THE OREGON OCEANBOOK

THE OREGON
OCEANBOOK

AN INTRODUCTION TO THE PACIFIC OCEAN OFF OREGON
INCLUDING ITS PHYSICAL SETTING
AND
LIVING MARINE RESOURCES

BY
Tish Parmenter
Robert Bailey

STATE OF OREGON
Victor Atiyeh, Governor

DEPARTMENT OF LAND CONSERVATION AND DEVELOPMENT
James F. Ross, Director

With special assistance from
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Robert Bailey is a native of Oregon's Coos County and grew up within earshot of the Pacific Ocean in North Bend. He received a BSc. in Earth Science from Portland State University in 1968. He has taught junior high earth science, helped establish the land-use planning program in Coos County, participated in development of a citizen involvement program using portable video for Southwestern Oregon Community College, roamed eastern Oregon as field representative for the Department of Land Conservation and Development, and worked for three years as senior planner for a Portland architectural firm. Since 1982, Bailey has been Outer Continental Shelf Coordinator for the Oregon Department of Land Conservation and Development.

THE OREGON OCEANBOOK

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DEDICATION

The Oregon *Oceanbook* is dedicated to the many marine scientists who, over the years, have worked to gather, record, and interpret clues to the mysteries of the ocean. Without their work, this book would not be possible. The *Oceanbook* is also dedicated to the people of Oregon, and elsewhere, whose tax dollars supported this marine research and the preparation of this book. In this sense, the *Oceanbook* is a return on that investment.

INTRODUCTION

All Oregonians are affected by the Pacific Ocean. Our landscape, whether that of eastern or western Oregon, is a legacy of its relentless forces. The mild, wet weather which nurtures our rich valleys and forested mountain slopes is generated far at sea. We live by the ocean or we visit often. We delight in a walk on a sandy beach; the sight and sound of churning surf refresh our spirits. We pause on a high headland for a sweeping view of the ocean and perhaps, beneath the curve of the horizon, a glimpse of the spout of a whale. Visitors tell us how fortunate we are to live here. We agree.

Yet, for all that we enjoy and find familiar in the ocean, it remains for most of us a mystery. Beneath its wave-tossed surface is a world we do not know. Beyond the horizon is more ocean, deeper and different from the green water that surges in white foam skirts against the dark rocks of the coast. And although crabs and salmon, seals and gulls are well-known representatives of the life which moves within this watery environment, plankton are only vaguely familiar.

More than a visual backdrop, the ocean has been a traditional part of life for Oregonians. Whether by frail sailing ships, bringing settlers and supplies to an emerging Oregon Territory, or by huge, modern ships, carrying tons of wood chips to the Far East, the ocean has been used for transportation. Fishermen, setting hooks and casting nets, have harvested from the teeming fish stocks not far offshore and brought this catch ashore at numerous ports along our coast.

Society's increasing demand for energy, minerals, and food, coupled with growing technological capability, means that these traditional uses of Oregon's ocean may be joined by new ones. Several of them, chiefly petroleum and mineral extraction, have the potential to adversely affect the ocean and coastal environment. In turn, our increasing sensitivity to potential consequences of ocean development has created a need to better understand the ocean, its capabilities, and its limitations.

Oregonians have long been concerned with the protection of ocean resources. This concern is reflected in Oregon's land-use program as Goal 19, Ocean Resources. This goal gives priority to protection and use of long-term renewable resources over the extraction and use of nonrenewable resources. The Ocean Resources goal requires that development of ocean resources be based on scientific information and understanding of the impacts of proposed actions.

WHY WE WROTE THE BOOK

Until now, no available publication has integrated fundamental oceanographic concepts with basic research from the Pacific Ocean off the coast of Oregon. Researchers have written hundreds of scientific papers on numerous aspects of Oregon's ocean representing countless hours of field work, but to most of us, such papers are neither readily accessible nor easily understood. Likewise, a number of good introductory textbooks on marine science are available, but they lack specific information for the Oregon region. The *Oceanbook* brings together both basic oceanography and research data to describe and characterize Oregon's ocean for the interested public.

SCOPE OF THE BOOK

The *Oceanbook* focuses on the ocean environment from the coastline to roughly 200 miles offshore, the limit of U.S. jurisdiction, and from Cape Mendocino, California, to Vancouver Island, British Columbia. We excluded the intertidal area of interest to low-tide beachcombers from the *Oceanbook* because this area is well covered in other publications.

We have organized the *Oceanbook* to reflect the structure of the marine ecosystem. After a brief introduction to Oregon's marine ecology, we include a discussion of the physical setting within which all marine life exists. These living marine resources vary from small and simple floating plants to increasingly large and more complex animals which swim freely through the ocean. We conclude with birds and mammals, many of which depart the sea to the shore for a portion of their lives.

Virtually all topics of the *Oceanbook* beg for expansion, and so we have attempted to exercise care in deciding what to include and what to leave out. Moreover, there is much important information yet to be gathered to improve understanding. To try to satisfy the unending need to know, the *Oceanbook* includes further references on particular topics at the end of each chapter.

SOURCES

In writing the *Oceanbook* we drew from a wide variety of sources, including technical journals, science magazines, and textbooks. In addition, publications similar to the *Oceanbook* but covering the adjacent regions of British Columbia, Puget Sound, and California provided useful information. Of most importance, perhaps, were the invaluable contributions of many individuals—scientists, resource managers, and scholars—who cast a critical eye over the manuscript, added up-to-date data, and provided much-needed encouragement.

ABOUT MEASUREMENTS

One of the more difficult decisions in preparing the *Oceanbook* was whether to use metric or English units of measure. We chose to use metric units because virtually all scientific sampling uses this system. However, we have included units in the more familiar English system where we felt clarification would aid understanding. Those who wish to convert from metric to English units are referred to the conversion table of weights and measures in the Appendix.

A FINAL WORD

Preparation of the *Oceanbook* has enriched our understanding of the ocean's complexity and has impressed upon us that we are indeed part of a web of life that begins in the ocean. Assembling and condensing the volumes of information, we have come to appreciate the detail in which the ocean has been studied. Although we have been unable to include all of this fascinating material, we hope that the *Oceanbook* will be beneficial as well as enjoyable.

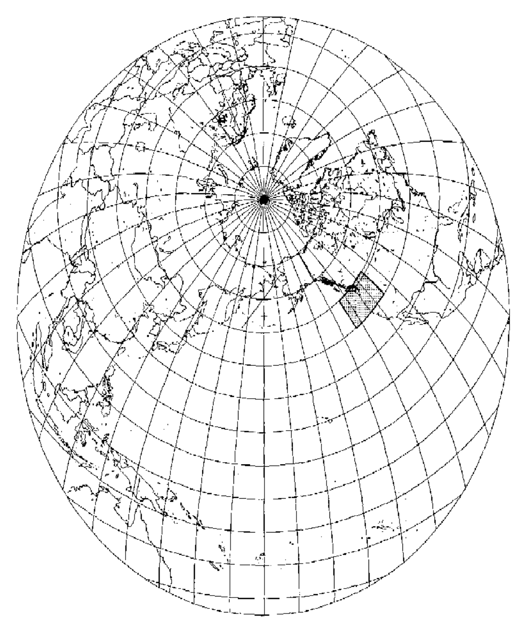


Figure 1: Oregon's Ocean in Perspective

This drawing of a satellite view of the Pacific Ocean places the Oregon ocean into regional perspective. The small, shaded rectangular area on the east side of the Pacific Ocean is the same area shown enlarged on the map in Chapter Two, "Geology: the Rocks."

CHAPTER ONE

MARINE ECOLOGY

Life and The Environment

INTRODUCTION

Beneath the wave-tossed surface of Oregon's ocean lies a rich and varied realm of marine life. In this undersea world, no organism exists in isolation; each is linked to others and to the physical elements of the sea through complex interactions. Though the details of these interactions vary from place to place within the ocean, the interactions of all organisms in all natural settings have two consequences: first, a flow of energy from autotrophs, plants which make their own food through photosynthesis, to heterotrophs, animals which are unable to manufacture their own food and must rely on autotrophs or heterotrophs; second, a cycle of inorganic materials from the nonliving environment through the bodies of living creatures and back again. Such a combination of living and nonliving elements through which energy flows and materials recycle is known as an ecosystem.

Marine ecosystems are biologically complex and respond to many physical variations in the environment. Daily and seasonal changes in sunlight filtering through the top layers of the ocean surface determine the input of energy to the ecosystem. Weather patterns, changeable with the seasons, affect ocean production in two major ways. Winter rainfall and spring snowmelt erode continental soils, carrying inorganic nutrients into coastal streams and the Columbia River, which then discharge into the coastal ocean. Summer winds produce upwelling conditions which bring nutrients to the surface at a time when light and temperature are most advantageous for growth. Other physical factors, including water depth, distance from shore, and the nature of sediments on the ocean bottom, further influence variations in marine life.

In turn, the life processes of marine plants and animals can influence the physical properties of the sea. The concentration of dissolved gases, such as oxygen and carbon dioxide, is determined in large part by the metabolism of microscopic plants near the ocean's suface. This essential biologic activity of plants removes nutrients from the water and incorporates them into living tissue. Nutrients are then returned to the environment as organisms die and decay. Thus, the marine ecosystem is a product of the interaction between marine plants and animals and their environment (see Figure 2).

Although the sea is a watery environment, requirements for life in the sea are the same as those on land: energy, living space, and the chemical building blocks needed for growth and reproduction. And as with life on land, plants and animals in the sea vary greatly in size. The range in size of marine life is impressive: from microscopic one-celled plants and bacteria to the great blue whale, perhaps the largest animal ever to live on earth. Equally impressive is the wide variety of form and function which enables marine organisms to occupy diverse niches in the ocean environment.

Light, temperature, salinity, bottom sediments, and other characteristics of the ocean vary from one location to another. Unique combinations of these conditions create specific environmental opportunities known as habitat. Within any particular habitat is a community of organisms well-suited to exploit the food and shelter there.

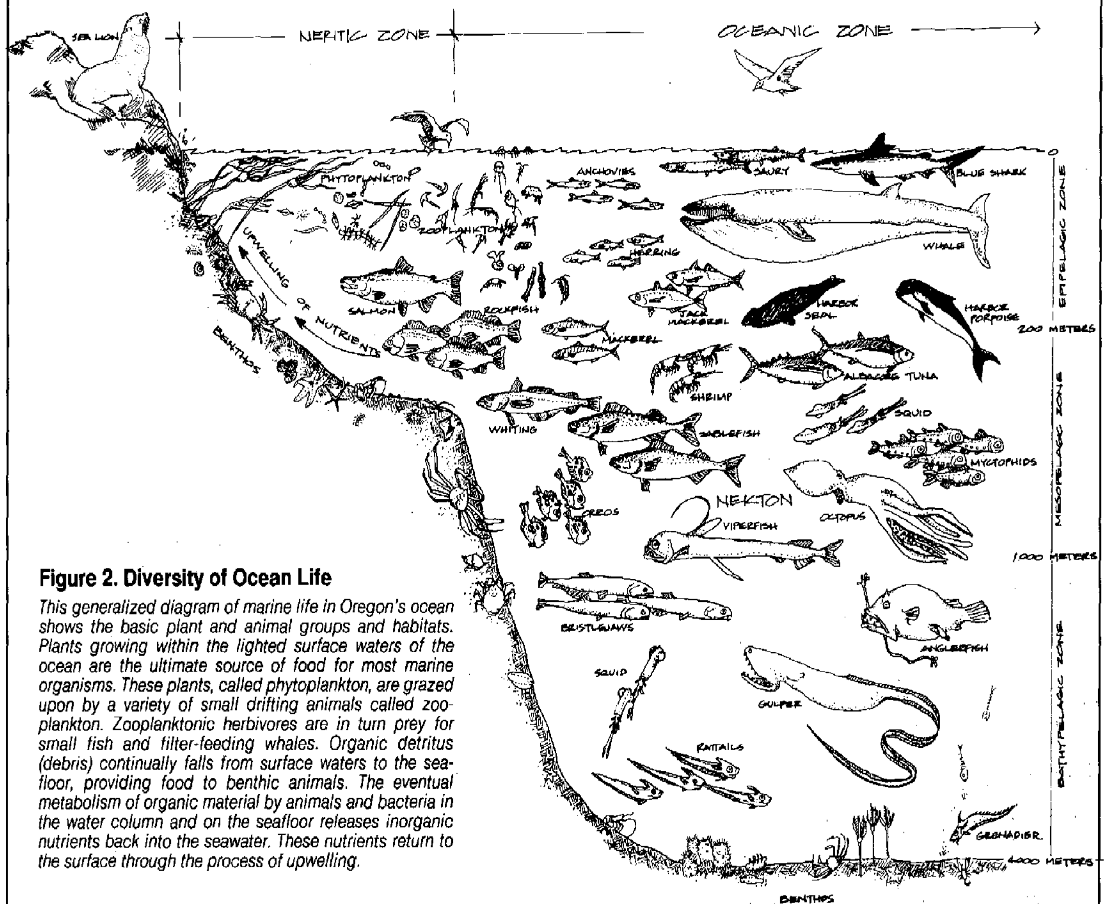


Figure 2. Diversity of Ocean Life

This generalized diagram of marine life in Oregon's ocean shows the basic plant and animal groups and habitats. Plants growing within the lighted surface waters of the ocean are the ultimate source of food for most marine organisms. These plants, called phytoplankton, are grazed upon by a variety of small drifting animals called zooplankton. Zooplanktonic herbivores are in turn prey for small fish and filter-feeding whales. Organic detritus (debris) continually falls from surface waters to the seafloor, providing food to benthic animals. The eventual metabolism of organic material by animals and bacteria in the water column and on the seafloor releases inorganic nutrients back into the seawater. These nutrients return to the surface through the process of upwelling.

Marine groups shown in this figure:

- **Phytoplankton:** *small free-floating plants (primary producers—first trophic level)*
- **Zooplankton:** *small, free-floating animals (mainly herbivores—second trophic level)*
- **Nekton:** *organisms large enough to effectively swim against currents, i.e., fish, squid, mammals, and birds (typically carnivores—higher trophic levels)*
- **Benthic:** *bottom-dwelling animals and plants (all trophic levels)*

Habitats shown in this figure:

- **Pelagic:** *ocean environment and the animals that live there, i.e., plankton and nekton*
  - **Epipelagic:** *upper 200 meters*
  - **Mesopelagic:** *between 200 and 1,000 meters*
  - **Bathypelagic:** *between 1,000 and 4,000 meters*
  - **Neritic:** *the environment over the continental shelf, also referred to as open ocean*
- **Oceanic:** *the environment beyond the continental shelf, also referred to as open ocean*
- **Benthic:** *bottom sediments and the overlying portion of water within 1 meter of the bottom*

CLASSIFICATION OF MARINE LIFE

One way oceanographers classify marine life is by the habitat in which an organism lives. The two broadest categories of habitat are the pelagic (water-dwelling) environment and benthic (bottom-dwelling) environment. The pelagic region, where most marine life exists, is divided horizontally into a neritic province, from shore to the edge of the continental shelf, and an oceanic province beyond the shelf break (see Figure 2). The pelagic region is also categorized vertically into an upper, euphotic layer, where there is sufficient light for plant growth (usually greater than one percent of the incoming solar radiation), and a lower, aphotic layer where there is not. The boundary between these two layers varies daily and seasonally according to the angle of the sun's incoming rays and to the amount of turbidity in the water. In the turbid and highly productive waters of the midshelf off Oregon, light may penetrate to 30 meters (though it varies from 15 to 35 meters, depending on location over the shelf) and to 60 meters in the less productive, less turbid waters over the continental slope (5).

Pelagic Environment

Although pelagic organisms exhibit a variety of life modes, scientists group them into two broad categories. Drifters are termed plankton and active swimmers are called nekton. Drifting plankton may be either plants or animals. Plankton vary in size from ultraminute bacteria to large jellyfish. They live in the euphotic zone as free-floaters unable to move faster than the speed of the current. Nekton include invertebrates (animals without backbones) and vertebrates (animals with backbones) such as fish, seabirds, and mammals. Because of their ability to swim, they range throughout the depths of the ocean.

Phytoplankton are microscopic, free-floating plants which provide the nutritional base for most of the sea's vast array of life (see "Plankton: the Drifters"). They are the most numerous of all organisms in the ocean. Unlike higher plant life, which can contain billions of cells, each phytoplankton, such as a diatom, consists of only a single cell. Though the cells are sometimes linked together to form chains, each individual cell is self-sufficient; the chains are colonies, not organisms.

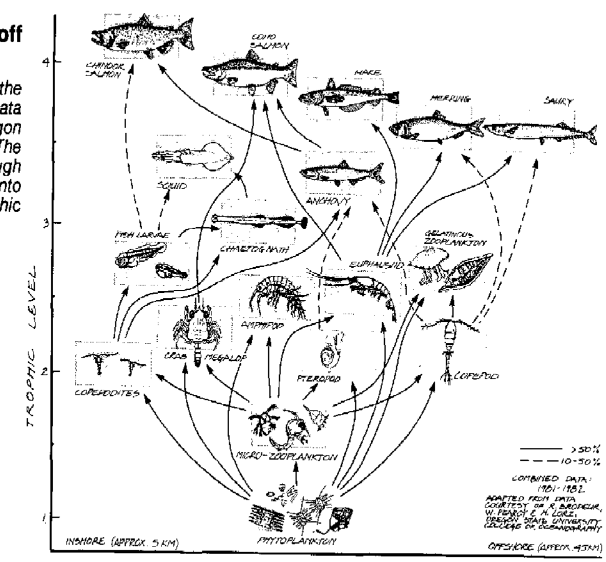
Zooplankton, planktonic animals, include many major animal groups (see "Plankton: the Drifters"). Zooplankton convert plant material to animal tissue and are a crucial food for larger animals. The young of many species, such as fish, exist as zooplankton until they grow large enough to swim independently or until, as is true for clams, they emerge as adults living on the bottom. Organisms that remain plankton all their lives, copepods for instance, are known as holoplankton; animals that are planktonic temporarily, such as most fish species, are called macroplankton. The planktonic phase of an organism's life history allows for widespread dispersal to suitable environments by ocean currents.

Many zooplankton are restricted to the surface euphotic zone since they live by grazing on light-dependent phytoplankton. However, some can swim. Many groups of zooplankton, including copepods and euphausiids, migrate from 100 to 200 meters to the surface at night and move back down during the day.

