones, that constitutes the nation's domestic petroleum production."[69]

The other national benefit would be money. MMS estimates that the net economic value of the petroleum off Washington and Oregon—that is, what it would be worth after deducting the expenses of exploration, development, production, transportation, and refining—would be $130 million to $486 million, depending on the price of oil.[68] The gross value, at today's depressed oil prices, would be around $800 million. That figure takes into account an 80-percent probability of finding nothing. If oil and gas were actually found, it would increase to $3.2 billion; under MMS's high-case scenario, it would be $9.6 billion. As a comparison, according to the Washington Department of Fisheries the total value of all crabs, shrimp, and oysters harvested on the Washington coast, including the Columbia River, in 1986 was $21 million. The total value of the coastal salmon net fisheries in Grays Harbor, Willapa Bay, and the Columbia River was $9.2 million.[91] Bottomfish landings for the entire state were worth $34.4 million. For another kind of comparison, an extended-range Boeing 767 is worth about $70 million; Boeing's 1988 orders for commercial jets reached a record $28 billion.

The local environmental costs are hard to calculate. The inevitable costs are low. The conceivable costs are very high. An absolute upper limit might be the *Amoco Cadiz* spill off Brittany. The *Amoco Cadiz* spill was a tanker accident, not a platform blowout, and it took place under weather and wave conditions that both carried that oil to shore and made immediate containment impossible. It was probably the costliest spill of all time. Estimates of its cost to Brittany, in 1988 dollars, range from $158 million to $250 million.[70] Less apocalyptic accidents—and even the celebrated Santa Barbara spill of 1969 was considerably less apocalytpic—would produce correspondingly less damage.

In addition to any environmental damage that occurs, the costs borne by local communities are basically the same costs that would be borne if any other big construction project came to town. The smaller the community, the greater the impact. There will be more people, more traffic, more demands on infrastructure and social services. Communities are seldom prepared in advance for the effects of a major project. Sometimes they are reluctant to get prepared at all. In Fairbanks, "before the pipeline, the municipal governments were unwilling to spend money because they were not sure the permit for the pipeline right-of-way would be granted," recalls the *Alyeska-Fairbanks Case Study*. "During the pipeline, government was so busy coping with crises it had not prepared for, it did no planning for the future. Now that pipeline construction is over, the local government is trying to cut the budget for services because taxpayers are not willing to support an increase in the mill rate."[99] Construction of the Trans Alaska Pipeline was an immense project that at its peak employed more than 30,000 workers, and Fairbanks was a community more isolated by geography than any place on the Washington coast. The scale of development and social disruption that the pipeline brought Fairbanks exceeded anything that offshore oil development is likely to bring Washington. The Minerals Management Service expects offshore development to produce a peak population gain of 1,450 people and a long-term gain of 153, not all of them necessarily in any single community or even on the coast. The MMS "high case" scenario would produce roughly three times the population gain.[69] Nevertheless, some kinds of impacts seen in Fairbanks might be seen, on a much smaller scale, in Washington's coastal communities. And the government and citizens of Fairbanks may have responded much as people would respond in coastal Washington.

(There is something to be said for a community's waiting until it has a financial bird in the hand. The Shetland Islands, off the northern tip of Scotland, which have been a major support center for the North Sea oil fields, got a financial jolt when major oil projects on which they were counting got held up. Tax revenues from the Sullum Voe oil terminal were already in the Island Council's budget, for example—when a suspected leak in an underwater pipeline forced a delay in the terminal's opening.[44] Seward, Alaska, hadn't banked that heavily on offshore development, but when Gulf of Alaska exploration started in the mid-1970s, the city did annex a new industrial area—over the protests of residents—for oil development, the local technical institute did start training people in skills needed by the oil industry, and a lot of people did get their hopes up—only to have the exploratory drilling find nothing of value and the oil companies go away. A lot of people in Seward were disappointed and were left with the feeling that nothing ever worked out for their community.)[9]

If a major offshore find required onshore facilities, the counties and communities would get some extra revenue from property taxes, but the increased tax revenues might not cover the full cost of the increased services that would be needed. A 1985 report for the Minerals Management Service on projected statewide effects of outer continental shelf development in Alaska predicted that "OCS development results in significant new revenues to state and local governments. However, the increase in revenues is not sufficient to offset the increased demand on public services created by the influx of new residents." The report suggested that "as a result . . . state and local governments must raise tax rates or reduce services, or both. . . . We project the principal effect to be an additional reduction in per capita government services."[10]

At best, new revenues that can help pay for improvements in infrastructure and services always lag behind the need for those improvements. In the Shetlands, by 1974, according to *The Shetland Way of Oil*, "the roads were deteriorating under the weight of heavy loads, incoming firms were desperate for workers and local firms were suffering on account of the competition for labor. The [governing] council was at pains to point out to the oil companies that their arrival had placed a severe strain on the whole economic and social structure of these islands and that they ought to provide some compensation for the inconvenience caused."[18]

In Fairbanks, because people were reluctant to prepare for the pipeline boom until it was certain to happen, and reluctant to spend money on infrastructure anyway, the telephone system was soon overloaded, the water system couldn't handle all the increased demand, roads were congested, and people had to wait in line to do almost anything. Businesses that had gotten ready for a boom in the late 1960s and earliest 1970s were left high and dry when construction of the pipeline was delayed. Others took their experience to heart, so that while three new shopping centers were built to handle the extra demand, they weren't finished until the tail end of the boom. New schools were built, but there turned out to be no great influx of families, so the extra capacity wasn't used. Social services were severely strained. The population of Fairbanks grew by an estimated 57 percent from 1970 to 1976, yet, an Alyeska-Fairbanks case study funded by MMS observes, "housing, electricity, water, roads, police protection, schools, consumer goods, health care, recreation . . . were not improved much by the borough, the city or private enterprise until the boom was underway. Some were not attempted until it was nearly over."[99]

Inevitably, housing became a problem—just as it did in Aberdeen during the North Sea boom. Fairbanks had substandard housing before its boom even started, and new construction didn't reach its peak until the pipeline boom was already under way. Newcomers lived in shared housing and mobile homes. The governor declared a housing emergency in Fairbanks in order to deal with both the shortage of places to live and the soaring rents. The Alyeska-Fairbanks case study noted that "the housing shortage . . . was the subject of many newspaper stories, both local and national, and the source of some of the worst horror stories of the period."[99]

The Salvation Army shelter got plenty of business. Half its visitors, probably, were people from out of town who had come looking for pipeline jobs. Many of the rest were marginal residents of Fairbanks whom the strains and inflation of the boom had pushed over the edge.[99]

Crime rose in Fairbanks, just as it rose in Grays Harbor County during Satsop construction—and just as it could be expected to rise in any coastal community close to a major offshore oil development.[99] Aggravated assaults would certainly rise in the neighborhood of a major offshore development. So, most likely, would some kinds of theft.

In a very small community, the sheer number of newcomers brought in by a major project might very well overwhelm local institutions. Looking at scenarios for petroleum development in the northern Gulf of Alaska in 1979, the Alaska OCS Socioeconomic Studies Program concluded that in the event of a midlevel oil find, "the socioeconomic basis of the traditional Yakutat community would be submerged under a wave of new economic forces and new residents with a decidedly different social and cultural orientation."[1]

Yakutat didn't want to be submerged, and when oil exploration began, the native village corporation decided to keep oil workers in an enclave. ARCO had originally purchased an old cannery building to use as a supply base. The village corporation used zoning to make that illegal, created a legal zone outside the town, and engineered a land swap that enabled the town itself to own the enclave in which oil activity and oil company employees would be kept.