Nekton are a diverse group of free-swimming animals, both with and without backbones, which range throughout the pelagic zone (see "Nekton: the Swimmers"). Although nekton generally are widely dispersed, some nekton are restricted to certain depths or geographical locations. The limitations are not necessarily physiological. They can be environmental boundaries such as changes in temperature, salt content, oxygen, and nutrients.

Figure 3. Pelagic Food Web for Coastal Waters off Oregon

A representative food web for a number of pelagic species off the Oregon coast. This food web has been simplified from data collected during the summers of 1981 and 1982 by the Oregon State University Early Life History of Salmon Project (1981-83). The web shows how food energy enters the marine ecosystem through phytoplankton at the lowest trophic level and is accumulated into increasingly large and more complex organisms at higher trophic levels. Drawings are not to scale.



Off Oregon, the nekton include two important groups, the invertebrate squids and the vertebrate fish. As a group, the fish nekton make a major contribution to Oregon's recreational and commercial fish catches, both in pounds landed and in dollar value.

Marine mammals and sea birds are often included in the nekton category since both spend all or much of their lives at sea (see "Marine Birds and Mammals: Residents and Visitors"). But some marine mammals, like seals and sea lions, must come ashore to give birth. Others, like the great whales, reproduce in the ocean. Sea birds also use terrestrial sites for nesting and breeding. Both groups have evolved a diversity of body shapes and feeding apparatus to pursue and capture their prey. Most of the adult species of this group are ultimate consumers in the marine environment.

Benthic Environment

Benthic organisms are the bottom-dwelling plants and animals of the ocean (see "Benthos: the Seafloor"). They exhibit a variety of different life modes: sessile (attached to the bottom), burrowing, and creeping. The distinction between a pelagic and a benthic existence is not always clear since some adult demersal organisms (nekton living on or near the sea bottom), such as shrimp and rattail fish, regularly move from the seafloor into the water column for food. The benthic habitat is extremely diverse with a variety of niches on the seafloor. There, different habitat opportunities abound, ranging from hard, exposed rock to soft, unconsolidated sediment. Variations in particle size and organic content of the soft sediments create a multitude of different sites for specialized benthic development.

In the unconsolidated sediments, infauna, such as worms and clams, burrow or otherwise live below the surface. These organisms are important in reworking the soft sediments, mixing deposits of mud and sand into combinations of the two. Epifauna, such as starfish, crabs, and sponges, live on the surface of all bottom material. Most of the ocean bottom lies in total darkness. Only in the ocean's thin surface layer is sunlight sufficient for the synthesis of organic material that fuels and builds life in the sea. Thus, benthic animals are dependent upon a "rain" of dead or decaying plant and animal material falling from above as a source of food. (Animals living around deep-sea hydrothermal vents are an exception to this generalization. This community derives its energy from the vent fluids rather than from the sun.) Food items reaching the benthos are varied; they include organic material absorbed in tiny sediment particles and an occasional large carcass of a whale or fish.

TROPHIC STRUCTURE

The marine ecosystem, like all biological systems, is driven by energy. Energy moves through the ecosystem along trophic pathways—the means by which more complex organisms of higher trophic levels obtain nutrition from simpler organisms of lower trophic levels.

In the first trophic level, plants convert the sun's energy into simple inorganic elements (carbon, hydrogen, oxygen, and nitrogen) dissolved in the sea into energy-rich, complex, organic compounds which the plants use to carry out their life processes. In the second trophic level, herbivores (plant-eating animals) consume this flourishing plant biomass to sustain their life functions. In the third trophic level, other animals consume the herbivores. This consumption of a lower trophic level by organisms at a higher, more complex level continues up the trophic ladder until the highest order of carnivores, organisms that consume flesh, is reached. Detrivores, animals that take advantage of waste in the system, eat particles of decaying plant or animal matter not consumed by herbivores or carnivores.

A trophic pathway is not a single chain of linear interactions, but a web of several interlocking feeding sequences (see Figure 3). In practice it is difficult to categorize species according to trophic level. Some species are ominivores, feeding on several different trophic levels during a single life stage. For example, the northern anchovy feed on both phytoplankton and zooplankton. Trophic position can also change throughout the life cycle of an animal: larval fish may feed on phytoplankton, but juvenile fish of the same species probably consume zooplankton. Some prey upon species belonging in their own trophic level. For example, starfish larvae are preyed upon by other zooplankton, including certain larval stages of the shorecrab.

No energy transformation is 100 percent efficient. Energy is lost at each transition between trophic levels. For instance, in areas of coastal upwelling, of the total amount of energy captured by plants, approximately 15 percent shows up as increased growth and reproduction of herbivores. Only about 15 percent of the energy consumed in herbivores emerges as new growth and reproduction in primary carnivores, and so on (4). Energy not used for new growth and reproduction is lost from the ecosystem in a variety of ways: as unassimilated food matter (fecal pellets) which sinks to the seafloor; as metabolic processes, such as respiration, which releases energy as waste products; and as non-predatory mortality. Such energy losses lead to a decrease in the number of individuals in successively higher trophic levels that can be supported by the trophic level below.

NUTRIENT CYCLING

Whereas energy flows from one trophic level to the next, being converted to organic matter in ever-decreasing quantities, inorganic nutrients recycle through the marine ecosystem. Many simple inorganic elements, the building blocks of a biological superstructure, abound in the sea. Some elements, however, are available in marginal quantities, and their scarceness could become a limiting factor to the growth of marine plants. This is particularly true of nitrogen off the Oregon coast.

Nutrients are taken up by phytoplankton at the surface during photosynthesis and incorporated into organic compounds (proteins), first in plants and then in animal tissue. Plant nutrients not converted into animal tissue are returned to seawater as both particulate and dissolved organic matter.

Particulates, known collectively as detritus, include uneaten food, fecal pellets, and plant and animal fragments. Marine bacteria decompose these particles as they slowly sink to the ocean bottom. Thus, the bacteria return inorganic elements to the ocean in a form again usable by plants. Other organisms, such as single-celled animals, may also be important, but little is known about them. Some of the detrital material reaches the seafloor where it becomes a source of food for scavengers and other bottom-dwelling creatures.

Dissolved organic material, a much greater proportion of the organic soup, is produced during animal metabolism. Zooplankton and fish can excrete highly concentrated organic elements which are of direct use by marine plants and bacteria.

As plants grow, they continually remove nutrients from the surrounding water. To sustain growth, nutrients must be resupplied to the surface waters. Since detrital particles sink, nutrients are released back into the ocean beyond the reach of the plants which need them. Several mechanisms for replenishing the surface waters with nutrients are at work off the Oregon coast, including wind mixing, upwelling, and coastal runoff (see "Oceanography: the Water").

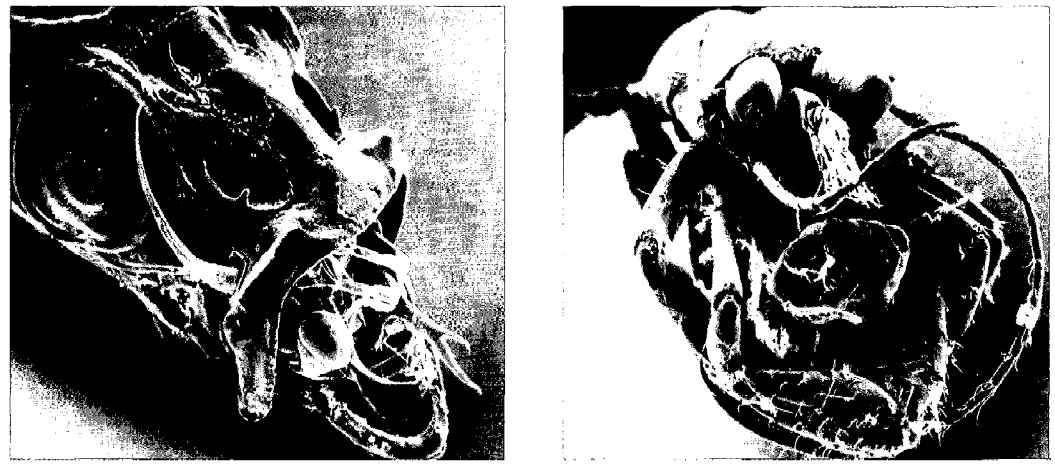


Figure 4. Electron Micrographs Reveal Microscopic Hunter and Prey

These photographs, taken with an electron microscope, provide marine scientists with a look at the microscopic world of hunter and prey. At left, a surf smelt larvae (approximately 100 days old) has attempted to eat a crab zoea. The long dorsal spine of the zoea has pierced the upper lip of the surf smelt larvae just below its developing nostril. The eye of the smelt larvae is the large round feature at the left of the photograph behind the tip of the protruding spine (55x). At right, the microscope dramatically magnifies hunter and prey approximately 600 times life size. A larval hermit crab has captured a tiny copepod. Had the larval hermit crab not been captured by scientists, it too may have become prey for a larger animal. (Electron micrographs by Carla Stehr, NMFS, NOAA.)

CONTRASTING THE COASTAL AND OCEANIC ECOSYSTEM

Several important differences exist between Oregon's continental shelf ecosystem and that of the deepwater oceanic region. On average, because of coastal runoff and updwelling, the flux of nutrients into surface waters is greater over the shelf than that into surface waters of the deep sea. Therefore, plant production is higher over the shelf than it is in the deeper waters beyond. The large quantity of phytoplankton produced in coastal regions, approximately three times that farther offshore (4), also means that a greater abundance of animals can be maintained over the continental shelf than in deeper water.

There are usually fewer trophic levels in the nearshore than in the open ocean environment. In the high-nutrient, turbulent environment of the coastal region, phytoplankton cells tend to be large or form colonies of several individual cells which are in turn eaten by large herbivores. These large herbivores serve as prey for large carnivorous fish such as salmon.

In contrast, the low-nutrient input of the stable, open-ocean environment tends to favor the growth of much smaller phytoplankton. Furthermore, herbivores are usually smaller, although large herbivores like the filter-feeding whales often feed in these waters. Several more trophic levels might be required before prey items reach sufficient size for larger fish to effectively forage for food. Thus, the larger the plant cells at the bottom of the food chain, the fewer the trophic levels required to convert the organic matter to a useful form (4).

The number of trophic levels present can have important consequences. The yield of large commercial fish species may be increased when there are fewer trophic links. In other words, the sun's energy is converted more efficiently into large fish when there are few trophic levels because of the great reduction in energy conversion with each succeeding trophic step. This increased yield in the coastal zone, coupled with the economic hardship of fishing far out to sea, explains why most commercial fisheries are located near the coast (3).

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Note: References are cited in text by number. References marked with an asterisk (*) are recommended because they are comprehensive, easily understood and/or accessible.

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CHAPTER TWO

GEOLOGY

The Rocks

INTRODUCTION

The spectacular Oregon coastline of today is the result of geological and oceanographic processes, some of which have occurred over a long period of time and on a vast scale. The slow, relentless movements of the earth's crust or the gradual rise and fall of sea level are neither seen nor felt but nonetheless play a fundamental role in creating the unique features and resources of the Oregon coast. Other forces act on a daily or seasonal basis and result in changes that are evident in a short time. Wind and rain, rivers and surf, summer sun and winter storms all continue to refine, remake, and rework coastal features.

Although some 400 miles long, the Oregon coast is but a very short segment of the Pacific coast of North America. Thus, many of the factors affecting the development of Oregon's coastline must be seen in the larger context of the development of the present Pacific coastline and of the formation of all of the Earth's continents.

This chapter of the *Oceanbook* first introduces plate tectonics, the theory that explains the slow, massive shift in continental and oceanic outlines over time and how this shift has formed the Pacific Northwest. The chapter also reports an exciting discovery and the pioneering research taking place deep on the ocean bottom off the Oregon coast. Finally, it takes a look at the features and processes of Oregon's nearshore ocean, with comments on economically valuable resources of Oregon's offshore geologic environment.

PLATE TECTONICS — A REVOLUTION IN EARTH SCIENCE

One of the most significant ideas to emerge in the earth sciences began to take shape during the 1600s when geographers observed that the coastlines on either side of the Atlantic were a remarkably good fit. Perhaps, it was thought, the two continents had been joined together at some time in the past. Biological evidence began to accumulate in the late nineteenth and early twentieth centuries to support this hypothesis of continental connection. It was not until the 1960s, however, that geological evidence gathered through more sophisticated measuring and mapping techniques confirmed that the dynamic interactions which occur between the earth's inner and outer layers provide a possible explanation for the lateral and vertical motions of the earth's surface (18).

This new evidence revealed that the earth's surface is merely a skin of crustal material lying upon thin, rigid blocks embedded in the lithosphere, the layer from which the blocks are made. These blocks or plates "float" upon the asthenosphere, a hot, soft, subsurface layer of the earth. Deep, internal heat currents, generated by radioactive decay, drive the blocks slowly across the face of the earth. Below the asthenosphere, semimolten material is layered around what is thought to be a solid inner core (see Figure 5).

The movement and interaction of these plates is called plate tectonics. Seven major plates and several minor plates have been identified (see Figure 6). Two hundred million years ago the positions of the continents and the shape of the ocean basins that lay between them were significantly different than they are today. Similarly, 50 million years from now, these relationships will again be quite different. For instance, Baja California will move north to a position off the west coast of the United States, and the Pacific Ocean basin will be much smaller than it is today. Thus, any map of the present position of the continents is only a snapshot.

The earth's plates interact in three fundamental ways: they diverge, converge, or slide past each other in a continual cycle of destruction and renewal (13). Tectonic activity takes place primarily at the edges of plates; the centers of plates are relatively stable. Plates diverge along a spreading ridge, and new rock material is added to a plate. Where plates converge, ocean crust material, originally created at the spreading ridge, is consumed in the earth as one plate overrides another. Plates slide past each other where the rate of spreading within a single plate varies or where two plates move in opposite directions along a common edge.

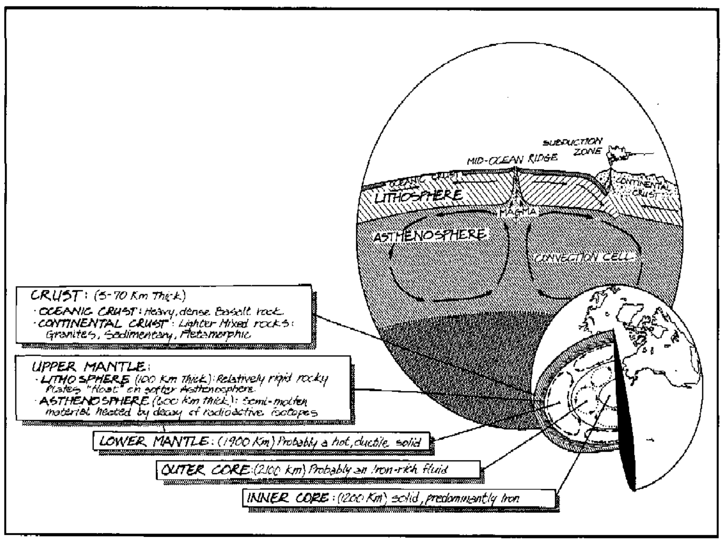


Figure 5. Earth's Internal Structure

The earth's internal structure is composed of several concentric layers. Scientists study how seismic (earthquake) waves change as they pass through these layers to determine their characteristics and thickness. Composition of the layers is still a subject of study and debate.

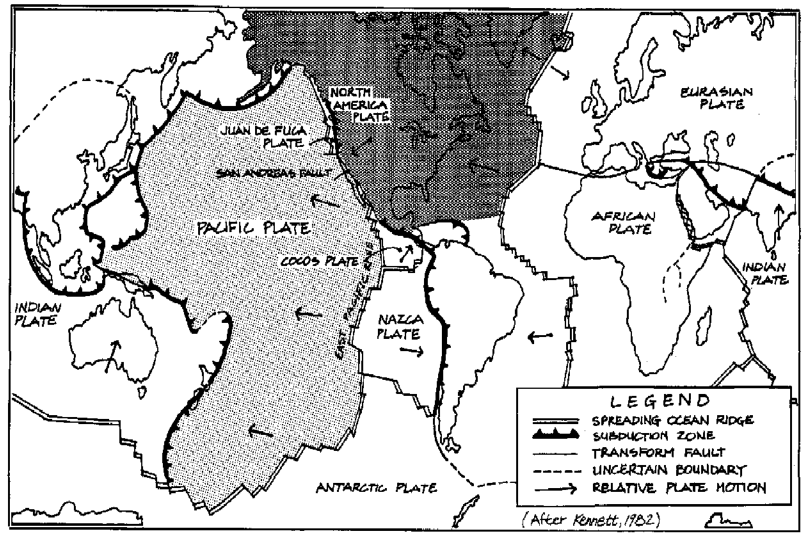


Figure 6. Tectonic Plates of Earth

Earth has seven major plates; those affecting Oregon and Washington are shaded. Plates diverge along ocean-spreading ridges, converge along subduction zones, and slide past each other along transform faults known as fracture zones. Plate boundaries do not necessarily coincide with continent or ocean outlines. Arrows indicate the relative motion of the plates. The North American Plate is moving westward away from the Mid-Atlantic Ridge. The Juan de Fuca Plate and the Cocos Plate are remnants of the ancient Farallon Plate now consumed beneath the North American Plate.

TECTONICS OF THE PACIFIC NORTHWEST

The tectonic history of the Pacific Northwest provides a good example of the changing relationships between the earth's plates. The plates now found off the Oregon coast have not always been in their present locations, nor have their boundaries always been what they are today. Over the past 30 million years, the Farallon Plate, one of four ancient Pacific Ocean plates, has gradually disappeared under the westward-moving North American Plate. The Juan de Fuca is a remnant of this plate. The once-continuous ocean ridge which connected the Gorda and Juan de Fuca ridges to the East Pacific Rise far to the south off Central America has been consumed in the ocean trenches that once lay offshore California and has since been replaced by the San Andreas transform fault (26).

Oregon lies at the junction of many complex plate interactions (see Figure 7). Offshore, the floor of the Pacific Ocean consists of the Pacific Plate, moving northwest, and the Juan de Fuca Plate, moving northeast. These two plates diverge along the Juan de Fuca and Gorda ridges. The Juan de Fuca Plate, in turn, is converging with the North American Plate at the coastline and is being subducted; that is, one plate is being pulled under another. In addition, parts of the Juan de Fuca Plate are sliding past the Pacific Plate along transform faults, known as the Mendocino, Blanco, and Sovanco fracture zones.

It appears, too, that the remainder of the Juan de Fuca Plate is itself in the process of breaking up into small plate fragments (33). The movement of the Juan de Fuca Plate no longer dominates the Explorer Plate fragment off Vancouver Island or the Gorda South Plate off northern California. Their motion seems to be more strongly influenced by the pull of the adjacent Pacific Plate as it moves slowly to the northwest. This motion, along with the buoyancy of the fragments and their decoupling from the downward pull of the Juan de Fuca Plate, appears to be causing these microplates to pivot slowly as they resist subduction under North America (33).

Ocean Ridges

Some 200 to 400 kilometers off the coast of California, Oregon, and Washington lie the Juan de Fuca and Gorda ridges (see Figure 7). These midocean ridges form part of a global network of ridges nearly 60,000 kilometers long, linking the major ocean basins of the world (13). The Gorda Ridge, located within 200 kilometers of the Oregon coast off Cape Blanco, is one of the ridge segments closest to the continental United States.

The geological processes at the Juan de Fuca and Gorda ridges result in the formation of new oceanic crust and in volcanic activity. As the plates move away from the ridge, pressure on the underlying volcanic material is relieved and hot volcanic magma from the mantle wells upward into a magma chamber underneath the crest of the ridge (see Figure 9). Liquid rock, chiefly basalt, in the upper layers of this chamber makes its way to the surface through vertical passageways and erupts on the ocean floor (13). Other molten material remains trapped in the vertical cracks to become sheet dikes, vertical slabs or ribbons of basalt. Then it cools, hardens, and becomes part of the plate.

Once added to the plate, the now hardened basalt material is transported away from the ridge. The rock continues to cool and contract, forming cracks and crevices. The plates are driven away from the ridges by convection currents generated by heat within the rocks of the upper mantle of the earth and by gravity as the plates slowly slide off the elevated ridge.

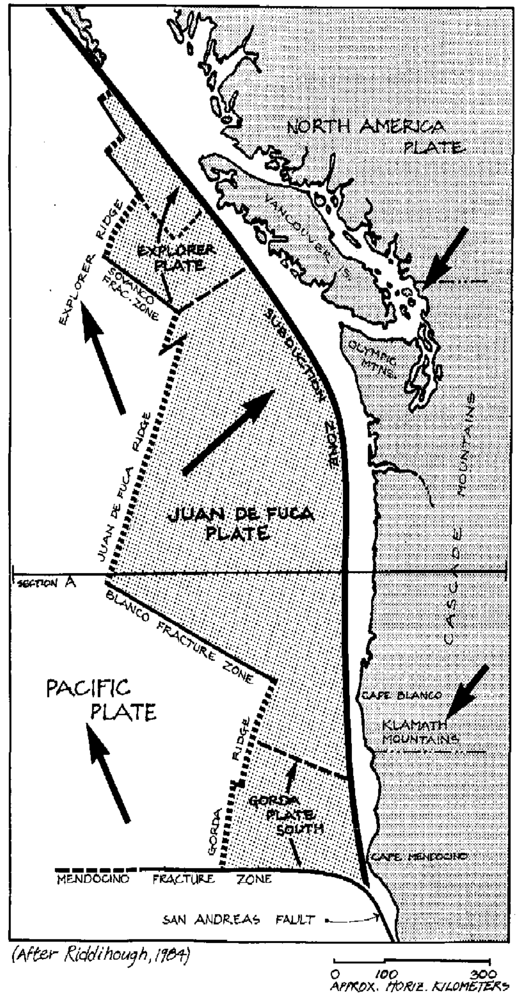


Figure 7. Movement of Plates Affecting Oregon

The Juan de Fuca Plate is subducting beneath the North American Plate. The Explorer Plate and Gorda South Plate fragments, which have decoupled from the motion of the Juan de Fuca Plate, are increasingly influenced by the motion of the Pacific Plate and are resisting subduction under the North American Plate. Arrows show the relative motion of the plates.

Both the Gorda and Juan de Fuca ridges are elevated submarine features. Hot new volcanic material welling up beneath them is less dense and more buoyant than the colder, older crustal material away from the ridge. They have a central or "axial" valley along the length of the ridge crest, usually several kilometers wide and of rugged topography caused by faulting and uplifting. Within the axial valley, mounds of smooth lava flows, toothpastelike, rounded pillow lava formations, and chimneylike structures indicate volcanic activity (18).

The Gorda Ridge is approximately 300 kilometers long and consists of three segments. The axial valley of the Gorda Ridge is quite deep, ranging from 3,200 meters in the south to 3,800 meters in the north. The valley is also wide, from several to nearly 19 kilometers. Within this valley, vertical relief ranges from 800 to 1,400 meters. Many small, conical seamounts, probably submarine volcanoes, lie adjacent to the ridge axis; all but the larger ones to the east of the axis are buried beneath sediments (7).

The 500-kilometer-long Juan de Fuca Ridge, north of the Gorda Ridge, is offset to the west by the Blanco Fracture Zone. The depth of the axial valley is 2,200 to 2,600 meters, although where the ridge intersects with the Cobb Seamount it comes to within 1,500 meters of the surface (the Cobb Seamount itself projects to within 100 meters of the ocean's surface). This is significantly shallower than the Gorda Ridge. The axial valley of the Juan de Fuca Ridge is more V-shaped than that of the Gorda Ridge and only 1 to 2 kilometers wide (5).

The ridges form a topographic barrier for sediment movement from the nearby continent. The northern portion of the Gorda Ridge is narrow, deep, and rugged (7); but the southern third of the Gorda Ridge, known as the Escanaba Trough, is filled with sediments derived from both the Columbia River and the Klamath Mountain drainages. These sediments appear to have been transported through the Blanco Gap (sometimes called the Blanco Saddle) and around the south end of the ridge before settling out in the Escanaba Trough (23). The reverse appears to be true for the Juan de Fuca Ridge; its southern half is rugged whereas a thick blanket of sediments covers the northern segment.

Full spreading rates (the total amount of crustal formation at a spreading center) vary along the two ridges. The full spreading rate on the northern end of the Gorda Ridge is approximately 5.5 centimeters (slightly more than two inches) per year but only 2.3 centimeters per year on the southern end, more typical of slow-spreading centers like the Mid-Atlantic Ridge. Total spreading rates for the Juan de Fuca Ridge, on the other hand, are somewhat faster and range from 4 centimeters per year in the south to 10 centimeters per year in the north (7).

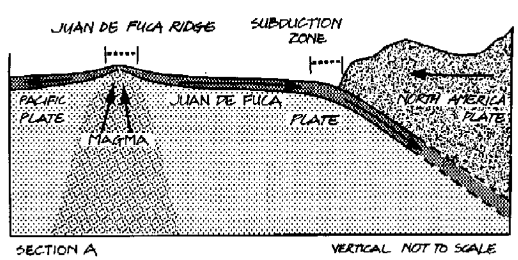
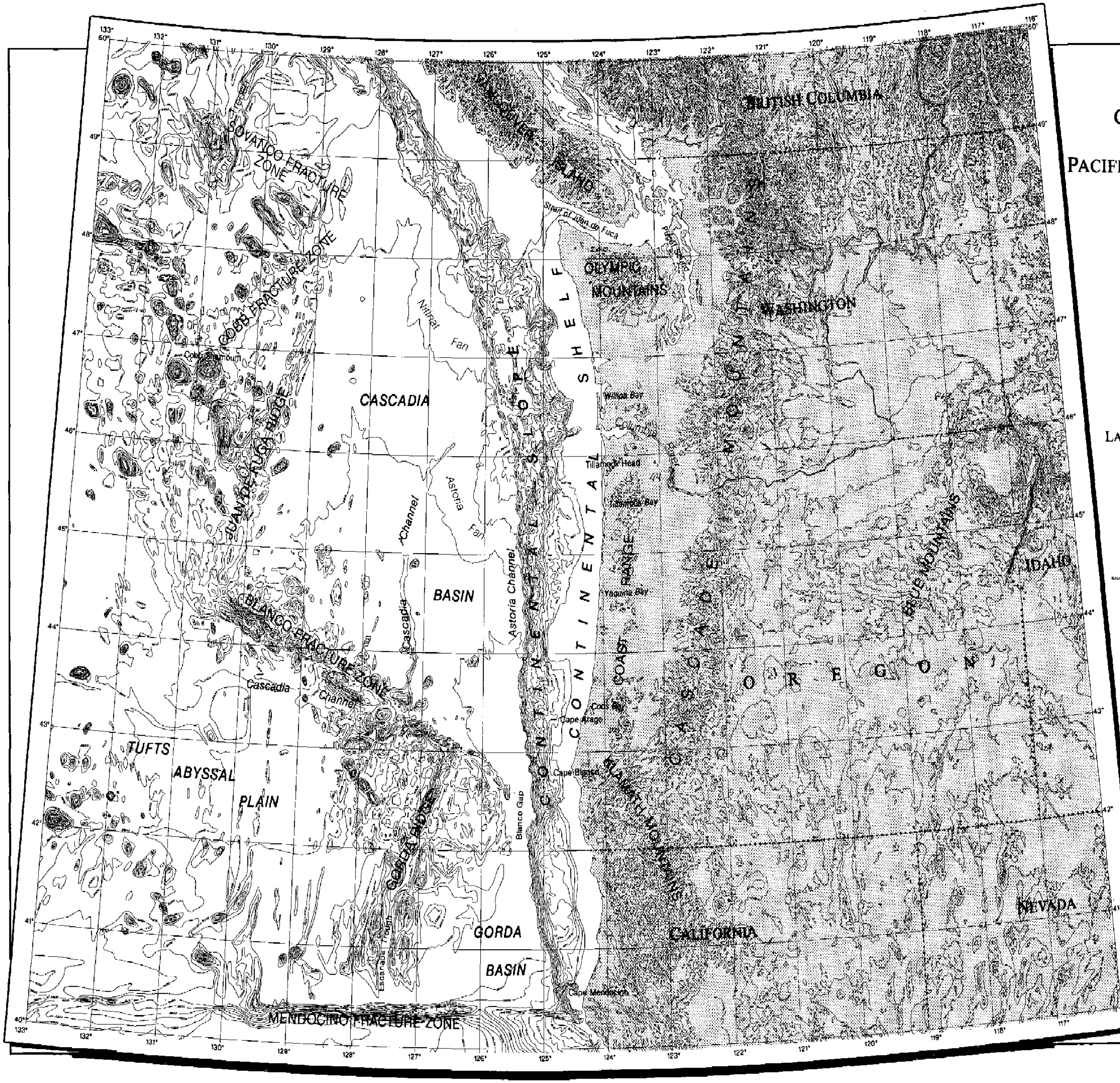


Figure 8. Seafloor Spreading off the Oregon Coast

This diagram, which is not to scale, shows the relative movement of the Pacific and Juan de Fuca plates away from the Juan de Fuca Ridge. The Juan de Fuca Plate is being forced down under the overriding North American Plate; this process is called subduction.



Geomorphic Features of the Pacific Northwest Ocean Basin and Adjacent Continent

THE OREGON OCEANBOOK

OREGON DEPARTMENT OF LAND CONSERVATION AND DEVELOPMENT

1985

The differences in the spreading rates along the Gorda and Juan de Fuca ridges result from the varying directions of motion of several plate segments (see Figure 7). The subduction trench lies relatively close to the ocean ridge system where plate material is generated, but the younger, more buoyant plate material resists subduction and is increasingly influenced by the motion of the Pacific Plate sliding northwest.

The Juan de Fuca, Gorda South, and Explorer plate segments exhibit varying degrees of clockwise pivoting motion as they are consumed under the continent. The Juan de Fuca Plate system appears to be an example of the final stages in the plate tectonic process, where small plate fragments become dominated by the motion of larger, bordering plates (33).

Subduction Zone

From Cape Mendocino to Vancouver Island, the Juan de Fuca Plate and the North American Plate converge to create a zone of very active geologic forces. As the Juan de Fuca has been thrust under the North American Plate, sediments riding on the oceanic crust have been scraped off and added to the edge of the continent in complex geologic structures. This convergence has also resulted in the uplift of the entire continental margin, including the Coast Range, the Cascade Mountains, and perhaps even the Blue Mountains of northeastern Oregon (10). Finally, eruption of the Cascade volcanoes is the result of the partial melting of this oceanic plate as it slides under the earth's upper layers and re-emerges as volcanic material on the continent.

Although subduction zones are usually characterized by earthquake activity, the Oregon coast is unique because there is a notable—and as yet unexplained—absence of earthquakes (10). One possible explanation is that the still-warm, relatively young Juan de Fuca Plate is slowly bending, like taffy, rather than breaking and releasing earthquake energy. Another explanation is that sediments, riding on the down-going plate, have a lubricating effect between the two plates.

Transform Faults

The Juan de Fuca and Pacific plates slide past each other along the transform faults of the Blanco Fracture Zone and the Mendocino Fracture Zone. Likewise, the North American Plate and the Pacific Plate slide past each other along the San Andreas Fault. Considerable earthquake activity and geologic uplift occur along the Blanco and Mendocino fracture zones, as evidenced by the rugged undersea mountains. Because these rock layers are not well lubricated, resistance between the rocks on either side of the plate boundary builds up tremendous strain. When a threshold level of stress is reached, the rocks give way and energy is released as an earthquake.

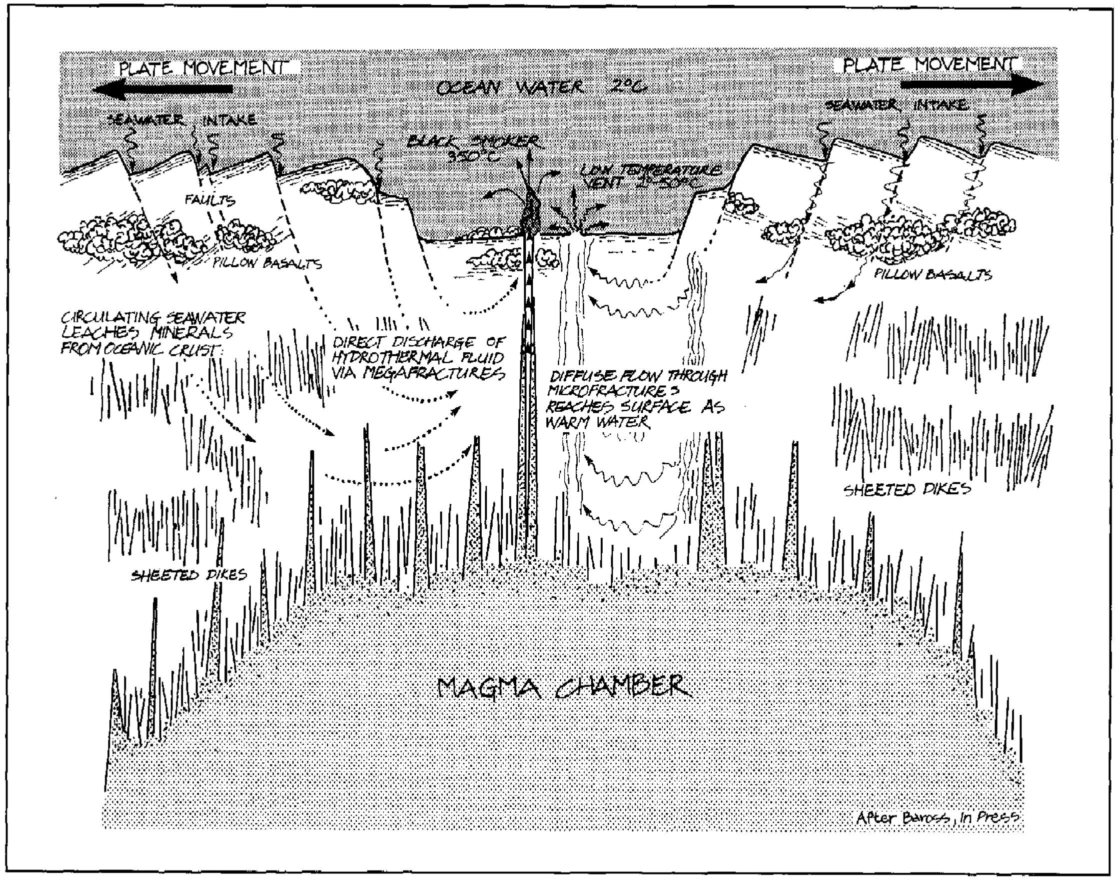


Figure 9. Cross Section of An Axial Valley

Magma (molten rock) rises beneath an ocean ridge, a zone of plate separation and seafloor spreading. Seawater percolates through a network of cracks in the rocky ocean floor, is heated by magma, and leaches minerals from the oceanic crust. Hot, mineral-rich water is ejected into cold seawater at hydrothermal vents. Magma moves upward through fractures, cools, and adds new basalt to the oceanic crust.

MIDOCEAN RIDGES AND HYDROTHERMAL VENTS

Since World War II scientists have used remote sensing techniques such as magnetometers and acoustic reflection to sketch a picture of the shape and structure of the ocean bottom. However, direct exploration of deep midocean ridges with submersible research vessels has been possible only in the last two decades. The Mid-Atlantic Ridge was the first area to be directly observed. The ridges off Oregon have been directly observed only since 1979.

In 1977, 320 kilometers northeast of the Galapagos Islands, oceanographers John B. Corliss of Oregon State University and John M. Edmond of the Massachusetts Institute of Technology became the first to witness the hot springs of a midocean ridge. Geologists had suspected that such activity, analogous to geysers and hot springs on land, might exist on the ocean floor. Although the geological discovery may have been anticipated, the biological one took the scientific community by surprise. Nearly three kilometers below the surface of the Pacific Ocean was a community of worms, crabs, and fish clustered around the hot springs thriving on the chemically rich vent fluids as a food source totally independent of the sun.

Scientists have begun to understand how such hot, super-saturated fluids are generated within the earth and how this process effects the chemical balance of the ocean, deposits metal-rich sediments on the seafloor, and creates an environment for a unique biological community in the deep ocean (40; 16; 1).

As the newly emerged ocean crust moves away from the spreading ridge, it cools and cracks. Cold seawater seeps into these cracks, draws heat from the molten rock, and rises to the surface through vents on the ridge crest. As the water circulates it leaches iron, zinc, copper, nickel, and other metals out of the rock. These heavy-metal molecules combine with sulfide, a compound of sulfur and oxygen, and remain in solution under the tremendous pressures and temperature of the vent network. When this hydrothermal solution erupts into the cold, deep ocean, the sulfide compounds precipitate out as polymetallic sulfides, forming chimneys, spires, and metal-rich sediments (see Figure 9).