The village corporation signed a lease with ARCO and Shell to operate a 77-acre service base and industrial park. The oil companies agreed to minimize the number of families moving to Yakutat and to hire locally whenever possible. They would make any necessary capital improvements. At the end of the lease period, those improvements would belong to the village corporation.[2]

As it happened, development never got beyond the exploration phase. At most, perhaps eight jobs were created in Yakutat. When exploration ended, the only lingering sign of oil industry presence was a new dock. While Yakutat's approach was never tested by a really large influx of oil workers or oil activity, it does provide an example of one way to handle—or try to handle—offshore development.[54]

The effects of a major development could not be kept in an enclave, though. And presumably, nearby communities wouldn't want them all to be. No community would welcome the social problems, the congestion, or the sheer volume of newcomers, not to mention increased housing costs, housing shortages, or speculation. (Speculation would be virtually inevitable. It happened in Scotland. It happened in Newfoundland. It would happen here.) But the jobs and increased business would be hard to turn down. In fact, communities might well compete with each other to attract them. The same cities that in the mid-1980s offered free infrastructure and services to attract the minesweepers that were supposed to be based along the Northwest coast—Port Angeles, Grays Harbor, Astoria, and Coos Bay all competed; Astoria won, but there was no money in the federal budget for the minesweepers—might well start a bidding war for an oil supply base.[88]

The impacts on local businesses would depend on a lot of different factors. There is no reason to believe, particularly at the beginning, that oil companies and their contractors would do much local buying. The smaller the community and the narrower the range of goods and services available, the more would be bought somewhere else. Local purchases might increase after the initial stages, as they did in Scotland, but it is unlikely that coastal Washington would ever be able to supply the bulk of what the offshore industry needed. (In the early years in Aberdeen, Scotland, the involvement of local companies "was small and limited to standard items of equipment and service," wrote G.A. Mackay and Anne C. Moir in *North Sea Oil and the Aberdeen Economy*. "There is a fund of stories of the ilk of American companies importing light bulbs from Houston, airfreighted into Aberdeen.")[61] Consequently, it would be unrealistic to expect coastal Washington to enjoy the kind of employment multipliers found in areas with large, long-established petroleum industries that can supply virtually everything an oil company needs. In Louisiana, the economics department at Louisiana State University found that each of the state's 41,781 jobs in the offshore petroleum industry created more than two other jobs.[3] The Washington coast couldn't expect that high a multiplier. During Satsop construction, the Grays Harbor Regional Planning Commission calculated, each basic job in the economy created 1.28 other jobs.[42]

Some purchases would certainly be made locally. If many workers came to town, the numbers of motels and restaurants would almost inevitably increase. (In Aberdeen, Scotland, the numbers of hotel rooms and restaurants doubled in ten years.)[61]

Other kinds of businesses, such as laundromats and grocery stores, would serve the companies and workers involved in the oil buildup, too. But in many cases it is far from certain that existing local firms would be the ones making the sales. They might not be big enough. Local businesses might have to choose between expanding early, before they could be sure it would pay off (like the eager Fairbanks businesses that got burned), and being too small to take advantage of the new opportunities. Outside capital might very well come in to compete with established firms or buy them up. (When the boom hit Peterhead, Scotland, for example, local builders couldn't handle the volume of construction that needed to be done, and big national firms moved in. At least one builder described by Robert Moore in *The Social Impact of Oil* lost one-third of his skilled men to the big contractors; he was also priced out of the house-building market when land costs rose more than tenfold. Moore described four local building firms that did survive the boom. One was simply bought by a big out-of-town firm. Two lost at least half of their workers but survived by going into new niches. One did some small jobs at big sites and concentrated on ship work. The other, which had specialized in bricklaying and roofing, trained part of its work force to drive heavy equipment. The fourth firm, which had money in the bank from a housing development it had built before the oil boom started, was able to expand and do very well building houses.)[71]

The federal government cannot require any bidder for offshore oil leases to buy or hire locally. And in fact, just as many purchases would undoubtedly be made outside the local area, so many of the workers hired, especially in the early stages, would come from outside. "Very few of the offshore jobs associated with exploration operations, platform installation and pipelaying will go to Alaskans," predicted the Alaska Department of Community and Regional Affairs in a book entitled *Planning for Offshore Oil Development.* "Typically, oil companies or their subcontractors will recruit and transfer experienced workers from other areas of operation. All offshore employment for the first eight years following the lease sale is temporary. . . . Permanent production and maintenance staff will reside in Alaska."[2]

The Minerals Management Service suggests that offshore oil and gas production in the Washington and Oregon area will create 1,176 jobs, 571 of them in the oil and gas industry, in the peak year of 2001. By the year 2003, the MMS says the number of jobs will drop to 124, 60 of them in the oil and gas industry; that number should hold relatively constant until production ends in the year 2028. The MMS also hypothesizes that there will be only one production platform, which will be located near Coos Bay, Oregon.[68] If that really were the location, oil and gas production would generate little or no employment growth in coastal Washington. If the platform were located off the Washington coast, most employment growth would probably take place north of the Columbia River. The MMS doesn't suggest where the jobs will be created or how many of them will be filled by local residents.

Virtually no one would be hired during the initial exploration phase. The big surge in offshore employment would take place during development drilling. According to one estimate, during the development drilling phase, a platform would employ 105 people per 12-hour shift. There would be 2 shifts a day, and each crew would work 7 days on and 7 days off. Other rule-of-thumb estimates say that a platform will employ 175 people per 7-day shift. The pay for members of the drilling team would average about $50,000 a year. Drillers would make the most, $70,000, while roustabouts would earn $25,000-40,000. In addition to the drillers and roustabouts, a platform crew would employ culinary workers, electricians, mechanics, diesel mechanics, engineers, mudloggers, medical people, and scientists. Perhaps half the drilling crew would be hired locally. The rest would be skilled people probably brought in from Texas and Louisiana. Other workers might or might not be hired locally, depending on the skills that were locally available. The workers who came in from outside would almost certainly leave the area during their 7 days off. They would have little or no impact on nearby communities. They would not bring their families. All members of exploration and pipelaying crews would probably be imported. During production, only two to five workers might be employed on each platform. If there were a major find and administrative personnel were brought in, probably most of the administrators and support staff would come from parent offices.[11]

Many of whatever jobs were created locally would probably involve supplying the oil rigs, building the onshore facilities and other support activities.

A supply base would have to be built within 200 to 300 miles of each rig. It would not have to be built on the Washington coast in order to serve rigs on Washington's outer continental shelf. It would require a harbor with a channel depth of 20 feet, a depth at the entrance of 29 to 33 feet and a turning radius of 480 to 840 feet. There would have to be 20 feet of water at the pier. Each berth would require about 5 acres and employ perhaps 15 people. Supply boats would run around the clock.[2] It might be feasible to supply rigs off the Washington coast from Westport or elsewhere in Grays Harbor. It might also be feasible to supply them from Astoria, from Port Angeles, from Portland or from Tacoma, Seattle or Everett.

Headquarters will probably be established not on the coast but in a major city. In its book, *Planning for Offshore Oil Development*, the Alaska Department of Community and Regional Affairs suggested that "the impact on Anchorage [is] potentially the greatest in terms of employment and population."[2] If oil really is developed off the Washington coast, the greatest increases in employment and population may well come in Seattle or elsewhere on Puget Sound. Smaller increases that take place in the much smaller communities of the coast would be more noticeable, though. An increase that would pass unnoticed in the Seattle metropolitan area might create dramatic social strains and economic shifts on the coast.

It is possible that most of the population growth—and therefore most of the need to spend money on infrastructure and social services—would flow to one community and most of the additional property tax revenue to another. It would depend on the most logical location for onshore facilities—the only portions of the petroleum activity that could be taxed locally—and the most logical or desirable place for people to live. It is also possible that any impact money provided by higher levels of government would not flow down to the communities that needed it most. California, for example, got $338 million in April, 1986, plus $289 over 15 years as a retroactive payment for offshore oil production adjacent to state waters. (In addition, from now on, California will get its 27-percent share of rents and royalties from federal leases adjacent to state waters.) The state was free to distribute the money however it pleased. Most has simply gone to the general fund. Twenty-five million dollars has gone to coastal counties and cities, but not only to counties affected by offshore oil development. Some county governments have resented this. (Some coastal fishermen have also resented the expenditure of money on projects that don't help them to deal with the real or alleged problems of oil development. In 1988, though, the state government has started a $2.5-million local marine fisheries program to mitigate the cumulative impacts of past oil development.)[80,59]

Any significant influx of people and economic activity might very well lead to political changes in small communities. Actually, some effects might be felt before the first newcomers hit the beach. Looking at what happened in the Shetlands, Anthony Cohen writes that the islanders' self-perceptions were changed not by the reality but also by the prospect of oil development, by "the traumatic and irrevocable induction into the realization that the familiar may not, after all, be permanent."[44] (In Seward, getting prepared psychologically for offshore development seems to have a lasting impact even though development didn't happen. Seward had not been especially enthusiastic about growth until then, but exploration did not have the traumatic effect that some people had feared, and after the oil companies left, Seward tried to find other means of developing.)[9]

The prospect of oil and oil revenues may encourage the growth of a stronger regional self-awareness and assertiveness, more of a tendency to insist on some identity or prerogatives separate from those of the central government. North Sea oil has fueled nationalist sentiment in Scotland. Habitat North, in a study of foreign outer continental shelf development for the Bureau of Land Management, observed that "the political impact of oil on Scotland can be portrayed in politicization terms. . . . A peripheral area, regarding itself as a nation (or at least a collection of common interests) has used a 'found resource' of global significance as a means of exploring and expressing its uniqueness and apartness. What Cohen describes in Shetland—a verification of identity—occurs across an entire country, be it Scotland or Mexico."[44] Habitat North does not address the growth of political consciousness in a portion of a single state, but it seems reasonable to assume that something analogous, albeit much milder, would occur.