Two kinds of vent systems have been found. The type of mineral deposited by a vent depends on the internal plumbing of the cracks. In a "leaky" system, of which the Gorda Ridge is probably an example, seawater and hydrothermal fluid mix but deposit the sulfide minerals below the surface within the vent system. The waters which are eventually returned to the ocean environment are on the order of 19° to 57° C (water boils at 100°C) (7).

In a "tighter" system, such as the one at 21° N on the East Pacific Rise (see Figure 10), the minerals remain in the superheated solution until they reach the surface. At the surface, the mineral-rich brine emerges at 350° C through chimneylike features known as "black smokers" and precipitates in massive deposits. Hydrothermal systems like this one appear to be the origin of geologic formations that contain significant quantities of metal ore. One such formation on Cyprus has yielded copper ore for centuries (27).

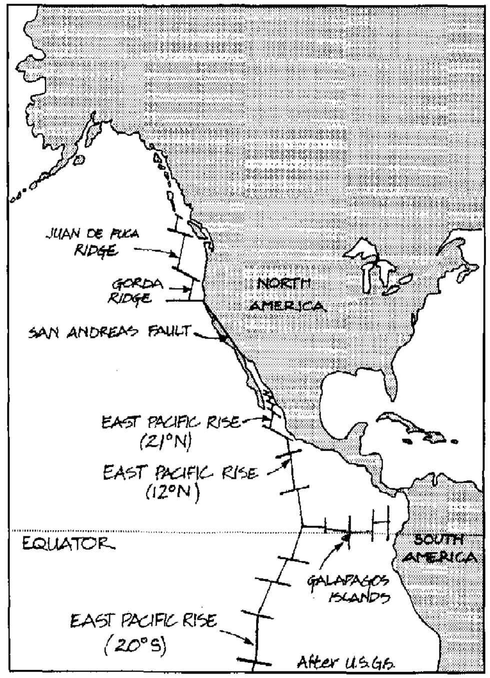


Figure 10. Juan de Fuca System and East Pacific Rise

Spreading centers along the East Pacific Rise have very active hydrothermal vents and major sulfide mineral deposits. The once-continuous ocean ridge system connecting the Juan de Fuca and Gorda ridges with the East Pacific Rise has been consumed under North America and replaced with the San Andreas Fault.

Active hydrothermal vents provide an environment for remarkable biological communities on the deep ocean floor. Instead of using sunlight and photosynthesis to sustain life, the food chain thrives on chemosynthesis, that is, the metabolism of hydrogen sulfide ejected from the hot springs. Bacteria use the hydrogen sulfide for energy to incorporate carbon, oxygen, and hydrogen—the building blocks of life—into organic tissue (16).

These bacteria are abundant and very productive even at the incredibly high temperatures found at 21° N and the enormous pressure at depths of 2,000 to 3,000 meters. The bacteria that live on the sulfur are 2 to 4 times as productive as surface bacteria and 100 to 1,000 times more productive than seafloor communities away from vent sites (16). When lights are shined through the water issuing from the vents, it appears faintly milky and bluish from the concentrations of bacteria and sulfides. The bacteria are ubiquitous: in the vent fluids, on all surfaces, in the water column above the vents, and within organisms.

A host of creatures either feed directly on the bacteria or rely indirectly on the bacteria to provide their nutrition. Mussels and clams, some over 30 centimeters long, extract bacteria from the water. The magnificent mouthless tube worms, up to two meters long, feed by absorbing dissolved nutrients created by bacteria living within their bodies. Many new families and subfamilies of marine worms, clams, crabs, and barnacles have been found in these spectacular oases of abundant life in an otherwise deep ocean desert (14).

The discovery of these hydrothermal vent systems and their circulating sea water may also have given scientists a keener understanding of the chemistry of the ocean. It is estimated that on a global scale hydrothermal vent systems circulate approximately 6,000 cubic meters of water per second (about one-third the annual flow rate of the Mississippi River) (39). At this rate, the entire volume of the ocean could circulate through the worldwide midocean ridge system in about 8 million years (11). And in the process, minerals contained in the hydrothermal fluids return to the ocean soup substances that have been removed in biological and chemical processes.

In 1983, the U.S. government, excited by the prospect of valuable minerals on the ocean floor within the U.S. 200-mile Exclusive Economic Zone, proposed to lease an area the size of South Dakota surrounding and including the Gorda Ridge. The leases would have been for exploration and mining of the polymetallic sulfide minerals hypothesized to have been formed in the sea. It was determined, however, that too little was known about the Gorda Ridge to proceed with a lease. But the U.S. Geological Survey, the National Oceanic and Atmospheric Administration, and other research agencies have begun a program of detailed exploration of the Gorda Ridge. This program is intended to provide information about the geologic formation of the area, its mineral resources, and the extent and kinds of biologic communities at vent sites.

MAJOR GEOMORPHIC FEATURES OF THE OCEAN FLOOR OFF THE PACIFIC NORTHWEST

The floor of the northeastern Pacific Ocean is dominated by two major regions: a large, deep ocean basin and a relatively narrow, shallower continental margin (see map: *Bathymetry: Oregon Continental Margin)*. These distinct regions result from the interaction of crustal plates and subsequent continental uplift, erosion and deposition, oceanographic processes, and seasonal weather patterns.

Ocean Basins

The Cascadia Basin, the deep ocean basin off the Pacific Northwest, is the sediment-covered surface of the Juan de Fuca Plate north of the Blanco Fracture Zone. A gently sloping, deep-sea plain, the Cascadia Basin ranges in depth from 2,400 meters in the north to 2,800 meters in the south (15). The southern portion of the basin is quite flat and is characterized by nearly buried seamounts, thought to be volcanic in origin, protruding through the sediment cover.

The basin receives a large load of sediment from continental and nearshore sources via submarine canyons which deposit their load in thick deposits known as deep-sea fans. The Nitinat Fan, west of the Juan de Fuca Strait, fills the northeast portion of the basin and is composed of sediments from Puget Sound and the Fraser River drainage of British Columbia. The Astoria Fan off the Columbia River fills much of the eastern portion of the basin with sediments from this great river system.

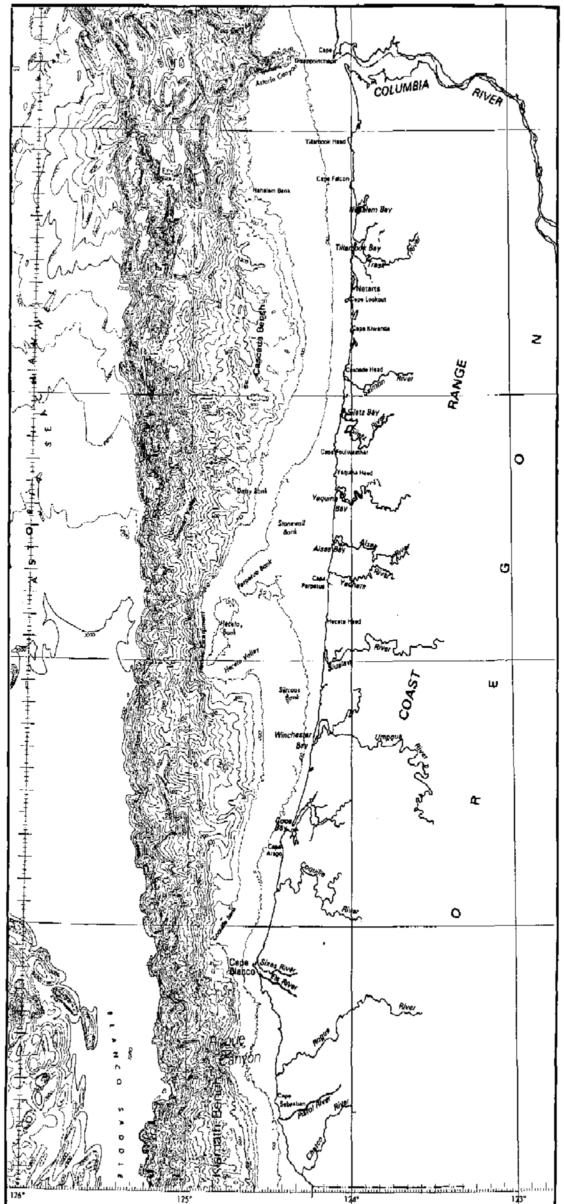
One of the longest seachannels in the world, the Cascadia Channel, bisects the basin from north to south. Originating at the base of the continental slope, the Cascadia Channel is two to four kilometers wide and 20 to 300 meters deep. This channel system is an important avenue for moving sediment from the continental margin to the deep ocean basin beyond the Blanco Fracture Zone. Although a substantial amount of sediment has bypassed the Cascadia Basin by means of this channel, thick layers of sediment have ponded in the southern and western sections against the mountains of the Juan de Fuca Ridge and the Blanco Francture Zone (15).

Along the eastern edge of the Cascadia Basin near the toe of the continental slope is another smaller channel. The Astoria Channel carries sediments from the lower flanks of the Astoria Fan southward to the Blanco Gap and the Gorda Basin beyond.

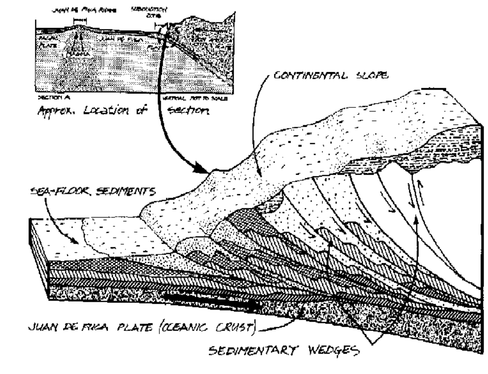
The Gorda Basin, lying south of Cape Blanco between the Gorda Ridge and the continental slope, is much smaller than the Cascadia Basin. Its southern edge is enclosed by the east-west ridges of the Mendocino Fracture Zone. However, the Gorda Basin is deeper than the Cascadia Basin and is filled with sediments to a virtually flat 3,000 meters. These sediments have buried many of the mountains on the landward flank of the Gorda Ridge and also filled the Escanaba Trough (23).

The Continental Margin

Oregon's continental margin is composed of three major features: the continental shelf, the continental slope, and submarine canyons dissecting both. The continental margin has been shaped by two fundamental geologic processes: plate tectonics and sea level change. Plate tectonics has built Oregon's continental margin slowly westward over the past 60 million years whereas sea level changes have occurred within the relatively more recent period of 10,000 years.



BATHYMETRY: OREGON CONTINENTAL MARGIN
BATHYMETRIC INTERVAL = 100 METERS



After Kulm & Scheidegger, 1979

Figure 12. Sediment Thrusting under the Continent

Subducting oceanic crust carries a sediment load which is scraped off and thrust as successive wedges under older layers at the toe of the continental slope. The rates and locations of uplift vary over time. Arrows show the relative movement of layers.

As the oceanic crust is subducted, the overlying sediments are scraped off the oceanic plate and added to the continental plate as wedges thrust successively one under the other (24) (see Figure 12). This scraping process, termed "imbricate thrusting" by geologists, accounts for the presence of older oceanic sediments found uplifted above younger sediments on the shelf. Rates of uplift have varied over time and range from 100 to 1,000 meters per million years. Areas of active uplift may also vary along the coast; the Cape Blanco area appears to have been the most active in the recent geologic past (4). This steady uplifting and tilting of rock layers in the coastal area continues today (33).

Historical changes in sea level have also influenced the nature of the continental margin. Extensive glaciers formed in the polar regions approximately 2 million years ago and captured enough of the earth's water as ice that sea levels dropped dramatically. Since then, a number of climatic oscillations have taken place with shifts in the mean annual temperature between interglacial and glacial periods of 3° to 6° C in maritime areas and 12° C in continental areas (12). The most recent glacial period has had the most effect on the Oregon continental margin. This period ended about 10,000 years ago as glacial ice, covering the Puget Sound area and much of the Olympic Peninsula, melted and returned as water to the oceans. The continental ice sheet covering parts of Puget Sound does not appear to have moved as far south as Oregon (28).

During the last period of lowered sea level, Oregon's shoreline was well to the west of its present location. Coastal rivers cut across the continental shelf to deliver sediment directly to the deep ocean. When temperatures warmed and the ice sheets gradually melted, the previously exposed coastal plain was flooded by ever-advancing shorelines and covered by deposits of mud, sand, and gravel (21). The rising sea level reduced the rate of sediments delivered to the deep ocean by creating a depositional environment over the now submerged continental shelf.

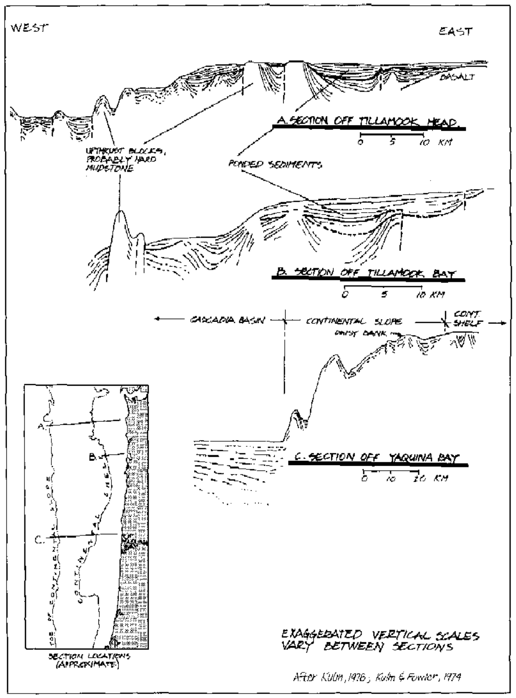


Figure 13. Seismic Profiles of the Continental Margin

Seismic surveys provide clues to the sedimentary structure beneath the seafloor. These three cross sections of the Oregon continental margin show how sediments appear to have been ponded behind blocks of older sedimentary rocks upthrust by plate subduction. Drilling is needed to obtain rock samples and confirm the shape and composition of these structures.

Continental Shelf

Oregon's continental shelf is a relatively flat, gently sloping terrace. It is narrow in comparison with worldwide averages and ranges from about 17 kilometers (10 miles) off Cape Blanco to 74 kilometers (46 miles) off the central coast (24). In general, the shelf is steepest where it is most narrow. The depth of the shelf varies but is usually taken to be 200 meters, at which point the shelf merges with the steeper continental slope.

The shelf has several prominent, rocky, submarine banks of varying size. Four major banks create locally shallow areas amidst the otherwise deeper water of the shelf: Nehalem Bank, Stonewall Bank, Heceta Bank, and Coquille Bank. The rock blocks which form these banks have been uplifted by the underthrusting process at the base of the continental slope.

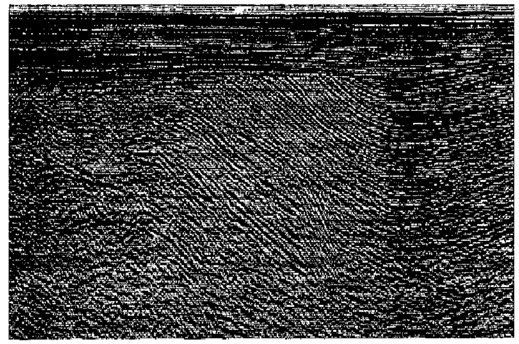


Figure 14. Seismic Survey Profile Printout

Rock layers underlying Oregon's continental shelf are shown in this computer printout of a seismic survey performed in fall 1984. The horizontal bands at the top are over one kilometer thick and were deposited on an erosional surface on top of folded sedimentary rocks. This cross section, which shows rock layers over 7 kilometers deep and nearly 13 kilometers wide, was taken by the R/V "Arco Resolution." (Photo courtesy of Mike Bell, ARCO Exploration.)

Rocky outcrops, erosional remnants of shoreward rock formations, are also found on the inner shelf, especially between Coos Bay and the Rogue River (22). Nearshore, sea stacks and other rocky islands provide nesting sites for sea birds. Many of these features are part of the Oregon Islands National Wildlife Refuge system.

Continental Slope

Like the continental shelf, Oregon's continental slope is also relatively narrow, from 20 kilometers (12 miles) at Cape Blanco to 96 kilometers (60 miles) off the Columbia River. Here the ocean floor drops rapidly to meet the Cascadia Basin some 2,000 meters below.

The upper slope is characterized by gently sloping benches and low-relief hills. Blocks of rocky material, probably hard mudstone (23), have been rapidly uplifted by the underthrusting oceanic plate and the building of an accretionary wedge at the bottom of the slope. Sediments have ponded behind these blocks to form the Cascade Bench off the north coast and the Klamath Bench off the south coast and northern California (see Figure 13). The lower slope below 2,000 meters is quite steep and intersects the deep-sea bed of the Cascadia Basin at 2,200 meters off the north coast and 3,000 meters off the central and south coast (25).

Submarine Canyons

The outer edge of the continental shelf and continental slope is breached by two prominent submarine canyons and numerous smaller ones. The Astoria Canyon cuts into the outer shelf about 16 kilometers (10 miles) west of the Columbia River. During periods of lowered sea level, the Columbia and Rogue Rivers drained across what is now the continental shelf. The Astoria Fan, a large depositional feature on the eastern Cascadia Basin, lies at the base of the canyon. The Rogue Canyon is much smaller than the Astoria Canyon. It begins near the edge of the shelf offshore of the Rogue River and feeds directly down the continental slope onto the deep ocean floor.

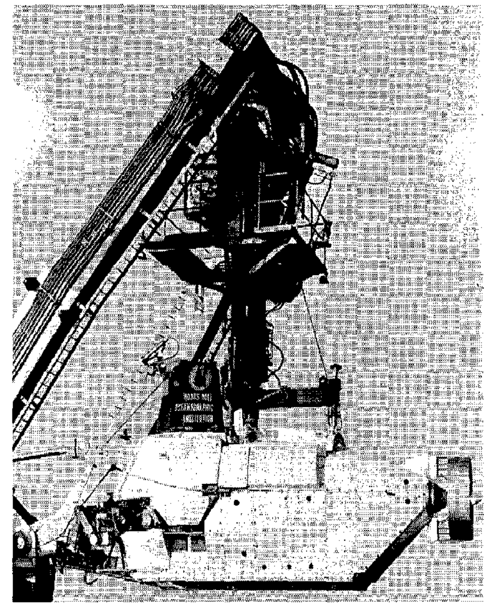


Figure 15. Deep Submergence Research Vehicle Alvin

The DSRV "Alvin" being lifted from the water by an A-frame hoist installed on the stern of the mother ship "Atlantis II." Scientific equipment on board includes remotely controlled mechanical arms and various sampling equipment, underwater cameras, lights, a water temperature monitor, a current speed meter, and a precision depth indicator (photo by Rod Catanach, WHOI).

1984 ALVIN DIVES ON THE OREGON CONTINENTAL SLOPE

During the summer of 1984, marine scientists participating in the dives of the deep-sea research vessel *Alvin* on the Oregon continental slope discovered a prolific, deep-sea benthic community (35). Tube worms, giant clams, carnivorous fish, and crabs were thriving in 2,036 meters of water, well below the range of sun-driven food webs. These animals were either identical or very similar to those found at the hot vents of the midocean ridges, but the dominant source of energy on the continental slope appeared to be methane, not hydrogen sulfide.

On the continental slope, water rich in methane and nutrients is squeezed from the sediment of the Juan de Fuca plate as it subducts beneath the North American continent. This discovery interests scientists because although the emerging water is not significantly warmer than the surrounding bottom water, a highly productive deep-sea community has adapted to an environment of high pressure, low temperature, and very low productivity.

SEDIMENTS OF THE CONTINENTAL SHELF

Geologists studying sediments on the Oregon coast are hampered by lack of data from core samples. The Oregon continental shelf, one of the least studied in the United States, has been only superficially probed. Surface sediment distribution, inferred from surface "grab samples," may not reflect the composition of deeper sediments (31).

Sediments found today on the continental shelf consist primarily of relict deposits, those laid down during the last advance in sea level, and those which are being deposited under present hydrodynamic conditions (22). Sedimentation on the continental shelf is controlled by river discharge, estuarine circulation, wave characteristics, currents, density differences in the water column, and benthic organisms. Nearshore surface sediment distribution is mapped in Figure 9.

The Columbia River and other coastal rivers; including the Rogue and the Umpqua, supply the bulk of the sediment reaching the continental shelf. Sediment supply shifts seasonally with peak discharge of the Columbia occurring in the late spring and early summer, several months after peak discharge of the smaller coastal streams.

Estuaries can act as a settling basin for the larger sand-sized particles carried in coastal streams so that only the finer suspended particles enter the ocean. However, during winter, high-volume river discharge into small estuaries carries river sand and gravel through and into the ocean. In summer, ocean beach sand is transported into estuaries by incoming tidal currents and is deposited along the margins of the estuary several kilometers from the mouth (32).

Waves stir and lift shelf sediments for transport by currents on the shelf (22). The winter wave regime off the Oregon coast is noted for its intensity, whereas summer waves are much less energetic (29). Winter storms generate long-period waves capable of rippling the sediment on the ocean bottom to depths of 150 to 200 meters across the entire width of the shelf. Lower-energy summer waves may produce ripples to depths of 50 to 100 meters.

Wave activity in the surf zone is important in lifting and transporting sand alongshore and in creating both a surface turbid layer and a midwater layer. This surface turbid layer of fine-grained materials can extend the width of the shelf, although its intensity will decrease with distance from the source. The midwater layer consists of suspended material which has settled out of the surface layer and which moves across the shelf along a boundary of different water densities (22).

A third turbid layer develops on the bottom of the shelf in response to resuspension by surface waves, to bottom currents, and to the settling of material from the surface and midwater layers. This layer can be as intense as the surface layer (22).

Modern continental shelf sediments are derived from three principal sources: river discharge, coastal erosion, and federally authorized dredging projects undertaken by the U.S. Army Corps of Engineers (22; 6). The large drainage basin of the Columbia River contributes approximately 11 million cubic meters (approximately three cubic miles) of suspended sediments each year to the ocean. Other major coastal rivers, the Umpqua and Rogue of Oregon and the Klamath of northern California, carry lesser quantities of sediments to the continental shelf. Heavy-mineral sediments flow from the Klamath Mountains and are deposited in offshore placer deposits (see "Resources of the Continental Shelf").

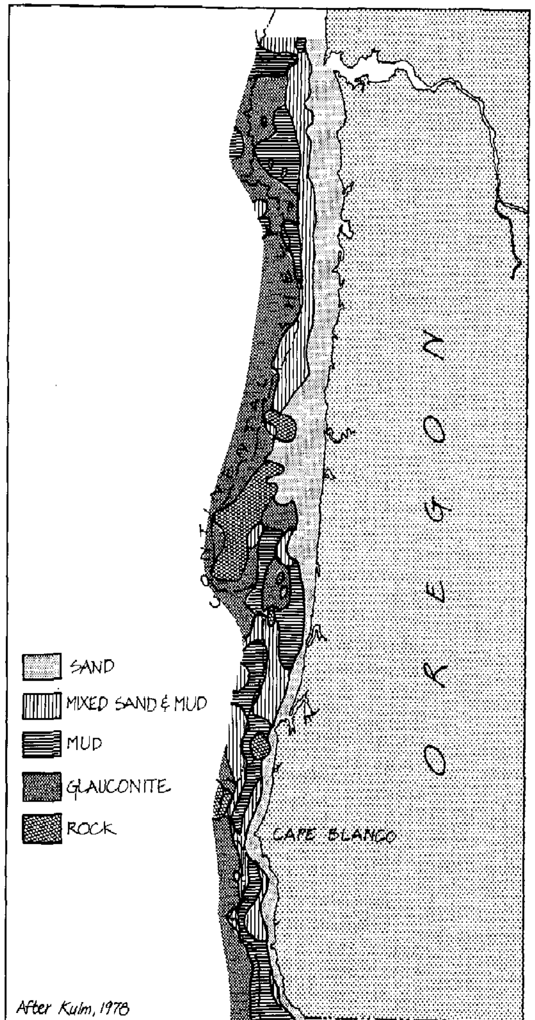


Figure 16. Sediment Distribution on the Continental Shelf

Sandy bottom is prevalent near the coastline; muddy areas and mixed sand and mud occur farther out. Hard, mudstone rock outcrops at submarine banks are not covered by sediments. The continental slope is covered with glauconite mud, an iron-rich sediment formed by chemical action in deep marine waters with a high organic content.

In addition, calculations show that coastal erosion of sea terraces, cliffs, and other nearshore features could add as much as 600,000 cubic meters of sediment per year to the shelf. A third source, the U.S. Army Corps of Engineers' coastal dredging project, adds from 7 to 11 million cubic meters of sediment off Oregon per year into the ocean from material dredged from Oregon's harbors and rivers (7).

The inner shelf consists of sand derived from wave erosion of coastal features and from coastal drainage, especially that of the Columbia River, which has been deposited onto a layer of clean, well-sorted sand laid down during the last rise in sea level (34). Sediments of the middle and outer continental shelf tend to be very fine-grained muds of silt, clay, and organic material. Patchy areas of muddy sediments appear to be concentrated near rivers of high discharge, especially the Columbia River, where there is a high-volume discharge of fine sediments during late spring and summer, a period of relative ocean calm. The mud layer is quite thin or is entirely absent off central Oregon because of the low sediment supply from the small river basins of the north and central coast (25).

Farther to sea, the outer shelf and upper continental slope are covered by poorly sorted, very fine sediment (34). These upper-slope sediments originated in streams of southern Oregon and northern California and were transported northward by a north-flowing undercurrent over the outer shelf and upper slope (25).

The burrowing of marine organisms is the principal way in which mud and sand are mixed. This action usually occurs in the transition area between the nearshore deposits that are exclusively sand and the mud deposits farther offshore.

RESOURCES OF THE CONTINENTAL SHELF

The geologic resources of the continental shelf are of increasing interest to industry and commerce. As onshore gravel deposits are depleted or allocated to other uses, deposits on the ocean floor may attract developers. Rare and exotic minerals, needed in sophisticated metallurgy, concentrate in deposits on the continental shelf. Oil and gas reserves may lie buried in basins beneath the ocean and may be increasingly important as society looks for alternatives to depleted land reserves. Oregon's continental shelf could be the site for development of some of these resources.

Gravel Deposits

The gravel deposits on Oregon's continental shelf are relicts of a time dating from approximately 15,000 years ago when sea level was about 200 meters lower than it is today (29). Surf action during the rise in sea level concentrated gravels in small pocket beaches between what are now submerged ridges. The active wave environment along those rocky shores carried away the smaller sand- or silt-sized sediments and left the heavier gravels. Oregon's larger gravel bodies are situated in depressions between submarine banks. Other smaller gravel deposits lie near submarine rock outcrops.

Gravel deposits off Oregon are relatively small and localized (see Figure 17). Major Oregon offshore deposits, which lie in shallow water, are located near Stonewall Bank (60 meters); between Heceta and Stonewall Banks (100 meters); at Cape Arago (70 meters); off the Coquille River (60 to 70 meters); at Cape Blanco (40 meters); and off Humbug Mountain (40 meters) (29). Recent dredging by the U.S. Army Corps of Engineers indicates that deposits may be present at the mouth of the Rogue River. Geologists suspect these deposits lie in former river channels that once cut across the continental shelf. Estimates of the volume of gravel deposited off Oregon range from 100 to 500 million cubic meters.

By contrast, gravel deposits off the Washington coast are extensive and are the result of a different geologic process. Vigorous meltwater streams from retreating continental glaciers in Canada and alpine glaciers of the northern Cascade and Olympic mountains carried tremendous volumes of gravel to be deposited in broad fans on the continental shelf. These large deposits are located off the Strait of Juan de Fuca and off the Chehalis and Quinalt rivers.

Placer Deposits

Buried off the Oregon coast are layers of sediments containing high concentrations of heavy minerals—chromite, ilmenite, magnetite, zircon, and traces of gold (21) (see Figure 17). These mineral-rich deposits, known as placers, are of two kinds: relict deposits, which were formed during lower sea level stands, and modern deposits, which are currently being formed. The process of formation is the same for both kinds.

The minerals originate in the mountains of southern Oregon and northern California. The Rogue, Sixes, Chetco, Klamath, and other rivers drain these mountains, discharging sediments rich in heavy minerals into the surf zone. Waves and currents sort the heavier mineral grains from such lighter ones as quartz and feldspar. Winter longshore currents carry sediments northward until a major headland interrupts the flow and the heavy minerals settle out. In summer, the currents shift and carry the lighter minerals south, enriching the deposit. Over thousands of years, this sorting has resulted in concentrations of similar mineral types into "lenses" along the shore.

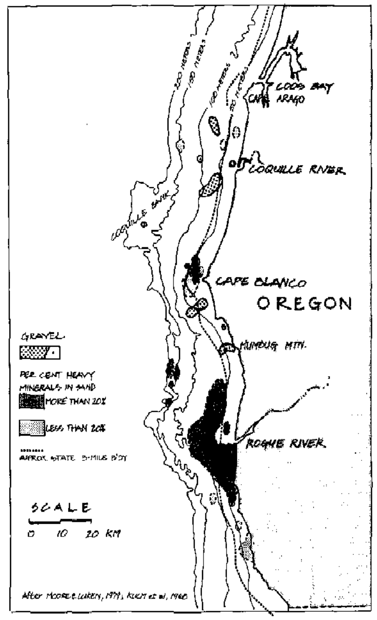


Figure 17. Gravel and Heavy Mineral Deposits of the South Coast

Oregon's south coast has most of the state's offshore gravel deposits and all of the heavy-mineral deposits. Gravel deposits are small and patchy but relatively shallow. Heavy-mineral deposits are relict concentrations from periods of lower sea level.

It appears that major deposits occur on the southern Oregon shelf off the mouth of the Rogue River and off Cape Blanco at depths varying from 20 to 100 meters. The offshore Rogue deposit is approximately 37 kilometers long and extends to a depth of 90 meters. This area contains 20 to 30 percent heavy minerals. The Cape Blanco deposit is less extensive but contains a higher mineral concentration. Approximately 13 kilometers long and 6 kilometers wide, it is found in water depths ranging from 30 to 55 meters. This volume of these deposits is not yet known (21).

South of Cape Arago, rapid uplift of the coast has preserved heavy mineral deposits onshore. These deposits were mined for chromite during World War II and until the late 1950s. Mining ceased when the federal government discontinued subsidy of the mining operations (36).

Oil and Gas Deposits

Oil and gas are hydrocarbons, chemical compounds once part of living organisms which have been buried, heated, and squeezed into new forms.

Oil's origin lay in the sunlit, shallow, coastal waters of ancient seas, where vast numbers of tiny marine plants and animals flourished. As countless generations of these organisms grew and died, their remains settled to the seafloor and were covered by fine particles of clay, silt, or sand.

This process, repeated through thousands of years, led to the accumulation of dense sediments on the ancient seabed. The weight of these sediments, combined with certain chemical, bacterial, and temperature conditions, transformed the buried organisms into petroleum and natural gas, much as ancient forests were converted into coal.

The compacting pressure of the ancient sediments also changed the clays, silts, and sands into rock: shale, mudstone, or sandstone. Oil and gas, squeezed from the denser source rocks such as shale, migrated into porous sandstone and limestone.

As the earth's crust fractured or folded, the shifting layers of rock formed traps, barriers to the oil's migration. Lying next to or beneath impermeable rock, a reservoir was formed, holding a pool of natural gas and petroleum above a deeper layer of water. (30)

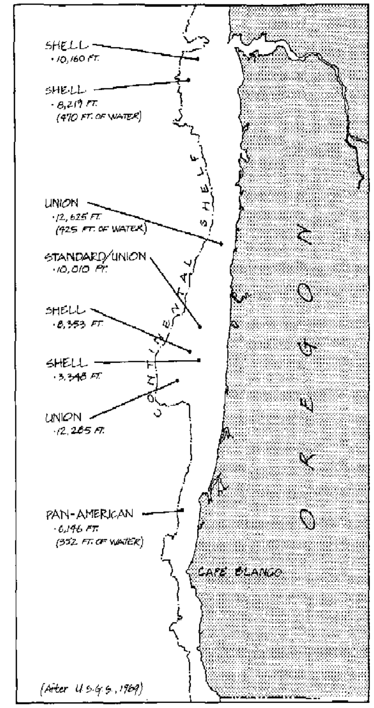


Figure 18. Exploratory Wells Drilled In Federal Waters, 1967-69

Eight exploratory wells were drilled as part of the U.S. Department of Interior's offshore oil exploration program. None revealed commercial quantities of hydrocarbons.

Onshore hydrocarbon deposits at Mist in northwestern Oregon have been tapped for several years. Conditions favoring the formation of source rock and traps appear to be present off the Oregon coast; however, the uplift and deformation of the continental margin have resulted in very complex structures which are difficult to analyze.

Exploration for oil and gas off the Oregon coast has been sporadic since the early 1960s. Of the eight exploratory wells drilled in federal waters (beyond three miles from the shoreline) from 1965 to 1967 (see Figure 18), only one produced hydrocarbons, although not in commercial quantities (39). Even though commercial quantities have not yet been found, interest in these areas remains as oil companies conduct geologic studies off the Oregon coast.

THE COASTLINE

Oregon's relatively young, straight coastline is the remnant of rapidly rising sea level and lack of sedimentary buffer along the shoreline. Under these conditions, the Pacific Ocean actively attacks and erodes promontories while simultaneously filling and straightening embayments. Interaction between the nearshore wave environment and local geology produces a unique set of shoreline features.

The shape and depth of the shelf just offshore and the direction of wave approach are major factors in how the wave energy affects the shoreline (see Figure 19). Capes, headlands, and reefs projecting into the ocean tend to focus wave energy on themselves. Thus, only the most resistant of rocks can long withstand the increased pounding of waves. Over time this relentless focusing of the ocean's energy either will erode and remove the promontory or will gnaw away at both sides of the landward end of an especially resistant formation until the rock is encircled by the ocean and exposed to attack from all sides (see Figure 20). Along beach fronts and embayments, however, the energy of ocean waves is dissipated, allowing sediments to settle out, thus tending to fill these indentations.

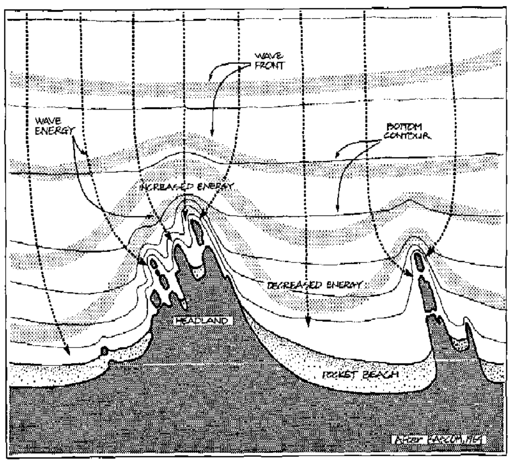


Figure 19. Wave Refraction

Wave fronts (shaded bands) approaching the shoreline are bent (refracted) by ocean bottom contours and promontories (solid lines). Wave energy (dashed lines) is focused onto projecting features and diffused in embayments.

While the lifespan of some coastal features varies over geologic time, others respond to seasonal fluctuations. Beaches are transient, ever-changing landforms responding almost overnight to the action of waves, currents, and wind. Seasonal changes in the beach face result from water sweeping onto the shore and off again (see Figure 21) (19). Storm waves, driven by strong winds and high tides, break directly onto the beach and surge to the foot of coastal cliffs. Erosion is most severe during this time, particularly of the cliffs and terraces of softer sedimentary rock. Waves pull sand from the beach and deposit it beyond the active surf zone as offshore sand bars. In the summer, wave conditions are less harsh and sand is returned to the beach. A wide summer beach buffers the cliffs and dunes from wave erosion.

Figure 20. Aerial View of Wave Refraction Around Offshore Rocks

Waves moving through the water are bent (refracted) around offshore rocks and islands. This refraction is visible around rocks offshore of Port Orford in Curry County.

Beaches are also influenced by currents flowing parallel to the shoreline. When waves approach the shore at an angle and break in the surf zone, part of their energy will go into pushing a longshore current. The larger the waves or the greater the angle of approach, the stronger this longshore current. Wave action keeps sediment suspended in the water, and the larger the waves the more sediment that can be moved. This transport mechanism can move tremendous amounts of material during winter storm conditions.