A report prepared for the Bureau of Land Management on the effects outer continental shelf development might have on the non-Native population of Kodiak suggested that "one positive impact left behind after the petroleum industry has departed may be a strengthening of the political organization." Meeting the challenges and threats of development "would likely heighten Kodiak's political strength and expertise. It is probable the community would once again know it has the capacity to meet challenges."[73]

While a community was in the throes of those challenges, though, old leaders might well become less influential as representatives of the oil industry became prominent. In Peterhead, Robert Moore wrote, "it is quite clear that there had been a succession of power and status in the town. This was also noted by the authors of the Impact Study conducted in the University of Aberdeen. Prominent figures in business and politics in the late 1960s and up to 1972 seemed to have slipped from public view. Most frequently mentioned were the managers of Crosse & Blackwell and General Motors who were said to be much more a power in the land 'until the coming of oil.' Members of the 'old elite' still perform honorific functions at presentations and school prize days."[71]

The Grays Harbor Regional Planning Commission's study of Satsop construction impact noted that between 1974 and 1980, Montesano and Oakville changed all their elected officials, Elma changed 83 percent and McCleary changed half. All those cities were revising their zoning ordinances and all had adopted new comprehensive plans. The planning commission did not suggest a causal link between Satsop and the turnover of local officials, but it did present the phenomenon as one aspect of the social change that accompanied the building of the two nuclear plants.[42]

A major oil development might also affect the way local people felt about their elected officials. *The Shetland Way of Oil* suggests that Shetland officials would simply be incapable of major corruption. Nevertheless, it says, "much of the history of oil in Shetland has been accompanied by claims of secret deals and underhanded negotiating."[18] If people's lives are altered by decisions beyond their control, they may not look charitably on the decision-making process.

On a state level, the political power of the oil industry would almost certainly increase. The industry represents a tremendous concentration of capital and lobbying expertise, and if commercial quantities of oil or gas were found offshore, it would probably use that expertise to look after its new interests in the state.

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6

Conclusions

Offshore oil and gas development will not wipe out unemployment or poverty on the Washington coast. It will not wipe out the coast's fish or shellfish or marine mammals, either. Short of these dramatic outcomes, the impact of petroleum development on the coast is a matter of probabilities. Oil would almost surely have effects on the coastal economy—probably small and localized, but real. In contrast, the odds are that it would have very little effect on marine life—but with bad luck and a major spill, there could be serious, long-lasting biological damage.

By and large, the scale of offshore development determines the magnitude of its impact, both positive and negative. MMS[5] predicts a relatively modest scale of development on Washington's outer continental shelf. It calculates that the Washington/Oregon planning area has only a 20 percent chance of containing commercial hydrocarbon deposits; taking that probability into account, MMS projects economically exploitable undiscovered reserves of oil and gas equal to 50-60 million barrels of oil, depending on price. This quantity would support operation of only one platform, a far smaller scale of development than occurs off California, in the Gulf of Mexico, or in the North Sea. That does not reduce the probable impact to zero, but it does minimize both the jobs and revenue and the social and environmental disruption that oil development should be expected to bring.

Nevertheless, the state should realize that if substantial hydrocarbons deposits are found, the ultimate scale of development could be much larger than these initial projections suggest. If an energy crisis breaks out and prices rise higher than the forecast $32.50 per barrel (as they have in the past), and if some of the less conservative reserve estimates (ranging up to hundreds of millions of barrels of oil equivalent) prove accurate, the scope of oil development described above could be just industry's foot in the door of coastal Washington.

The impact of offshore development will also be influenced by its location—which will not be known until areas are leased and exploratory wells are drilled. The impacts—both those that are certain and those that are the products of chance—will be different for different stages of the production process. That fact helps to explain the origin and nature of the impacts. But it may also be misleading: each stage of development implies all later stages. While the very first stage, leasing, itself has no direct effect on the natural environment of a coast, a company that buys an oil lease will expect to go through all the remaining stages; if the geology and economics work out—and there are no judicial or legislative impediments—it certainly will.

Actually, while leasing itself does not physically alter the coastal environment, it does affect people (as the existence of this report testifies): the leasing process has stimulated political activity at the state and Congressional levels and has become the focus of lawsuits; it might also cause political polarization and touch off some business expansion and real estate speculation in coastal communities.

THE EXPLORATION STAGE

The first stage at which something happens physically would be exploration, both seismic surveying and exploratory drilling. Seismic surveying might kill some small immature organisms near the surface within a few feet of the air guns (mainly fish and crab larvae), but research suggests that the effects would be localized and would not noticeably deplete fish or crab populations. (The industry occasionally uses explosives in shallow water where air guns cannot be used. This practice can kill significant numbers of fish and other organisms.) The air gun blasts might disturb gray whales and other local sea mammals that are very sensitive to underwater sound, but the evidence remains a matter of dispute.

California fishermen report that seismic surveys near reefs reduce their catch of rockfish in the area, and preliminary data indicate that some species can be disturbed by the acoustic pulses under experimental conditions. It is unknown whether catches are reduced under realistic fishing conditions, how long the effect lasts, and how large an area is affected. There are also unverified suspicions that seismic surveying causes premature release of rockfish larvae. No inventory has been taken of rockfish reefs and other areas of aggregation where seismic surveying might cause problems on the Washington shelf.

Seismic surveying would create little or no local employment (there is a geophysical company in Seattle, but the survey vessel and crew might be brought in from elsewhere), no increase in local population, and no extra demands on local services or infrastructure. It would not make the area less attractive to tourists.

It might very well make fishermen apprehensive and hostile, though. The memory of the survey vessel that snagged the buoys from a thousand crab pots with its towed seismic gear hasn't faded away since it happened in 1980. Industry suffers from these accidents as well, and has taken significant steps to eliminate a recurrence. The possibility of future conflicts between survey vessels and fisheries remains, but such conflicts can be minimized and possibly avoided. Surveying could be done in late summer or fall, when little or no crab fishing was in progress. In addition, the crab and oil industries could start meeting on a regular basis to discuss and negotiate possible conflicts before surveying began; experience in California suggests that this kind of informal industry-to-industry contact can reduce the conflicts over seismic surveying.

Large structures start appearing offshore after leases are sold, with the onset of exploratory drilling. Exploratory drilling brings many of the same environmental risks and impacts and many of the economic and aesthetic conflicts that can accompany developmental drilling and production, but only for a matter of months. The drilling crew will be imported, any supply base operations will be only temporary, and the number of jobs created will be negligible at best. The aesthetic impact of an exploratory rig will be the same as that of a production platform. Because of its anchoring system, an exploratory rig will occupy more space in the ocean than a production platform. It would therefore exclude commercial fishermen from a larger area. A single rig would not take up much space in the ocean, although if it were located in a rich fishing area, it might disrupt trawling patterns substantially. Because exploratory drilling is relatively short-lived, conflicts with fishermen—and with fish, bird, and mammal populations—might be minimized by careful scheduling. Again, discussions between the fishing and oil industries should be established before operations begin.

THE DEVELOPMENT STAGE

EMPLOYMENT EFFECTS

In both developmental and production drilling, offshore platforms become, for rational planning purposes, permanent structures. Some conflicts can no longer be avoided by scheduling. Aesthetic and other impacts can no longer be regarded as transient.

In many of their socioeconomic impacts, the two stages are radically different. Most of the employment and population growth will take place during the development drilling stage. After that, employment will decrease, and will hold steady at a much lower level through the productive life of the wells. (Employment will increase during "workovers," but only temporarily.) MMS[4] predicts 1,176 jobs will exist during the peak of development drilling—only 541 of them actually in the oil and gas industry—and 124 during production. A larger find than anticipated would create more jobs; a smaller find, fewer jobs.