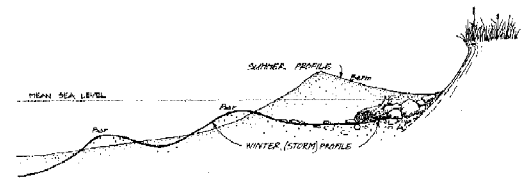


Figure 21. Seasonal Beach Profiles

Sand accumulation on beaches is different in summer than in winter. High-energy winter storms pull sand from beaches and deposit it as offshore bars; low-energy summer swell pushes sand back up onto beaches into a high berm.

The direction of longshore transport varies seasonally with wind direction. Generally, beach sediment is moved south in the summer and north in the winter, although local variations can occur. Every beach has a "sand budget." If the amount of sand deposited on the beach is balanced with the amount being removed, the beach is in equilibrium. If not, a change in the beach will occur.

Man-made structures like jetties interrupt longshore transport. Winter longshore transport along the Oregon coast is south to north; sand, trapped on the south side of the jetties, causes the beach to grow seaward. Summer longshore currents move from north to south so that beach growth occurs behind the north jetty at river mouths. The accompanying aerial photo shows how sand has accumulated behind both jetties at the mouth of Tillamook Bay.

Rip currents also play an important role in the movement of sediment and shaping of beaches (see Figure 14). When longshore currents from opposite directions meet, water is forced out to sea in a rip current. Likewise, when a longshore current meets a headland or jetty, a rip current is commonly observed alongside those features. (17)

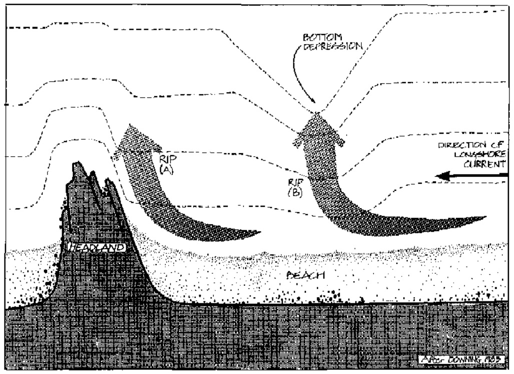


Figure 22. Nearshore Circulation: Longshore and Rip Currents

Rip currents are produced when longshore currents meet the headland (A) or where a bottom depression (B) allows a longshore current to flow seaward.

WIND WAVES AND TSUNAMIS

Waves are created primarily by wind, but they can also be caused by underwater landslides and earthquakes. When wind blows across the ocean, the friction between the air and surface of the water forms waves. The size of the wave is determined by how fast the wind blows, how long it blows, and how far over the water it blows. Storms blowing in the open ocean create a frenzy of waves called a sea (2). As waves leave the storm-generating area, they become sorted according to their period. Shorter-period waves are left behind and longer waves of similar period and height form lower, more rounded, powerful waves called swell.

Swell moves across the open ocean toward distant shores in groups of waves called trains. A train whose wave period averages twelve seconds will take two days to cross 1,000 miles of open ocean (2). These trains can travel great distances with little energy loss; swell generated in the Antarctic has been detected on the Alaska coast (38).

As waves move over the continental shelf and into water where the depth is less than half the wave length, their characteristics begin to change. Waves moving into shallow water become unstable because their height increases quickly relative to their length. Eventually, they oversteepen and break. Breaking waves generate back-and-forth currents along the bottom that contribute to sediment transport near the shore and even out to the edge of the shelf (37).

Figure 23. Effects of Man-Made Structure on Longshore Current

In winter, jetties at the mouth of coastal rivers, as here at Tillamook Bay, interrupt the sediment-laden longshore current flowing north and cause a sediment load to be deposited on the south side (the upstream side). Sand accumulates on the north side by means of a strong summer longshore current driven by northwest winds. This backfilling will occur until the profile of the ocean front is again in equilibrium.

Waves reaching the Oregon coast respond to the seasonal wind patterns in the Pacific Northwest: in summer, the predominant wave approach is from the northwest and in winter from the southwest. The highest waves are always in the winter when the wind blows many hours at high velocities. Exceptional storm wave heights were observed from an oil rig off the Oregon coast in 1968 where waves up to 18 meters (59 feet) and even one of 29 meters (96 feet) were recorded (41).

Seismic sea waves or tsunamis are generated by violent displacement of the sea bottom, for example, by an earthquake or a landslide. Although tsunamis are of relatively small height in the open ocean (less than 1/3 meter) (2; 3), they can move quickly across the surface of the ocean as a series of high-velocity, long-period waves. In parts of the Pacific their speed can exceed 720 kilometers (447 miles) per hour.

When the tsunami finally reaches the shallow waters of a coastal area, its height can be tremendous. The 1964 Alaska earthquake triggered a tsunami that produced waves onshore which ranged from 1 to 5 meters (3.3 to 16.5 feet) above mean high water. These waves appeared at intervals and surged into several Oregon estuaries and the waterfront area of Crescent City, California, causing extensive flooding, destruction of property, collapsed bridges, and loss of life (37).

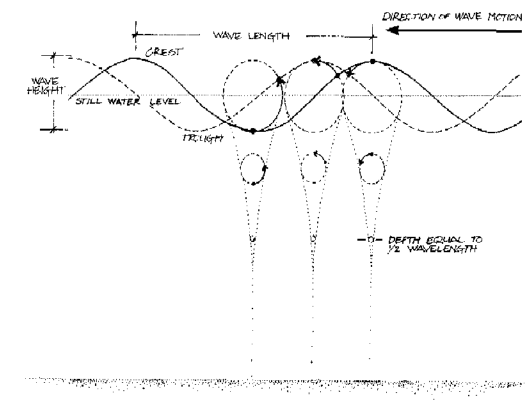


Figure 24. Diagram: Parts of a Wave

In an ideal wave, water rises and falls in an orbital motion as wave energy moves through the water. Wave energy is strongest at the surface (large circles) and decreases rapidly with depth. The wave period is the time it takes for a wave crest to traverse a distance equal to one wave length.

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Additional Reading

As the *Oceanbook* went to press, the *National Geographic Magazine* published the August, 1985, issue. In that issue is the article "Our Restless Planet Earth," by Rick Gore. A fold-out supplement, entitled "The Shaping of a Continent: North America's Active West," contains a three-dimensional drawing of the plate tectonic activity of the Pacific Northwest with focus on the Juan de Fuca Plate and Gorda Plate as they are subducted beneath North America. Interested readers will find the magazine article and supplement to be a fascinating and beautifully illustrated complement to the *Oceanbook*. The full citation is:

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CHAPTER THREE

OCEANOGRAPHY

The Water

INTRODUCTION

Earth is unique among the planets in our solar system in that 70 percent of its surface is covered by water, principally in the oceans. No mere basins of still water, oceans are dynamic systems of vast currents and tremendous energy driven by the sun's heat, the earth's spin, and the moon's pull. Earth's yearly journey around the sun creates a cycle of seasons in the oceans, especially near the coastline. Water is an impressive substance. The marvelously simple structure of the water molecule is essential to the roles it plays in our environment—climate control, food production, ocean circulation, and waste disposal, to name a few.

Although churning surf driven before a winter storm is an unforgettable sight, the ocean's most important feature, its internal composition, cannot be seen by the naked eye. Add the vast size and great depth of the ocean and the task of measuring and understanding the ocean becomes a formidable challenge.

Understanding of the ocean advances slowly as marine scientists gather bits of information at selected points. Typically, they make observations of ocean currents or seawater content by direct sampling. These observations are individual scenes of the ocean's condition at the point of measurement, and many scenes over a wide area over a long period may generate a motion picture of the ocean's dynamic conditions. Scientists must analyze and visualize the abstract data to construct a working model of the ocean.

This chapter of the *Oceanbook* describes how the earth's atmosphere influences weather and ocean circulation patterns in the Pacific Northwest. It discusses temporal variations in ocean circulation, those which occur over a span of from several days to several years, such as upwelling and El Nino, an occasional and unwelcome visitor to Oregon's ocean. Finally, the *Oceanbook* examines the physical and chemical characteristics of seawater, the influence of the Columbia River flow on the ocean, and the effect of all three on the ocean's structure and productivity off Oregon.

ATMOSPHERIC CIRCULATION AND OCEAN SURFACE CURRENTS

Atmospheric conditions and ocean currents may be examined at several levels of detail, in a sense adjusting the degree of magnification of the microscope, selecting all or merely a portion of the ocean for study. Beginning with a satellite panorama of the entire earth or an entire ocean basin, we may then increase the magnification to more closely observe regional atmospheric and oceanic circulation and finally the winds and currents in a particular locale. This method of zooming in, which is used in the *Oceanbook,* starts with a general picture which is then refined by overlays of more specific information.

Winds of the Atmosphere and Their Influence on the Ocean

The sun is the source of energy that drives the circulation patterns of the earth's atmosphere and oceans. Solar radiation is not evenly distributed over the earth's spherical surface, but intensifies in equatorial regions and diminishes at the poles. This uneven heating, coupled with the shape and size of the continents and ocean basins, creates a series of atmospheric circulation cells.

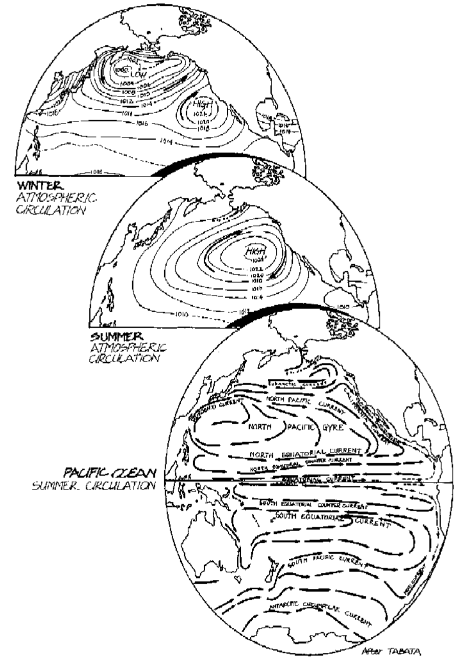

Figure 25. Major Circulation Patterns in the Atmosphere and Ocean

In winter, the large Aleutian low dominates the weather of the northern Pacific Ocean (top left). Storms move counterclockwise around the low, slide off the north side of the North Pacific high, and blow onshore from the southwest. (Atmospheric pressure gradients are shown in millibars.)

In summer, the North Pacific high moves northward off Oregon and northern California. Winds circulate clockwise around the high and blow north to south along the Oregon coast.

Ocean circulation in the north Pacific Ocean reflects large-scale air movements. The North Pacific gyre, composed of numerous currents, is narrow and strong on the west side of the ocean basin, broad and slow on the east side. A similar gyre in the South Pacific circulates in the opposite direction.

Two major atmospheric pressure cells over the northeast Pacific affect Oregon's weather: the North Pacific high and the Aleutian low (see Figure 25). Air flows clockwise around the high-pressure cell and counterclockwise around the low-pressure cell. (See satellite photo of storm systems, Figure 26.) Surface winds spiral in rotary fashion around these pressure gradients. (A storm system spins counterclockwise as it slides from the Aleutian low around the North Pacific high toward the coast.)

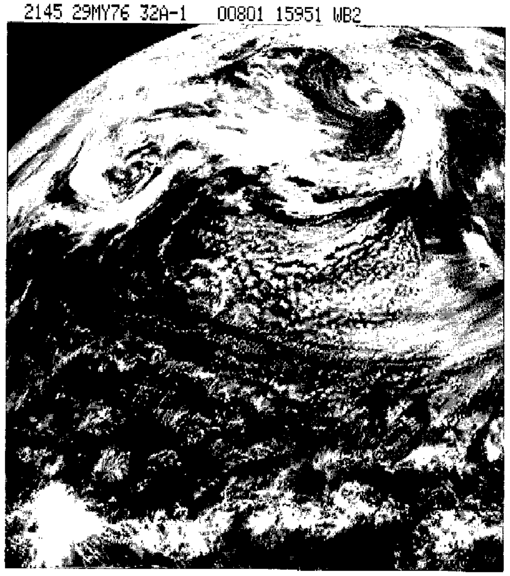

Figure 26. Satellite View of North Pacific Ocean Cloud Cover

A late spring storm is shown whirling ashore over the Pacific Northwest. The center of this counterclockwise spiral is just west of the northern tip of Vancouver Island. Clearing skies and cooler air will soon follow this Memorial Day storm. Far at sea, south of the Aleutian Island chain, another low-pressure cell is beginning to coalesce before moving eastward toward Oregon. (NOAA photo.)

The constant movement of air around these pressure cells delivers energy to the surface of the ocean. Thus, the surface circulation of the North Pacific Ocean is influenced by the direction and size of atmospheric flow, particularly the North Pacific high.

The North Pacific gyre is the great clockwise ocean circulation system spun from the North Pacific high. Although it encompasses virtually the entire North Pacific basin, the gyre is displaced toward the west side of the Pacific Ocean by the earth's rotation. As a result, currents along the coast of Japan are fast (40 to 112 kilometers per day) and narrow whereas those along the North American coast are slow (less than 10 kilometers per day) and wide (22).

This gyre is a composite of many different surface water masses and currents, each with distinguishing physical and chemical characteristics. Surface ocean currents flowing past the Oregon coast form part of the Subarctic Current, a broad, slow, cold current drifting easterly across the northern Pacific Ocean within the North Pacific gyre. Near the coast of North America this current divides in two: the Alaska Current loops north into the Gulf of Alaska, and the California Current swings southward along the Pacific coast (21).

Horizontal Circulation along the Oregon Coast

Much of the information presented on nearshore horizontal circulation is based on direct observations taken from current meters placed along the Oregon coast to record speed, direction, and temperature at regular 10- to 20-minute intervals. Although these measurements, taken over a period of several years, were widely spaced north and south, the data obtained can begin to describe general patterns of the ocean circulation system. Preliminary analysis suggests that currents are similar over alongshore distances of up to 200 kilometers (9) and across the width of the shelf (7).

Further analysis of current meter data indicates that ocean circulation off the Oregon coast responds principally to wind fluctuations and sea level. Currents over the shelf tend to flow in the same direction as the wind, south in the summer and north in the winter, not only at the surface, but to the bottom. Currents also correlate closely with sea level, flowing northward when sea level is high and southward when it is low. These general patterns become more complex when seasonal or localized conditions are considered.

On average, currents over the continental shelf and slope flow south at the surface and north along the bottom. This general behavior of ocean currents can be further refined for seasonal conditions. The summertime southward-flowing surface current responds to the northwest winds. It is called the California Current, a poorly defined and variable extension of the Subarctic Current. It is broad, approximately 500 to 1000 kilometers wide, and weak, moving an average of 4 to 8 kilometers per day (3). During the summer its speed may more than double within 100 kilometers of the coast (see Figure 27), reinforced by extended periods of northwest winds (21).

In summertime, the California Undercurrent is narrower, approximately 50 kilometers wide, and faster than the overlying California Current. It flows northward, flowing over the continental slope at depths below 200 meters (see Figure 27). The undercurrent, which originates off California, is believed to be linked to the equatorial Pacific water masses because of its slightly warmer temperature and higher salinity (3). This "poleward" (so named because it flows toward the North Pole) current may provide a feedback loop for nutrients which sink out of the productive surface waters to deeper water. These particles and dissolved substances can be transported back upstream and returned to the surface through upwelling (19).

In fall (late August and September), the southward surface current weakens and disappears. It is replaced by an increasingly strong poleward undercurrent that responds incrementally to each northward wind event of the oncoming winter.

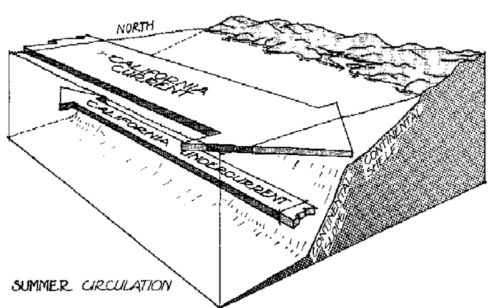

Figure 27. Summer Circulation off Oregon

The California Current, a broad, shallow surface current, drifts slowly southward over the continental shelf and slope during the summer. The California Undercurrent is a narrow, faster-moving current flowing northward at depths greater than 200 meters over the continental slope. This schematic diagram is not to scale.

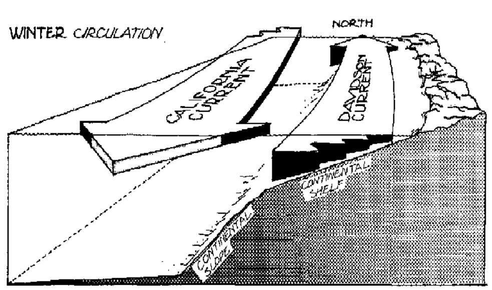

Figure 28. Winter Circulation off Oregon

The fast-moving, relatively narrow Davidson Current flows northward at all depths over the continental shelf. The California Current, flowing slowly southward on the surface, is pushed offshore by the Davidson Current. This schematic diagram is not to scale.

Winter flow (December to February) is northward at all depths over the continental shelf in response to the southwest winds. It is referred to as the Davidson Current (see Figure 28). It is a fast current, more than 150 kilometers wide (wider than the continental shelf) (6), and forms a band of low-salinity water from coastal runoff at least 90 kilometers wide (12). The Davidson Current extends from northern California to the Strait of Juan de Fuca and coincides with the direction of prevailing winter storm winds.

Transition to the regime of spring and summer circulation is accomplished over one or two days in response to a shift in the seasonal wind direction. Sea level falls as the North Pacific high sets in, bringing high atmospheric pressure and a reverse flow in currents.

Vertical Circulation along the Oregon Coast

Upwelling, an important ocean phenomenon, results from an unusual set of conditions most common along the west coast of North and South America, the west coast of Africa, and southern Europe. In coastal regions upwelling provides a consistent supply of nutrients that makes these waters some of the most productive in the world (15).

In Oregon, strong northwest winds begin in the spring and usually continue into the fall. As these winds blow south along the coastline, they produce currents which divert water to the right of the wind direction as a result of the Coriolis force (an effect of the earth's rotation) (see Figure 29). Studies off the central Oregon coast show that the surface layer in which the wind-driven offshore transport occurs is relatively thin—less than 20 meters deep (17). This offshore flow of water is replaced by an onshore flow of colder, nutrient-rich water that rises from depths of 100 to 200 meters. Vertical velocities of this onshore flow vary but have been estimated to be as much as 17.3 meters per day (12). Vertical flow is strongest near the surface and decreases rapidly with distance from shore (7).