Either way, the impact on coastal communities would depend on the location of the find and of the onshore facilities. A discovery off the southern coast of Washington that was supplied from Astoria and had its oil transported by tankers, rather than through a pipeline to shore, might have negligible socioeconomic effects on Washington communities. A discovery that was supplied from Westport and had its oil or gas piped to the Washington mainland might have significant effects. The smaller the communities in which bases and other onshore facilities were located, the greater the effects on those communities would be.

Basically, developing oil or gas wells offshore would be like having a large construction project in the area. Most of the local jobs would be construction jobs. Most of whatever workforce came into the area would be transient. Some workers would probably commute by car from other counties or from Oregon. Others would find temporary housing locally. The local housing supply might well be strained. Rents and real estate prices might increase. Some people who had lost jobs in the forest products industry might find employment with the oil companies' contractors, but the contractors would not be looking for older workers, and the federal government could not require any lessee to hire locally.

An influx of 1,176 jobs would obviously have a significant effect on a sparsely populated area such as Pacific County. (Not all of those jobs would be filled by Washington residents, though, and not all would necessarily be located on the coast.) There might be a small boom. Existing businesses might expand and new ones start up. Despite the chronically high unemployment, some low-wage local employers might have trouble finding or holding workers. Members of the community who had been struggling economically or personally might be pushed over the edge and add to the load on local social service agencies. In a very small and closely knit community, the continual presence of strangers in town might alter the established residents' experience of living there. Roads and traffic signals, as well as other services, might prove inadequate in places. The community might have to decide whether or not to spend money on infrastructure and social services despite the fact that the increased demand for them would not last and despite the fact that its tax revenues had not yet increased substantially. When the development stage ended, the area would experience a sharp rise in unemployment, which might again place extra demand on social service agencies. Again, those same effects might accompany any construction project.

IMPACTS ON AESTHETICS, TOURISM, AND FISHERIES

What would be unique about a project focused on offshore oil or gas? Public attention and political activity would probably focus on the possibility of oil spills, but a major spill would be unlikely—although certainly not impossible—and the cumulative effects of repeated small spills are unknown. The only certain effects at each stage of development are those caused by the physical presence of structures and processes that are used to locate, extract, and transport hydrocarbons. Assuming a commercial discovery is made, there may never be a significant oil spill, but there certainly will be seismic survey vessels, supply vessels, helicopters, exploration rigs, at least one production platform, and one or more onshore supply bases. There will be pipelines or tankers, or both. There may be a marine terminal and a separation and treatment plant. At the very least, all will occupy space. Most will be visible.

Whether or not exploratory rigs and drilling platforms are visible from shore depends on how far out they are, how high the waves are, and where the observer is standing. Beyond about 15 miles, the curvature of the earth would make them invisible from the beach. Platforms 25 miles out would be visible from a 100-foot bluff on a clear day. The closer they are, the larger they look. They are more apparent at night because they are lighted. It seems that platforms located in federal waters would not look huge from shore. But at three miles a platform would constitute a visible industrial presence. It would be incompatible with the aesthetics and the spiritual quality of the wilderness beaches.

Its effect on the aesthetics of the more heavily visited beaches farther south is less clear-cut, as is its effect on tourism. Some tourists might well be repelled by the fact or the idea that an oil platform was visible from a particular beach. Others might not. Certainly, it would be inconsistent to worry about introducing an industrial element into the atmosphere of certain coastal beaches while allowing people to drive trucks, cars, and mopeds along the sand. Extractive tourism—fishing, clamming—might not be discouraged by the sight of an oil platform.

Sport fishing from charter or privately owned boats might actually increase: offshore platforms can serve as artificial reefs, providing habitat for rockfish and other species. Fishing can actually improve around them. At least, it can improve for sport fishermen. Commercial trollers would not be affected much, but trawlers can't get very close to platforms and, depending on the location of a platform, might suffer some inconvenience and economic loss. For those restricted to specific fishing grounds, such as Indian tribes, such losses would be more difficult to compensate for by fishing elsewhere. The exclusion zone is larger around an exploratory drilling rig than around a production platform. Again, conflicts might not be totally eliminated, but they might be reduced by regular discussion and negotiation between the oil and fishing industries.

Whatever their impacts on fishermen, the platforms should be located with care to avoid harming fish and other organisms. Hard-bottom areas (where muds and cuttings have the greatest impacts on benthic organisms because of significant changes in the substrate) and productive fishing sites such as rockfish reefs should be avoided if at all possible. Platform siting also carries a small but real possibility of displacing groundfishes from important feeding and spawning habitats. Canyons and canyon edges, for example, are known areas of adult fish aggregation and focused fishery effort, and thus are potentially vulnerable to disruption by a platform. The state has no inventory of such critical habitats on the shelf that would enable it to respond in detail to specific proposals for platform siting.

Likewise, if a platform occupied space in which seabirds normally fed or through which gray whales normally migrated, it would force them to go elsewhere. This conflict is conceivable, but given the current stage of knowledge, it is mostly hypothetical. Birds, fish, and mammals congregate around certain areas of the sea surface in offshore waters where currents converge, but it is not known whether these occur in persistent locations and whether they are truly critical habitats. Gray whales are believed to have preferred areas where they feed on bottom animals. Observations in existing areas of oil development, such as Santa Barbara Channel, do not reveal obvious displacement effects on bird or mammal populations or on fishery yield. However, these effects are difficult to document and have received little formal study. The potential displacement impacts of platform siting cannot be assessed without additional study of organism distributions and abundances.

Space would also be occupied by a pipeline constructed to bring oil or gas to shore. While pipeline construction was going on, fish and fishermen would be excluded from a corridor of ocean and tourists would be excluded from a corridor of beach. The anchor scars left by the pipeline-laying barge might form a long-term hazard for bottom trawlers. The construction process might disrupt the habitat of bottom-dwelling organisms. If a pipeline were laid through Willapa Bay or Grays Harbor, it might affect oyster beds or cause other habitat loss. It might also cause some siltation or otherwise affect coastal erosion or accretion patterns.

Onshore facilities could be built in places and in ways that made them highly inconspicuous. Setback, landscaping, and other requirements could insure that their visual impact would be minimal. There might be some competition for harbor space between supply vessels and commercial or charter fishing boats.

THE PRODUCTION STAGE

SMALL SPILLS AND OTHER DISCHARGES

While the physical occupation of space would be the surest cause of environmental or economic conflict, it is not the aspect of offshore oil development that causes the greatest public concern. Most people's concern is reserved for the toxic substances that offshore production would release or could release into the environment at the well site or petroleum transfer sites. Spilled oil, of all these substances, receives the most attention, but there are other pollution effects.

Air pollution, for example, can be a significant result of offshore development. In southern California, where extensive offshore development has taken place in an area with serious air quality problems, it is a major issue. The small scale of the development that is projected in Washington, the absence of other major sources of air pollution along the coast, the strong winds bringing pristine air from the Pacific, and the relative infrequency of large-scale coastal thermal inversions all make serious air quality problems less likely than in areas such as southern California. However, periods of fog and deteriorating air quality can occur in all seasons, especially in the Puget Sound Basin.

MMS[4] projects that offshore development would cause reduced air quality only in the greater Puget Sound area, and only if tanker traffic and petroleum transfer increased there. However, it appears that reductions in air quality might result under other circumstances, for example if a large spill also involved a fire during a period of thermal inversion and fog in western Washington. Air quality also becomes an issue in Olympic National Park. The park is a Class I air quality zone in which any loss of visibility is prohibited by federal law. Also, not enough meteorological and air quality data for Washington coastal areas were found in compiling this report to conclude confidently that air quality impacts would be low under all development scenarios.

Discharges of drilling fluids (muds and cuttings) and produced waters generally have low toxicity and localized short-term impacts.[6,7] Depending on the strength of bottom currents, muds and cuttings bury and otherwise perturb ocean floor animal communities for about one kilometer around a platform, an effect that seems to last about a year after the platform is removed. Muds and cuttings have more harmful effects on rocky bottom areas, especially reefs, where organisms are not adapted to soft sediments. No inventory has been taken of the locations of reefs and other hard-bottom areas where drilling fluid discharges might cause problems on the Washington shelf.

Produced waters must be treated to lower their petroleum content if they are discharged; in well-mixed, flowing waters of the open shelf, these discharges appear to have negligible immediate effects.[7] The long-term effects of these discharges are poorly known—especially when several platforms are placed in an area of weak currents and flushing. There remains concern that oil in produced waters, along with spillage, could contribute to longer-term chronic effects. No studies have been conducted on the Washington shelf to determine whether it contains areas of weak circulation, such as eddies and convergence zones, that could be susceptible to such problems.

On the average, not much of the oil produced from an offshore platform is spilled routinely—about one barrel in a million is lost in small spills (less than 1,000 barrels). This figure suggests that in the absence of a major spill, only about 50-60 barrels would be routinely spilled off Washington/Oregon under current projections. This spillage does not apply to major accidents, which are rare. Almost all accidental operating spills from platforms are small; from what we know so far, their short-term effects are small as well, but the subject is not well studied. Increases in hydrocarbon contamination of sediments are seen within a few kilometers of platforms in the North Sea and Gulf of Mexico, but it has not been proven that observed declines in bottom-dwelling animal populations are caused by chronic low-level spillage. In areas of natural petroleum seeps on the seafloor off Santa Barbara, California, there is no evident damage to bottom animals or fish, although they do show some signs of metabolic stress. However, these are populations that inhabit a natural oil seep region and therefore have some tolerance to oil. Such effects are difficult to observe or measure, and at this point they are poorly understood. Chronic low-level spills might cause malformations in bottomfish in the vicinity of a platform, and stress on a fish population could increase its rate of mortality.

Many experts feel that long-term, low-level effects constitute the major area of uncertainty remaining in research on impacts of petroleum production. According to the National Research Council,[7] "...in sediments and in the water column there is no compelling evidence to date indicating permanent damage to the world's ocean resources or even a part of it. Nor is there yet evidence of increased pathological abnormalities in marine biota, due to petroleum hydrocarbons alone." However, these experts expressed concern that under some conditions—multiple platforms in coastal and shelf areas with weak currents—chronic releases could cause adverse effects over a period of years. They found the concern justifiable but the available data inconclusive. Such long-term effects would appear to be of concern off Washington only if the highest projections of oil reserves in the leasing area were borne out, and if weak circulation were observed in the area where production took place.

LARGE SPILLS

Large oil spills clearly arouse the greatest dread and carry the greatest potential for adverse impacts. They are rare events. On the average in federal waters, about 0.56 spills larger than 1,000 barrels occurs for every billion barrels produced from a platform, 0.67 spills occur per billion barrels transported by pipelines, and 1.3 spills occur per billion barrels transported by tanker.[1] The rates for platforms and pipelines have declined by about 50 percent over the last decade. Blowouts occur, on the average, about once in every 160 wells drilled in federal waters, but most of these do not cause large spills.[10] No major spill caused by a blowout has struck a platform operating in federal waters since the well-publicized Santa Barbara spill in 1969. However, MMS does not keep records of spills and blowouts that occur from platforms in state waters and neighboring foreign waters. For example, there were blowouts from gas fields in Cook Inlet, Alaska, in 1985 and 1987, neither causing a large spill. (With more than 785 wells drilled in Cook Inlet in the last 25 years, there have been six blowouts.) *Ixtoc I* blew out in Mexican waters of the Gulf of Mexico in 1979, causing the largest oil spill in history.

Under its "low case" scenario, MMS[4] calculates an 11 percent probability of a spill of 1,000 barrels or more from a platform off the Northwest coast over the life of the production field. The probability rises to 16 percent under the "high" scenario. Both of these scenarios assume transshipment of oil by tanker, which is the source of about half of the spill probability. If natural gas were produced instead of oil, there would be no risk of a major spill. (Gas would, however, create the same space-use conflicts, bottom disturbance, and discharge of muds and cuttings). The possibility of a spill on the scale of the 220,000 deadweight ton *Amoco Cadiz* disaster, the largest tanker spill in history, which dumped 1.6 million barrels off the Brittany coast, is a great deal more remote. But when these spills happen, they can cause damage that even the experts describe as catastrophic, and raise the question of whether the benefits justify the potential costs.

The Washington coast is noted for harsh offshore weather and wave conditions and for the number of ships that have been wrecked off its beaches. However, given the state of oil industry technology, weather and waves alone are not likely to cause a spill. Platforms in the Gulf of Mexico withstand hurricanes (although the crews are evacuated and the pumping is stopped). Accidents are more likely to be caused by operator error or mechanical failure, with weather conditions (such as fog or rough seas) as a contributing factor.

Perhaps the highest risk would accompany the docking of tankers or barges in the vicinity of platforms; transporting oil by tanker or barge instead of by pipeline would reduce construction impacts on the shelf, but would increase the risk of a spill. (Pipelines reduce the risk of a major spill but carry construction impacts that are virtually certain.) An analysis done in the 1970s concluded that sea conditions were not suitable for operating a monobuoy petroleum terminal along the Washington coast. If large volumes of oil were spilled from a barge or tanker, Washington's weather, wave conditions, and coastal geography and accessibility could make the containment and cleanup difficult or impossible.

No overall budget for petroleum inputs to the environment has been developed for Washington coastal waters, so it is not known how offshore petroleum production would change the budget. Based on the National Research Council's[7] global estimates, terrestrial sources and vessel traffic account for much more oil input to the oceans than offshore production or transshipment. Inputs from vessel traffic off Washington could be significant, but atmospheric and terrestrial sources in the coastal area are probably small today relative to those in the Puget Sound Basin, and will probably remain so.

Oil transshipment appears to be a major existing and potential future source of such oil input. Currently, tankers bring about 156 million barrels of oil per year into Washington—roughly three times as much as the minimum total estimated volume from offshore production over the 30-year life of the field. This figure does not account for transshipment that passes offshore, mainly from Alaska to California and other destinations. MMS[4] statistics, based on the "high case" scenario and accounting for future alongshore transshipment and imports into the states, project a 96 percent probability of one or more large spills over the life of a field off Washington, versus only 34 percent in the absence of offshore transshipment. These data suggest that offshore production off Washington/Oregon would increase measureably a significant oil spill risk arising from oil tanker traffic that already exists, and that will increase if the scenarios projected in MMS's current Five-Year Plan are realized. However, this report has not evaluated in depth the methods used by MMS to arrive at these spill probability estimates. The assumptions made in arriving at these figures were not closely examined, and independent estimates using different assumptions might alter the picture of potential spills.

Based on current knowledge, spills that travel seaward appear to be less damaging than those that contact the shore. The record of spills that traveled seaward and dispersed offshore—such as the *Ekofisk* (North Sea), *Ixtoc* (Gulf of Mexico), and *Argo Merchant* (Georges Bank) spills—shows some damage to individual organisms but no documented reductions in large-scale plant or animal populations at the community or ecosystem level. For example, no study has demonstrated a decrease in offshore commercial finfishery yield as the result of an oil spill. Such studies are fraught with logistical difficulties, however, and damage could have occurred in past spills without being observable in the vast and variable ocean environment.

An offshore spill would exclude fishing for salmon, groundfish, crab, and shrimp from an area around the slick. Whether fish, especially salmon, which are found near the surface, would avoid the spill area is not known. Depending on the season of the spill, the size, transport, and duration of the slick, and the availability of alternate fishing grounds, the displacement of fishing effort might or might not affect total catch for the year. Indian tribes restricted to certain fishing grounds would suffer losses if a spill displaced them from those grounds.

There also remains concern among experts that a worst-case-scenario oil spill in open waters could strike fish eggs, larvae, or juveniles in an important offshore rearing area at a critical time of year for fishery recruitment. There has been no thorough inventory of fish distributions, life cycles, and critical habitats (such as canyons and persistent convergence zones) on the Washington shelf, making it very difficult to evaluate the potential for damage from offshore spills. Offshore spills also could affect seabird feeding areas and mammal migration corridors, which are also poorly studied. These habitats would not be as critical as fishery nursery areas, however, for populations as a whole.

The most serious known damage from oil spills comes when they contact land. On the average, a spill would stand the greatest chance of striking the Washington coast in winter, when waves are large and the prevailing winds and near-surface currents are shoreward. These data may be adequate for analyzing mean probabilities that spills will travel in certain directions, and so for identifying possible subarea deferrals that are susceptible to oiling. But these averages are not very good at predicting where oil will travel on a given day, for use in spill response actions. For that, a mathematical model sensitive to short-term weather and current conditions must be developed, and considerable data to support the model must be collected. The biggest unknown is what would happen to oil when it got within a few miles of the coast, where current patterns have not been well studied and where small-scale irregularities in coastal configuration can have a big effect. Following the *Arco Anchorage* spill at Port Angeles in 1985, the oil followed a path along the shore that would not have been predicted from the large-scale mean current pattern in the Strait of Juan de Fuca (a deviation that was expected because scientists had studied nearshore currents).