Since the upwelled water now at the surface nearshore is denser and colder than the water it replaced, now farther offshore, a strong onshore-offshore pressure difference in the water column is established. This east-to-west gradient leads to lowered sea surface levels at the coast and causes a southward surface current called a coastal jet whose velocity is greatest (approximately 25 centimeters per second) 15 to 20 kilometers from shore (8).

As the local wind stress varies from day to day and from season to season, significant variations in the strength of coastal upwelling occur. Most upwelling occurs as a series of pulses or "events" with a time scale of days to weeks, as long as winds are favorable. When these northwest winds cease, warmer sea surface temperatures return to the area in a matter of days. Upwelling events can occur even in the winter when winds, generally from the south, shift direction and create the necessary conditions for upwelling (8).

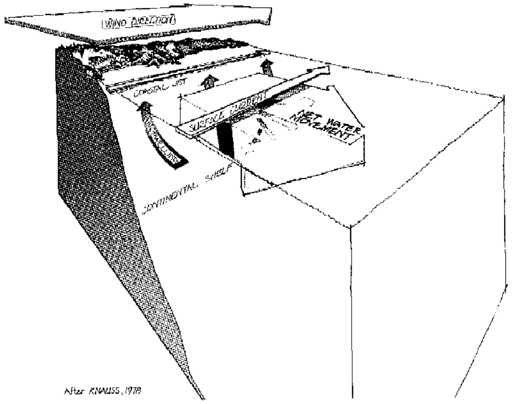

Figure 29. Offshore Water Transport and Upwelling

Wind blowing across the water sets up a spiral of water movement within the upper 20 to 40 meters of the surface. The result is a slow movement of this surface layer at right angles to the wind direction. Off Oregon, strong north winds in summer result in water moving seaward; deeper, nutrient-rich, high-salinity water flows shoreward and upwells into surface layers. A fast, narrow coastal jet develops along the coastline, moving in the direction of the wind.

Active upwelling is restricted to a narrow band ranging from 10 to 30 kilometers from shore, but it may influence a much larger region. Satellite infrared photos show that colder upwelled water is swept offshore as patches, tongues, and plumes that continually change shape (see Figure 30).

Just as wind direction influences horizontal surface flow, changes in wind direction can result in changes in vertical circulation. During winter, when winds frequently blow to the north, downwelling occurs. These north-blowing winds cause water surface transport to shift onshore (to the right). Water then "piles up" at the coast and, having nowhere to go, sinks and then moves offshore.

Upwelling, a product of seasonal winds, in turn strongly influences the climate of the coastal area and by extension the entire Pacific Northwest (13). Nearshore upwelled water is cooler than offshore water; warm marine air passing over these waters is cooled and forms fog. This cool, foggy air is pulled landward by warm air rising over inland areas.

Deep Ocean Circulation

Off Oregon, a deep poleward current has been verified over the continental slope in spring and early summer (7). Little is known of the deep ocean circulation off the Oregon coast beyond the continental slope since there are few direct measurements.

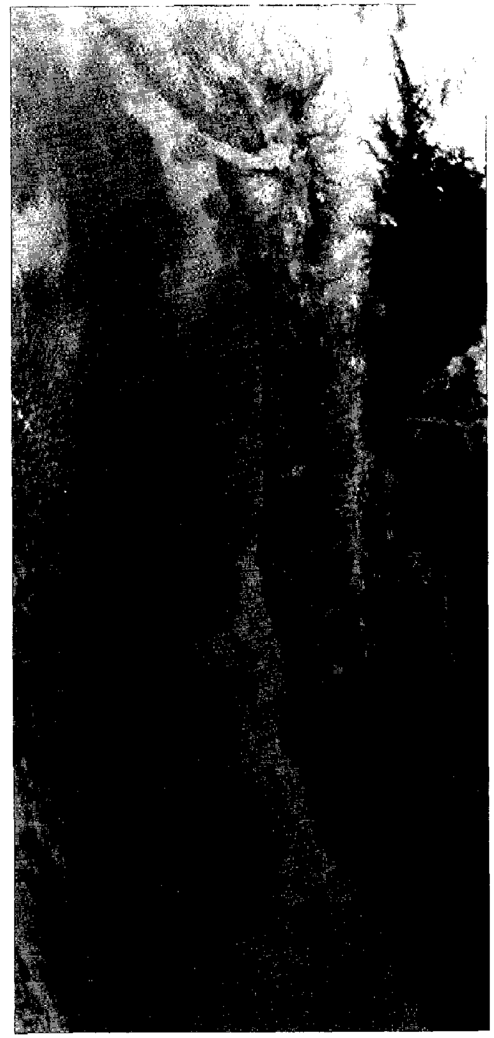

Figure 30. Infrared Satellite Photo of Upwelling

An infrared scan of the Pacific coast from Vancouver Island to just south of Monterey Bay, California (NOAA satellite, September 11, 1974, from 1,500 kilometers), shows cold, upwelled water as lighter grey areas along the coastline. Warmer water offshore shows as darker grey. Clouds (upper right corner) appear white. Upwelled water forms tongues and plumes which continually change.

Eddies

Satellite surveillance is a recently developed tool which is assisting in the study of large-scale ocean circulation features (20). Satellite images of the California Current reveal several eddies between Baja California and Vancouver, British Columbia. As large as 150 kilometers in diameter, these eddies rotate clockwise at about one kilometer per hour and drift slowly southward with the current (16). Their origin and extent have not yet been determined, but their formation and behavior appear to be linked to features on the ocean bottom such as the Mendocino Fracture Zone and to coastal features such as Point Conception in southern California.

El Nino

During the winter of 1982 and spring of 1983, an unusual set of ocean conditions occurred off the west coast. Sea temperatures were unseasonably warm, high seas and tides slammed onto the Pacific coast, causing substantial erosion, and heavy rains repeatedly drenched California. In Oregon, although upwelling may have continued, the cold, nutrient-rich water was replaced by warm, nutrient-depleted water which had a marked influence on the decline in fish harvest (19). These conditions are associated with El Nino, a periodic phenomenon noted and best studied off the coast of South America.

The causes of El Nino are not known exactly, but a clearly important relationship exists between the atmosphere and the oceans (10). The initial manifestations of El Nino off Oregon were noted in October 1982: anomalously high sea level, high coastal sea surface temperature, and increased poleward flow. These oceanic conditions occurred within one month of the onset of El Nino off Peru and preceded any atmospheric effect in the North Pacific by two to three months. The atmospheric conditions appeared in December and January, enhancing the initial effects and then inserting their own signal.

During a normal year, a persistent high-pressure system prevails over the western Pacific near Malaysia and a low-pressure system over the Indian Ocean. The pressure differential causes tradewinds to blow westward across the Pacific. In addition, the Peru and California Currents (see Figure 25) meet at the equator and then swing westward as the South and North Equatorial Currents, respectively. The tradewinds, combined with the westward-flowing equatorial currents, cause warm water to pile up in the western Pacific.

In an El Nino year, the atmospheric pressure system breaks down. As the tradewinds relax, the westward-flowing equatorial currents subside. In the absence of the forces needed to maintain high sea level in the western Pacific, a slosh of warm water begins to flow back across the ocean (19). When this water reaches the Americas, it spreads north and south along the coast. It is first detected by a slight rise in sea level. Later, weather and oceanic conditions such as those observed during the winter of 1982 and spring of 1983 begin to appear.

PHYSICAL PROPERTIES OF THE OCEAN

A large part of physical oceanography is concerned with the distribution of salinity, temperature, and ultimately, density of the ocean. Much can be learned by observing small variations in these properties: how oceans circulate, how heat is exchanged across the ocean surface to maintain a relatively constant global temperature, and how sound waves behave in the ocean.

Salinity

Seawater is a complex fluid, approximately 96.5 percent pure water and 3.5 percent dissolved salts. These salts include sodium chloride (common table salt), magnesium, sulfate, calcium, potassium, and other constituents in smaller amounts. A typical 1-kilogram sample of seawater will contain about 19 grams of chlorine, 11 grams of sodium, 1.3 grams of magnesium, and 0.9 gram of sulfur (5). Salinity, the saltiness of the water, is measured in parts per thousand (o/oo). The average salinity of the world's oceans is 35 o/oo. (2).

Temperature

With a few exceptions, the temperature of the oceans decreases with depth as the influence of surface heating becomes less pronounced. The water in the lower half of all the oceans is uniformly cold. Originating principally in the Antarctic Ocean, this cold, saline water sinks to the ocean floors and then spreads along the bottom toward the equator. Surface temperatures over the continental shelf vary from about 10° C in winter to 14° C in early summer. Surface temperatures decrease during summer upwelling to about 10° C (7).

Density

The ocean's density depends on three factors—temperature, salinity, and to a lesser degree, pressure (see Figure 31). Temperature and density are inversely related; that is, a change in temperature produces the opposite effect on density. Salinity and density, on the other hand, are directly related; that is, an increase in salinity produces an increase in density. Pressure becomes a factor only in very deep parts of the ocean; if the temperature is kept constant, an increase in pressure will cause an increase in seawater density.

Variations in the density of seawater are partly responsible for keeping the ocean's currents in motion. In the ocean, water generally forms layers of increasing density with depth. Where density layers are well developed and stable, as in the open ocean, vertical circulation is inhibited; in nearshore coastal waters, energy supplied by the wind can disturb the stratification enough to bring deeper, denser water to the surface.

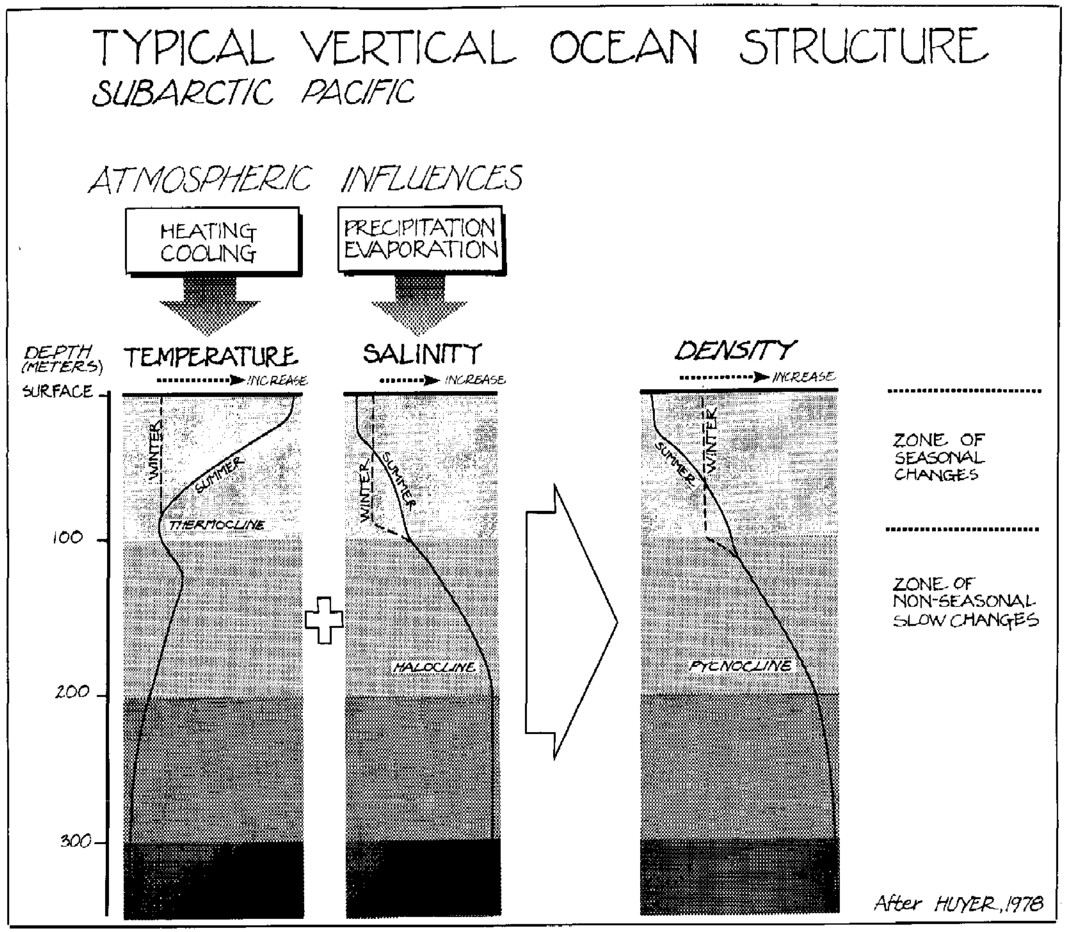

Figure 31. Vertical Structure of Pacific Northwest Ocean

Atmospheric influences lead to short-term changes in the upper layers of the ocean. The depth of the surface layer changes seasonally depending on surface inputs. Zones of rapid change buffer the more stable deeper waters from the dynamic upper layer:

Temperature (left): In the seasonal layer, a temperature high at the surface (due to solar heating) drops rapidly with depth in summer;

Salinity (middle): During both summer and winter, salinity is relatively low and uniform in the seasonal layer (upper 100 meters) but increases with depth in the permanent halocline—a zone beyond the reach of seasonal influence;

Density (right): Density reflects salinity and temperature changes both within the seasonal surface layer and below.

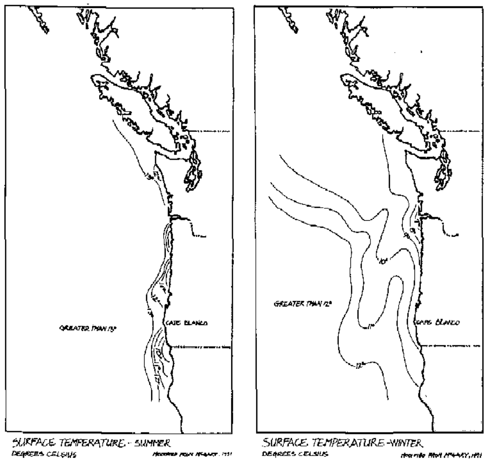

Figure 32. Sea Surface Temperatures

Mean annual temperature variations at the surface of the Pacific Ocean are relatively small. Because of the sun's seasonal effect, the mean summer temperature is 14° C while the mean winter temperature is 9° C. Summer upwelling brings colder, deeper waters to the surface along the central and south coast shoreline and supresses the normally high summer surface temperatures. During the summer, the warmer Columbia River waters are pushed seaward.

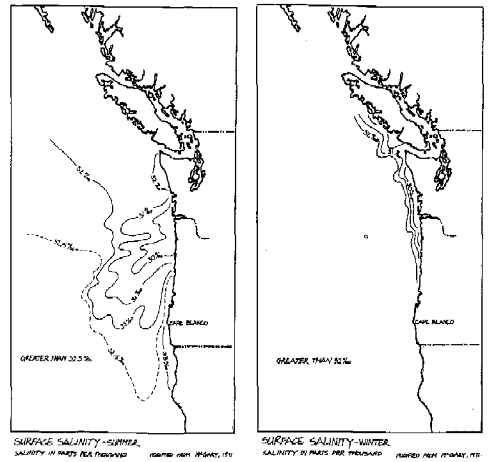

Figure 33. Sea Surface Salinity

The salinity of the surface layers off the Pacific Northwest reflects the freshwater inflow from the Columbia River. In summer a lower salinity plume spreads southwest. Its shoreward boundary may be pushed to sea by colder, highly saline, upwelled water. In winter, the Columbia River discharge creates a band of lower-salinity water along the coastline from Tillamook to the Strait of Juan de Fuca.

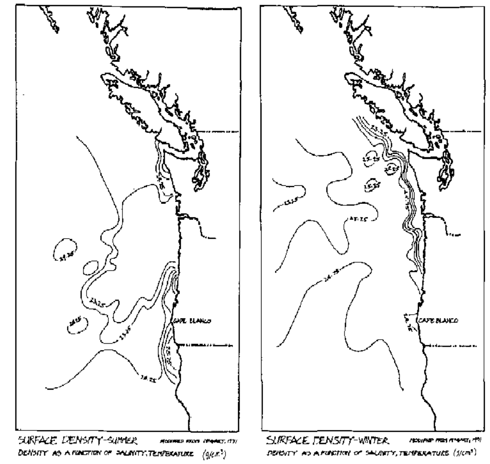

Figure 34. Sea Surface Density

Density is a result of temperature and salinity. Summer surface density is clearly influenced by the large freshwater flow from the Columbia River over a broad area and by the upwelling of cold, saline waters along the coastline. Likewise in winter the freshwater discharges from the Columbia and other coastal rivers result in a band of less dense water along the northern Oregon and Washington coastlines.

Vertical Structure

Oceanographic regions throughout the world vary in salinity and temperature as a result of particular combinations of heating, cooling, evaporation, and precipitation (22). A unique set of these environmental conditions occurs in an area of the northeast Pacific Ocean, referred to as the Subarctic Region, and gives the waters of the eastern North Pacific a distinctive vertical structure (see Figure 31). The upper layer is influenced by seasonal temperature and salinity fluctuations (13). In winter, precipitation, coastal runoff, and storm conditions produce a thick (75- to 100-meter) layer of low-temperature, low-salinity water. In summer, heating of surface waters and less intense wind conditions create a much shallower, warmer, surface layer. However, the salinity content of this summer surface layer is reduced by the large volume of fresh water from the Columbia River (13).

Below the influences of seasonal temperature and salinity fluctuations lies a middle zone where salinity and density increase rapidly with depth but where temperature remains relatively uniform. The greater density of this layer acts as a barrier to low-density surface water which cannot readily move down through it. In the third and deepest layer little change occurs; temperature slowly decreases and salinity slowly increases with increasing depth.

Horizontal Structure

Off the Pacific Northwest coast, surface water properties change over horizontal distance depending on the season of the year. The Columbia River has a significant impact on the makeup of the Pacific Ocean (see Figures 32, 33, and 34). Because the Columbia River drains an area of 662,000 square kilometers (13), its freshwater outpouring creates a sizeable plume of low-salinity water that differs markedly from the more saline ocean waters farther to the west. This plume migrates seasonally in response to local winds. In summer it forms a broad tongue of low-salinity (32.5 o/oo) water widely spread to the south; its inner edge may be pushed seaward by cold, saline water during periods of upwelling (see Figure 33). In winter this plume is driven by the Davidson Current and storm winds along the northern Oregon and Washington shoreline (see Figure 33).