Shoreward winds and surface currents occur in winter, and less frequently in spring, summer, and fall. In fact, tidal currents and wind directions fluctuate all year long, so that while wind and currents tend to have certain net directions, at any given time no shoreline adjacent to a spill would be risk-free. Because of the prevailing wind and current directions, the coast north of a spill site would probably be at greatest risk. The size of the vulnerable area would depend on the amount, location, type, and manner of oil spillage. In the event of a small spill, just a portion of the coast might be affected.

An upper bound on the length of coastline at risk from a major spill, derived from the *Amoco Cadiz* incident, is 190 miles—a figure that could encompass the whole Washington coast. The *Amoco Cadiz* probably offers the best model for a worst-case scenario of spill impacts on the Washington coast. The close proximity of rocky shores, exposed beaches, and sheltered estuaries along the temperate Brittany coast, with prevailing onshore winds and currents, is quite comparable to Washington's situation. Nearshore and estuarine fin- and shellfisheries (especially oysters, razor clams, and bottomfish) were seriously affected by the spill for several years. There are important differences between Washington and the site of the *Amoco Cadiz* wreck, however. The Brittany coast does not support the magnitude or density of bird and mammal populations found off Washington, nor is it a devoted wilderness/park region. It also lacks a major nearby river like the Columbia and a coastal upwelling current regime, both of which would affect the transport of oil.

The North Sea is probably the best place to examine the track record of offshore oil production under conditions similar to those of the Washington coast—temperate, stormy, heavily fished, shallow, sandy-bottom shelf waters without winter ice cover. Oil platforms operate successfully in the North Sea, and accidents there have not been caused directly by sea or weather conditions. Very little oil from the Ekofisk blowout and the recent Piper Alpha disaster was observed to make landfall, and seabird populations in the area appear to be stable in spite of heavy vessel traffic and oil production. The North Sea shelf (like that of the Gulf of Mexico), however, is much wider than the Washington shelf and has greater petroleum reserves. Since much less oil production is expected off Washington, the chance of a spill would be lower. But because production would occur much closer to shore here (most North Sea oilfields are at least 200 km offshore), and because the prevailing winds and currents are shoreward, a spill in Washington might be more likely to come ashore. In addition, seabirds in Washington congregate more densely in their colonies than North Sea birds and so would be more vulnerable to a spill making landfall.

Comparison of Vulnerability of the North and South Coasts of Washington

Most forms of development are restricted along much of the north coast of Washington by National Park, Wildlife Refuge, Wilderness, Marine Sanctuary, and tribal regulations. Accordingly, Washington State has requested that the waters roughly north of Grays Harbor be deferred from leasing. This situation raises the question of whether there are differences between the north and south coasts that merit different treatment. Is the north coast more vulnerable or more valuable than the south? Aesthetically—if one's criteria include a visual distinctiveness and harmony, the ability to evoke a memorable image, and a quality of wilderness (criteria developed in a federally sponsored study of California's coastal aesthetics)—the answer is "yes." Biologically and economically, the answer is unclear.

The north coast would probably recover more quickly from a spill because it lacks large estuaries and it has a higher proportion of rocky, high-energy shoreline. On the other hand, its inaccessibility would make cleanup and wildlife rescue very difficult. Dispersant use might be the only feasible response. Containment and cleanup gear could be stowed in harbors along the south coast, but weather conditions would probably not permit them to be deployed or to be effective. A spill on the north coast would have a more serious effect on mammals than one in the south, because it could eliminate the endangered state sea otter population. A large spill on the north coast also could decimate colonial nesting seabird populations (especially those of alcids such as auklets, which have global significance), and harm other bird and mammal species. Finally, Indian tribal shorelines would be much more susceptible to impacts of oil spills that struck the north coast.

It is not clear whether the risk to finfisheries would be greater in the north or in the south. The spawning and larval rearing areas for most groundfish and the nursery areas for north coast and Columbia River salmon are still relatively unknown. Known nursery areas for salmon and English sole, and possibly for other species, in the southern estuaries would be vulnerable. Fishermen would not be able to work where oil was on the water. The economic effect would depend greatly on where and when the oil was spilled.

A spill that entered the southern estuaries in the spring or fall could affect large numbers of migratory shorebirds feeding on their way to or from Alaska. In the spring, fall, and winter, it would affect large numbers of migrating or overwintering waterbirds, including abundant ducks, but also black brant, grebes, and loons, which have limited populations worldwide. Based on experiences elsewhere, these effects would not be permanent and would not threaten overall populations, but they would cause marked region-wide population reductions for a period of several years. Harbor seals would also be affected, but their population status state-wide seems fairly safe. Effects on all species would last well beyond the season in which the spill occurred—the soft sediments and slow flushing of the estuaries would trap oil for years, causing long-term effects on both farmed and natural oyster populations, and probably on natural populations of other shellfish, finfish, and birds. If Washington employed the same cleanup response as Brittany did to spills along its beaches—excavating the oiled intertidal zone with a bulldozer—it would cause at least as much biological damage as the oil did.

Clearly, oil in Willapa Bay could devastate the oyster industry, at least temporarily and possibly for a long time. Oysters might not be killed, but any taint of oil would make them unmarketable for a long time, and Willapa Bay oysters might acquire an image that would make them difficult to market even after the physical effects of oil wore off. A spill on the south coast could cripple other shellfisheries as well. Razor clam populations, which are still trying to recover from a chronic viral infestation, and Dungeness crab stocks, which depend on occasional good years of juvenile survival along the outer coast and in the estuaries, would be at great risk from a spill.

The image created by an oil spill might also have a serious effect on coastal tourism. Tourists would stay away from any beach that was contaminated by oil, of course, but if they got the impression that the coast was an ecological disaster area, they might also stay away from places in which no oil was present. It is difficult to evaluate whether this effect would be greater on the north or on the south coast. The south coast receives more visitors and has a greater economic stake in tourism, but alteration of the "pristine" quality of the surroundings may not have as great an affect in this area as it would on the north coast. The aesthetic offense of fouling the protected areas of the north coast may come to mind more quickly, but the actual impacts on wildlife and fisheries from oiled estuaries probably would last longer along the south coast.

Overall, from a qualitative perspective, the potential impacts on wildlife and fisheries would be appear to be different, but roughly equivalent, from large spills striking the north and south coasts. From a scientific and economic point of view, the vulnerabilities of the north and south coasts to oil spill damage seem comparable. Unless new information alters this balance, determining the relative degree of environmental protection afforded these two coastal segments constitutes a matter of value judgment.

GUIDELINES FOR FURTHER RESEARCH

The information needed to evaluate more rigorously the potential impacts of offshore oil and gas development along the Washington coast falls into two categories: data that pertain to petroleum impacts in a generic sense; and information that is specific to resources in Washington and specific aspects of potential impacts here. The generic aspects of petroleum impacts have received considerable expert review in recent years. The results of these reviews lay a foundation within which specific studies relevant to Washington can be planned.

In reviewing the effects of large-scale petroleum production in the North Sea, Clark[3] concluded that oil pollution "has a detectable but very localized impact, and that impact can be contained within acceptable limits." He further suggested that oil pollution research ". . . can no longer give useful direction to fundamental research," and stated that further research be "*ad hoc*, target-oriented, and narrow in scope." This is the sort of research conducted for environmental impact statements. Clark did concede the existence of gaps in knowledge, but considered them mostly "of trivial scientific interest" and having "no practical significance for the activities of the oil industry."

Other experts place greater weight on uncertainties in the impacts of offshore oil and gas production. The largest area of uncertainty in fates and effects of oil in the sea concerns the potential for long-term accumulation and impact of petroleum hydrocarbons under certain conditions. The most significant unanswered questions for offshore oil and gas development are those regarding the effects on ecosystems of long-term, chronic, low-level exposure resulting from discharges, spills, leaks, and disruptions caused by development and production activities. Existing knowledge of long-term impacts has been reviewed recently.[2]

Long-term effects can be studied only by conducting long-term studies before, during, and after any development. "Whatever the expected activity, baseline surveys of any inshore area prior to petroleum operations should include a thorough study of flushing rates and existing pollution levels. . . . There is concern that chronic releases in some coastal and continental shelf areas when coupled with restrictive circulation of water or mesoscale gyres could result in adverse effects over a period of years. While this concern appears to be justifiable, the current data related to this concern are not conclusive."[7] There are also considerable uncertainties about the cumulative effects of repeated spillage on nearshore biological communities, and about the community-scale (as opposed to organism-scale) nature and time course of recovery from oiling. Studies of long-term impacts are beyond the ability of the state of Washington to implement alone, but they should be kept in mind while planning studies here. Rational predevelopment studies of baseline conditions, and planning for monitoring during development, would ease the task of assessing later impacts. Pre-development studies also might suggest areas for deferral on the basis of potential vulnerability to long-term impacts.

Such accumulations may arise from both spillage and discharges of produced waters. Only a small number of laboratory studies have examined the effects of produced waters directly. More species need to be tested to confirm initial findings that produced waters are not toxic to organisms in the vicinity of a platform.[8] Also, research "definitely" is needed[8] to verify the small number of indications that chronic effects of produced waters are low. The effects of muds and cuttings are reasonably well known, and are a lower priority for targeted research. A National Research Council[6] panel concluded that further studies on drilling discharges could include acute, sublethal, and chronic bioassays that reflect actual discharge and exposure conditions; chemical composition of muds; and studies of resuspensive transport of muds. They recommended, however, that such studies would best be conducted within the broader context of accumulation and transfer of many types of materials in the marine environment, and that "extensive further research focused specifically on the fates and effects of drilling fluid discharges is not needed." These types of studies also would appear to be within the scope of MMS rather than state funding.

There has been a tremendous amount of research on effects of petroleum on organisms. Gaps still remain in the research record, however. According to NRC,[7] there is still considerable uncertainty about the effects of oil on maturation and behavior. "The evidence is accumulating that petroleum can cause gross and cellular abnormalities in marine organisms," but some of the details of this process, such as dose-response relationships and specific cause-effect relationships in mixtures of pollutants, are still poorly described.[7] The two major groups of marine biota whose physiological responses to oil have received inadequate study are the algae (phytoplankton and especially macroalgae) and larval and juvenile fish. "Embryos and larvae appear to be particularly susceptible to petroleum exposure." Likewise, "juvenile and molting stages tend to be more sensitive than the mature adult stages."[7]

Both large-scale acute and chronic spills would be expected to have substantial impacts on the surface microlayer and the fish eggs and larvae inhabiting it. There is some speculation and a few pilot studies of these possible effects, enough to demonstrate that such possible impacts deserve serious study.

The proper use of dispersants is still a matter of disagreement. Their greatest potential usefulness in Washington coastal waters would be in sensitive areas where containment or cleanup gear such as booms and skimmers could not be deployed quickly or effectively enough because of distance from ports, physical obstacles, or weather and sea conditions. An in-depth analysis would need to be conducted to identiify the trade-offs involved in dispersant use off the Washington coast, and to develop a policy for their local use. The results of a National Research Council study of dispersant use are expected in early 1989.

Current ability to predict and mitigate the potential impacts of petroleum development on Washington resources is limited by gaps in knowledge of the effects of oil and the potential responses of Washington resources. A survey of information gaps for Washington resources related to petroleum impacts is presented in Table 6.1. Many of the information gaps are geographic in nature—for example, locations of organisms, habitats, and activities—and need to be examined over a length of time, i.e. several seasons. Organization of data by geographic area would help the state to evaluate which resources may be affected by siting of facilities and by oil spills. Some of the data that could be organized geographically include geologic hazards; areas of weak currents and convergence zones; coastal and offshore critical habitats; and preferred fishing areas. These areas might be deferred from leasing, or might require special treatment such as seasonal closures on exploration or drilling. Many of these types of data already exist but need to be organized; others need to be gathered.

Another, longer-term and larger-scale information gap concerns sensitive ecological relationships that could be disrupted by petroleum activities. High on this list are life cycles and possible critical habitats of groundfish, and the nearshore distributions of juvenile salmon and shellfish. Although fishery impacts from oil spills are generally rated as low-priority research nationwide,[2] these groups are especially sensitive at key stages of their life cycles and are thought to be particularly vulnerable in nearshore or surface waters. Also high on the list of long-term data gaps are the seasonal and spatial distributions of feeding seabird species and the relationship of these distributions to oceanographic features such as convergence zones.

TABLE 6.1 INFORMATION GAPS

TOPICS NOT COVERED IN THIS ANALYSIS

- There has been extensive research on the Columbia River estuary, but little study of the potential impacts of offshore oil and gas development on it.

- MMS's estimates of oil reserves and oil spill risks off the Washington coast, and the methods used to obtain them, have not been critically evaluated in this report. Independent estimates of these quantities might give different results.

- It appears that offshore production would add slightly to the oil spill risk that is created by existing and future tanker and other vessel traffic into and past the state. However, a more thorough analysis is needed to determine the magnitude and severity of possible impacts.

PHYSICAL ENVIRONMENT INFORMATION NEEDS

- This report did not locate sufficient meteorological and air quality data for Washington coastal areas to conclude confidently that air quality impacts would be low, as MMS projects, under all development scenarios.

• The state of physical oceanographic knowledge of Washington coastal waters does not appear adequate for constructing real-time oil spill trajectory models. MMS's models may be adequate for identifying prospective area deferrals, but their results will need to be examined closely. The lack of data on variability of winds; on smaller-scale current patterns near the surface (upper 20 m), close to shore (shallower than 50 m), and in the vicinity of estuaries; and on exchange processes between estuaries and the ocean makes it very difficult to predict whether and where oil would strike shore.

BIOLOGICAL EFFECTS INFORMATION NEEDS

• The significance of impacts of seismic exploration on rockfish catches under realistic exploration and fishing conditions cannot be determined without further study. It is also uncertain whether seismic exploration causes premature release of rockfish larvae.

• The effects of seismic signals on marine mammals, which are sensitive to and dependent on sound, remain a matter of dispute.

• Good baseline and monitoring data on distribution, abundance, natality, mortality, and natural variability would be needed in order to make conclusive projections about the effects of oil spills on birds off Washington. Such data currently are lacking.

• There is inadequate knowledge of life cycles and ecology of local sea otter and harbor seal populations to determine the long-term effects of chronic low-level oil spillage on these resident mammals.

• Insufficient biological information is available on local harbor porpoise populations to evaluate their vulnerability to acute or chronic impacts of offshore oil development. There are few formal studies of effects of oil production and spills on cetaceans in general to verify indications that effects of these activities on their populations are negligible.

• The distribution and duration of the residence of juvenile salmon in the coastal nearshore zone are not known well enough to predict the probable magnitude of impacts from oil spills entering estuaries and river mouths.

• There is little understanding of the abundances or distributions of groundfish populations except when they are fished as adults, or of environmental factors that control their abundance.

• The potential magnitude of impacts of oil spills on groundfish eggs and larvae in the surface microlayer, and ultimately on fishery yield, cannot be predicted without further knowledge of their seasonal and spatial distribution and abundance.

• The sublethal effects of oil are not well known for larval, juvenile, or adult razor clams or their phytoplankton food source, nor for oysters.

• The susceptibility of planktonic larvae of crab and shrimp to oil spills, arising from both vertical and horizontal distribution and transport patterns, is not well known.

• Long-term effects of oil development on the environment—including cumulative effects of produced water and muds/cuttings discharges, and of small spills—are considered an open question, which implies the need for continued well-planned monitoring programs.

GEOGRAPHIC INFORMATION NEEDS

• Inventories of offshore convergence zones, fishery spawning areas, and reefs (where offshore platforms could pose space-use conflicts) have not been made on the Washington shelf.

• The existence and location of convergence zones, and the degree to which animals congregate around them and might be susceptible to offshore oil spills, have not been studied systematically off Washington.

• No inventory has been made of the locations of rockfish habitats that might be affected by seismic exploration on the Washington shelf.

• No inventory has been made of the locations of rocky reefs and other hard-bottom areas on the Washington shelf that might be impacted by disposal of drilling muds and cuttings.

• There has been almost no formal compilation of routinely collected catch data to analyze the distribution of preferred offshore fishing areas for salmon and groundfish.

• Not enough fine-scale inventory data on Washington coastal environments have been compiled to confidently assess the sensitivity of discrete habitats and locations.

SOCIOECONOMIC INFORMATION NEEDS

• A definitive economic comparison between oil and fisheries, tourism, and other coastal industries would be complex and has not been performed.

• Social structures of the coastal Indian tribes and the nontribal coastal communities have not been analyzed.

• Realistic unemployment (and underemployment) figures and their relationship to official unemployment figures; proportion of the chronically unemployed or underemployed employable by oil companies or contractors if production takes place; numbers of coastal residents who depend on commercial fishing and on tourism; and the nature and extent of the "underground economy" are unknown.

• The true effects of offshore development on fisheries in the Santa Barbara channel, the North Sea, and elsewhere; fishermen's allegations of significant losses from offshore petroleum operations; and the degree to which one can extrapolate to Washington from other communities' experiences with major offshore developments have not been objectively verified or analyzed.

• Estimates of tax revenues that would flow to state and local governments; of infrastructure needs and expenses depending on the location and nature of a petroleum find; of training needed to maximize local employment have not been made.

• Strategies for maximizing economic benefits and minimizing costs, and mechanisms for spreading benefits over the largest possible coastal area, have not been developed.

- Ways in which the offshore petroleum industry might affect the marketing of the coast as location for tourism or business, the availability of capital in coastal communities, and the available space in coastal ports have not been analyzed.

OVERVIEW & INTEGRATION

- Information is lacking to support development of a system of thought (conceptual framework) for organizing how natural and socioeconomic resource interests interact and for sorting out priorities.

- A risk analysis of occurrence of undesirable events, and severity of consequences of those events, integrating natural and socioeconomic resource risks, has not been performed.

SUMMATION

There are limitations on how conclusive scientific answers can be to such complex questions as oil and gas impacts. One major limitation is the difficulty of observing possible impacts in many situations. Impacts often amount to subtle alterations in physiology or behavior, or relatively small changes in population numbers of birds, fish, or other animals. There are many logistical problems in collecting such data: animals move about, they are obscured by weather and water, they are distributed in clumps over a wide geographic area, and they do not all behave alike.

Science is also limited by the funds and time provided. Large amounts of data are needed to measure accurately natural population numbers, which vary tremendously, and natural mortality rates, which are consistently high. Great effort also is required to detect with statistical confidence small changes amidst that variability. And finally, cause-effect relationships are elusive. Sometimes no amount of data can demonstrate that observed changes are caused by oil development rather than by simple natural variability or by impacts of other human activities. In practice, impacts must be large or distinctive before they can conclusively be linked to a specific cause.

These limitations dictate that science cannot answer all the questions about potential impacts of offshore oil and gas development. Statistics can tell how frequently accidents have occurred in the past, but they cannot predict exactly whether, when, or how they may happen again. And after the scientific research that time and funds permit is complete, uncertainty will still remain about the impacts that may ensue if an accident occurs. Decisions will have to be made despite these uncertainties.

In part those decisions will rest on an evaluation of probabilities that impacts will occur and projections of their magnitude. There will at least be some numbers, however speculative, to guide decision makers in these matters. But in large measure decisions will ultimately rest on matters that cannot be expressed as numbers—that is, on matters of values.

Do all the scientific uncertainties, coupled with the potential negative impacts, mean that, economically, the benefits are not worth the risks? Not necessarily. Although no one, including MMS, knows how much oil really will be found, the potential benefits of oil development can be expressed in very large numbers. The total gross value, even at the depressed oil prices of November, 1988, before OPEC agreed to try propping up prices, of the petroleum that MMS[5] projects will be found off Washington/Oregon is around $800 million. That figure, which covers the entire 30- to 35-year life of the field, takes into account an 80 percent chance of finding nothing. If oil and gas actually were found under MMS's low case scenario, the estimates of gross value would increase to $3.2 billion. Under MMS's high case scenario, they would be $9.6 billion. When oil prices rise (as they certainly will), those estimates will rise still along with them.

The value of fisheries can also be expressed in large numbers. By one estimate, the total 1987 ex-vessel value of coastal salmon, groundfish, halibut and shrimp catches in Washington and Oregon was roughly $122 million.[9] Over 30 years, assuming steady catch levels and prices, the cumulative value of these fisheries would be about $3.7 billion. Adding in crab and oyster harvests at current values increases the total to over $4 billion. Those are dollars that stay in the states, rather than being spread over the oil industry and the nation as a whole.

There is no way to eliminate all additional risk to coastal resources without simply forgoing *all* oil development. One gets either the entire 30-year benefit or none of it. On the other hand, neither history nor science suggests that an *entire* 30-year revenue stream from fishing or tourism or any other coastal industry would be at risk from oil development. If a major spill occurred, precedent does not indicate that the total revenue from either industry would be lost for even one year, or that any part of either industry would be lost permanently. For example, the 1969 Santa Barbara spill had no documented long-term effect on commercial fisheries in the Santa Barbara Channel. No significant long-term effects have been observed from any other spill, either—although realistically, it is difficult, in Santa Barbara or anywhere else, to distinguish the effects of a spill from natural variations in fish populations and the impacts of other human activities.

It is not enough, however, to say that 30 years' oil revenue would be a lot of money, and that 30 years' catch value of the coastal fisheries would not be at risk. A definitive economic comparison between oil and fisheries, tourism, and other coastal industries would be complex and has not been performed. How would the coastal fishing and tourism industries and the offshore oil industry compare under various plausible scenarios in terms of net present value? To whom would the economic benefits of oil production flow? How much of the net revenue would stay in the state? How much would stay in the coastal communities? How would the indirect economic benefits of oil production compare with those of the current coastal industries? What would be offshore development's monetary cost to coastal communities and to the state? What might be the total monetary cost of a major spill?

And what might be the other costs? It is easy to put a dollar value on, say, the Willapa Bay oyster industry, the temporary loss of which may constitute the greatest single plausible risk. In 1986, the gross value of the Willapa Bay oyster harvest was almost $5 million. The industry should not be seen in strictly economic terms, however. Like the salmon fishery, it has a cultural value, an historical value. Like all the finfisheries and the crab fishery, it represents a way of life. It has been there for 140 years, and with any luck, it will still be there long after any offshore oil platform has been disassembled. It is hard to measure such things in dollars and cents.

It is even harder to measure some of the other resources of the coast. What value does one place on sea otters? On shorebirds? On the "look and feel" or even the abstract concept of wilderness? One can add up the number of people who visit the beaches each year and calculate what they contribute to the coastal economy, but those calculations are largely beside the point. What matters is not just the number of people who experience the wilderness beaches but also the quality of the experience. The value is aesthetic, perhaps spiritual. It can be important not only to people who visit the beaches but to people who have never seen them, who like to know they are there, unspoiled, for the ages.

All the big questions, as Washington contemplates offshore development, are questions of values. Could the damage caused by a major oil spill be widespread, long-lasting, even catastrophic? Yes, it could be, at least for several species of birds, mammals, and shellfish. Is there much risk of such a spill fouling the wilderness beaches or the estuaries or another part of the coast? Statistically, the answer is "not much." Is the risk worth taking? That is not a question that statistics can answer definitely. And so it goes. This does not mean that the state should avoid tackling the narrower, more pragmatic issues. It should press ahead now with the task of data gathering and analysis. But it should also realize that while the natural sciences and socioeconomics can establish a framework and an information base for discussion of the big questions, they cannot provide all the answers.

CHAPTER 6 REFERENCES

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Appendices

ACRONYMS AND ABBREVIATIONS

API	American Petroleum Institute
COE	U.S. Army Corps of Engineers
CPUE	catch per unit of fishing effort
CREST	Columbia River Estuary Study Task Force
DCD	Washington Department of Community Development
DOC	U.S. Department of Commerce
EEZ	Exclusive Economic Zone
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
INPFC	International North Pacific Fisheries Commission
IPHC	International Pacific Halibut Commission
LC50	concentration of a toxin that is lethal to 50% of organisms
LNG	liquefied natural gas
MMS	Minerals Management Service
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
NRC	National Research Council
NWIFC	Northwest Indian Fisheries Commission
OCS	outer continental shelf
ODFW	Oregon Department of Fish and Wildlife
OPEC	Organization of Petroleum Exporting Countries
ORAP	Ocean Resources Assessment Program
OSU	Oregon State University

Pac FIN	Pacific Fisheries Information Network
PAH	polycyclic aromatic hydrocarbons
PFMC	Pacific Fisheries Management Council
PMFC	Pacific Marine Fisheries Commission
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
USCG	U.S. Coast Guard
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UW	University of Washington
WDF	Washington Department of Fisheries
WDNR	Washington Department of Natural Resources
WDOE	Washington Department of Ecology
WDW	Washington Department of Wildlife
WSG	Washington Sea Grant

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