Coastal upwelling also creates a marked difference in horizontal structure. Cold, nutrient-rich, high-salinity water rises to the surface along the coast during the late spring, summer, and fall, displacing warmer, nutrient-poor, lower-salinity surface water offshore (see Figure 32).

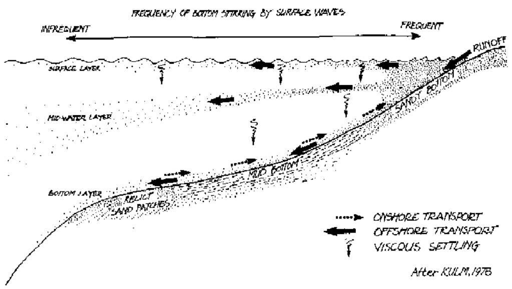

Figure 35. Turbidity Layers

Coastal erosion and river discharge add fine particles to the inner shelf, and surface waves, particularly in winter, stir bottom sediments, thus creating three turbid layers over the continental shelf. Wave action suspends fine particles and prevents them from settling to the bottom. In deeper water, waves reach bottom infrequently, allowing mud layers to accumulate.

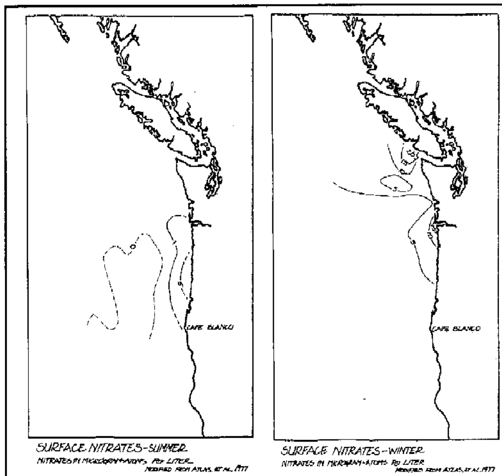

Figure 36. Nitrate Distribution

Inorganic nitrogen (nitrate) is the one nutrient usually in shortest supply off Oregon. A continual supply is essential for biological productivity. Winter discharges from the Columbia River and Juan de Fuca Strait show strong nitrogen input, but by late spring increasing biological productivity has significantly depleted available nitrates. Summer upwelling is the principal means of resupplying nitrogen to surface waters within a relatively narrow band along the coastline.

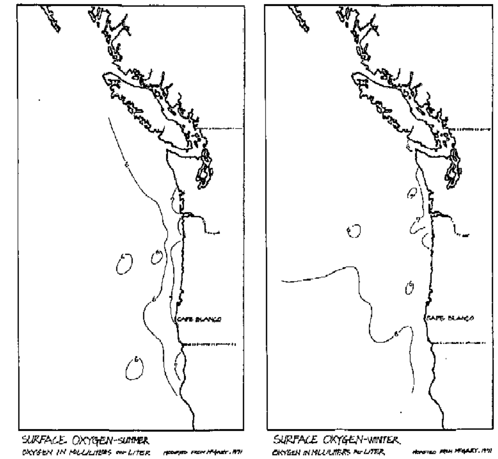

Figure 37. Sea Surface Oxygen

Oxygen is exchanged between the air and the ocean and is generated by plant growth within the sunlit surface waters of the ocean. In summer, upwelling brings nutrient-rich waters to the surface along the coast and promotes rapid plant growth. Thus, oxygen produced by plant photosynthesis masks the otherwise oxygen-poor nature of the upwelled water. Winter oxygen levels are influenced by wind mixing and precipitation at the surface of the water.

Turbidity, Nutrients, and Dissolved Gases

Turbidity, nutrients, and dissolved gases are also important physical attributes of coastal waters, particularly as they affect biological productivity. The concentration of these properties may change vertically from the surface to deeper water and they may change horizontally along the coast and with distance from shore.

Turbidity is an expression of fine particle concentration in the water column. Three turbid layers have been identified in the coastal waters off Oregon (see Figure 35) (also see in Chapter Two, "Sediments of the Continental Shelf"). The upper layer consists of organic and inorganic material originating from coastal rivers, especially the Columbia River, and from material suspended by wave action in the surf zone. Organic solids include excreted waste particles, the minute hard parts of microscopic organisms, and other plant or animal debris. Inorganic solids range from molecule-sized clay particles to larger particles of dust and silt (5). Away from the influence of nearshore sources, surface turbidity can be caused by an abundance of plant growth. The midwater layer extends to a depth where a rapid increase in density prevents continued settling of material from the water above. This material consists of ultrafine particles derived from living things (called biogenous sediment) and from the earth, such as sand, silt, and clay (called terrigenous sediment) (4). Material in the bottom turbid layer may originate in the surf zone but may also result from rippling of the bottom by wave action and resuspension of sediments by bottom currents (11). Between these layers, the water is quite clear.

Off Oregon, nutrient building blocks such as carbon, nitrate (see Figures 36, 37), phosphate, and silicate are introduced into coastal waters from three major sources (1). First, the slowly circulating waters of the northeast Pacific Ocean bring in a low but steady supply of nutrients. In the late spring, summer, and early fall, the Columbia River adds an important seasonal nutrient pulse (1) with high levels of silicate, moderate amounts of nitrogen, and phosphate levels comparable to those in the incoming ocean currents. Perhaps the most important source of nutrients is the highly saline upwelled water which brings nitrogen, phosphates, and silicates to surface layers during the summer months (see Figure 38) (12).

A steady supply of nutrients in the water is a critical factor in the ocean's biological production. If there were not a steady inflow of nutrients to the sunlit surface layer, those nutrients already present would be consumed and further productivity would be severely limited.

Weather patterns affect the seasonal distribution and amount of nutrients available over the continental shelf area. In winter, moderate, uniform concentrations of nitrogen are present off much of the Oregon coast (see Figure 36), but low light levels and low temperatures result in diminished biological productivity. Increased light, temperature, and nutrient supplies in spring stimulate plant growth. Nitrates and phosphates are reduced at the surface, which leads to a lull in productivity prior to the onset of upwelling. In summer and fall, upwelling brings an abundance of nutrients from deeper waters to the surface along the coast, enabling high levels of plant growth (see Figures 36, 38).

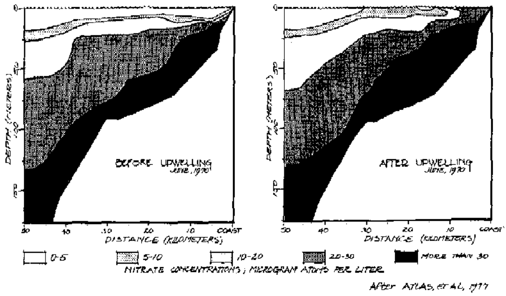

Figure 38. Vertical Nitrate Distribution

A comparison of the vertical distribution of nitrates immediately before and several days after an upwelling event shows a sharp increase in nitrate levels in the surface layer. Upwelling is fundamental to biological productivity along the Oregon coast.

Seawater also contains a number of dissolved gases which enter the ocean across the air-sea interface or which are generated during biological processes. The major gases are oxygen, nitrogen, and carbon dioxide. Gas bubbles are formed by breaking waves and the impact of raindrops and are important in two ways. They transfer gases from the air to the ocean and back again, and they carry minute salt particles, trapped within bubbles, into the atmosphere where they act as nuclei for water condensation and precipitation (2).

Oxygen concentrations are an important measure of the health of nearshore waters, especially where circulation is sluggish. Oxygen is generated in coastal waters as a product of photosynthesis (plants convert the sun's energy to living material through photosynthesis) and is introduced through exchange with the atmosphere. These processes, as well as the mixing of water masses, control the distribution of oxygen (see Figure 37). In summer, upwelling brings nutrient-rich but oxygen-depleted waters to the surface, where prolific plant growth returns oxygen to the water. Wind and waves mix the water column and increase the depth of oxygen penetration.

TIDES

On the open coast, tides determine animal and plant distribution in the intertidal area and contribute to coastal erosion, especially during winter when high tides and storms combine to tug at the shore. Tides are also of fundamental importance to estuarine circulation and to the animals of the open ocean which depend upon the estuary as nursery or feeding grounds. In this way, tides contribute to the productivity of the entire marine environment.

Tides, the regular rise and fall of sea level, are caused by the gravitational pull on the earth by the moon and sun. The moon, though smaller than the sun, exerts a stronger pull because it is so much closer to the earth. Its force is more than twice that of the sun. The gravitational attraction of the moon pulls ocean water nearest it away from the earth and at the same time pulls the earth away from the water farthest away. Two equal tidal bulges result on opposite sides of the earth (see Figure 39).

Lead by the moon's orbit about the earth, the tidal bulges move across the ocean as a long-period wave. A particular location on the earth will come under the influence of the moon each 24 hours and 50 minutes, slightly longer than one day. Since the moon's orbit is offset from the earth's equator by approximately 23.5 degrees, the Oregon coast experiences a procession of unequal tides spaced approximately six hours apart. These tides move northward up the coast; Coos Bay has high and low tides approximately 20 to 30 minutes earlier than those on the Columbia River (13). Each day there is a higher high tide, then a lowest low tide, then a lower high tide, and finally a higher low tide before returning to another higher high tide.

When the sun and the moon are in line with the earth, as at a new and full moon, their combined effect produces larger than normal, or spring, tides. When the sun, moon, and earth are at right angles, as at the first and third quarter moons, their forces counteract each other, and smaller tidal ranges, or neap, tides result. The earth is also closest to the sun during December, producing the highest tides of the year.

Tides produce minor coastal currents, but these are usually weak and masked by nontidal currents in the open ocean. Tidal velocities increase, however, when the tide moves through constricted channels like the mouths of coastal estuaries.

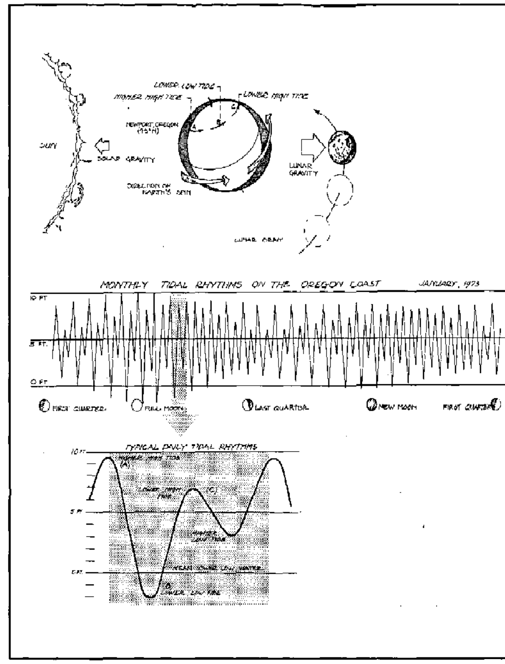

Figure 39. Tidal Rhythms on the Oregon Coast

A monthly progression of high tides and low tides at Coos Bay illustrates daily and monthly fluctuations in tide heights. The Earth rotates daily beneath tidal bulges, but the tilt of the Earth's axis results in a higher high tide at (A), a lower low tide at (B), and lower high tide at (C), and a higher low tide (hidden) before returning to (A). The Moon's orbit around the Earth brings it in and out of line with the sun.

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CHAPTER FOUR
PLANKTON
The Drifters

INTRODUCTION

Plankton are free-floating plants and animals of the sea having little or no ability to resist the current. Often transparent and quite small, they are not the most noticeable organisms in the sea though they are certainly some of the most important. Phytoplankton, simple single-celled plants, form the base of the pelagic food chain. These inconspicuous marine plants also produce 95 percent of the sea's oxygen, an element necessary to sustain all living creatures. Millions of years ago, plankton settled to the bottom of shallow coastal seas, where they were buried and subsequently compressed, forming the oil and gas deposits tapped today. Zooplankton, small free-floating animals, range in size from ultraminute organisms to large jellyfish. More complex than phytoplankton, these tiny animals convert plant material to animal tissue and provide the vital link between phytoplankton, the primary producers, and the rest of the ocean food web.

PHYTOPLANKTON

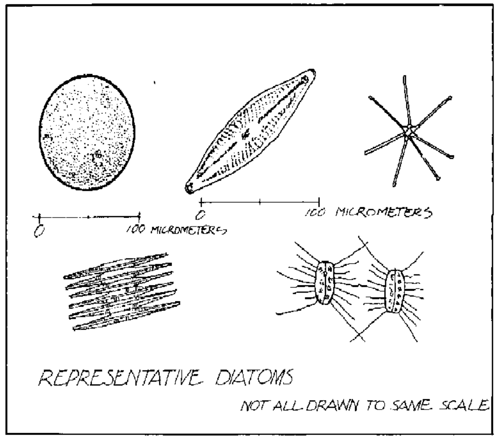
As on land, photosynthetic plants growing in the sea are the basis for most forms of life, converting the energy of sunlight into organic materials such as sugars, starches, fats, and proteins, which are then used by a vast array of marine animals. To synthesize these basic building blocks, phytoplankton require nutrients: nitrogen, most common in the sea combined with oxygen as nitrate; phosphorous, present as phosphate; carbon, potassium, sodium, calcium, and sulfur, all plentiful in the sea; trace metals; and vitamins.

Photosynthesis requires that phytoplankton remain at the surface in the sunlit waters of the euphotic zone. Lacking their own means of mobility, phytoplankton have adapted special means of remaining afloat. Smallness increases their resistance to sinking and facilitates the diffusion of nutrients into their cells. Some form chains or grow ornate appendages like wings or spines which help to keep them at the surface. In addition, surface-mixing processes of wind, waves, and currents assist in keeping these tiny plants within the euphotic zone.

Plant plankton fall into two size classes: the nannoplankton, those that are too small to be captured in a fine net, and the net plankton, plankton large enough to be sieved and captured in a net. Phytoplankton can also be classified by locomotion: some have whiplike swimming appendages called flagella, whereas others are true free-floaters. Although many different groups make up the phytoplankton, two are particularly important in coastal waters: diatoms and dinoflagellates (see Figure 40).

Diatoms are widely assumed to be the most common plants in the sea. They have an external shell composed of glasslike silica (see Figure 41). When diatoms die and fall to the ocean floor, they become a major constituent of marine sediments, especially in higher latitudes (20).

Each shell has two valves which fit together much like a pill box. A diatom can reproduce both sexually and asexually by simple cell division. When a diatom divides, the two valves separate, new opposing



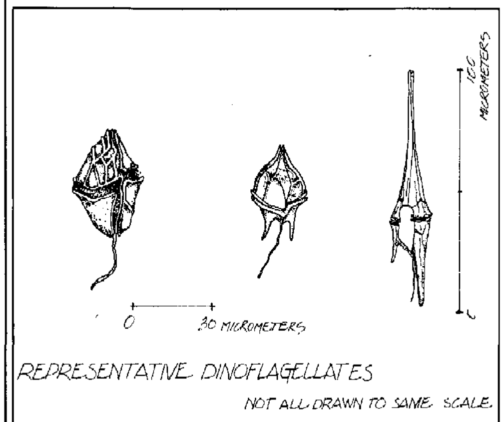


Figure 40. Phytoplankton of the Oregon Coast

Phytoplankton off the Oregon coast vary in size and shape. The diatoms and dinoflagellates shown here are typical examples. They are not all drawn to the same scale.

valves are secreted, and the parent ceases to exist. Simple cell division accounts for the rapid growth in phytoplankton. Dividing once a day, a single cell can produce a billion copies of itself in a month (20).

Dinoflagellates are a diverse group; some are plants, some are animals, some have an external cell wall of cellulose (hence the prefix *dino:* "armored"), and some are naked. The presence of toxins distinguishes others of the group. Mussels along the Oregon coast feed on phytoplankton, including dinoflagellates. If dinoflagellates are abundant enough to create a "red tide" (so called because of the color imparted to the water by the explosive growth of these organisms), they will be consumed in huge quantities by mussels. Toxins from the dinoflagellates can be stored in mussel tissue, often to the point that the mussels become extremely poisonous to humans who eat them. As a result, mussels are occasionally put off limits for human consumption.

In addition to studying diatoms and dinoflagellates, marine scientists recently began to appreciate the importance and wide distribution of the microflagellates. Somewhat neglected over the years, these microscopic plants are so small that they are difficult to sample and analyze. Scientists now use closeable bottles rather than nets in an attempt to capture and study these small organisms (20).

Phytoplankton Production

Determining the amount of organic material produced by marine plants is important in assessing the amount of food ultimately available to support the marine food web. Phytoplankton abundance in the ocean varies, depending on location, season, and even time of day. These variations are measured in two ways: by standing crop, which is the number or weight of individuals present at any one time (a static quality), and by productivity, which is the rate at which these microscopic plants convert nutrients and carbon dioxide into new plant tissue using light energy from the sun (a dynamic quality).

Since plants are the first step in converting the sun's energy to an organic form, they are called primary producers. Biomass, or primary production, can be measured by sampling a known volume of seawater, allowing the plankton to settle, and then either drying and weighing the sample or burning it and estimating the amount of organic matter from the amount of carbon dioxide driven off. Problems in separating live from dead material and in distinguishing plant from animal species prompted development of a second technique. The green pigment in plant cells, chlorophyll, is the link between the sun and virtually all life. Measurement of the amount of chlorophyll a (one of several types of cholophyll) can give an accurate count of plant production.

Phytoplankton productivity is controlled by several factors—light and nutrient availability, temperature, mixing, and herbivore grazing. Light and nutrients are essential; without them photosynthesis cannot take place. Temperature influences the rate at which metabolic processes proceed; photosynthesis and, in turn, respiration (which consumes the products of photosynthesis—oxygen and sugar) proceed more rapidly at higher temperatures than at lower ones. Mixing keeps phytoplankton suspended at the surface, but if too virgorous, forces them below the euphotic zone. Nutrients are also brought within the reach of phytoplankton by mixing and other circulation processes. Herbivores graze on phytoplankton, reducing their number, but may also be important in supplying nitrogen through excretion, which in turn can have a positive effect on phytoplankton populations.

In the temperate waters off Oregon, two factors are particularly critical: light intensity and nutrient concentrations. Light intensity varies daily and seasonally with cloud cover, day length, and sun angle. Moreover, turbid waters can significantly decrease the depth of sunlight penetration into the surface waters, thereby decreasing the zone in which light is sufficient to support plant growth.

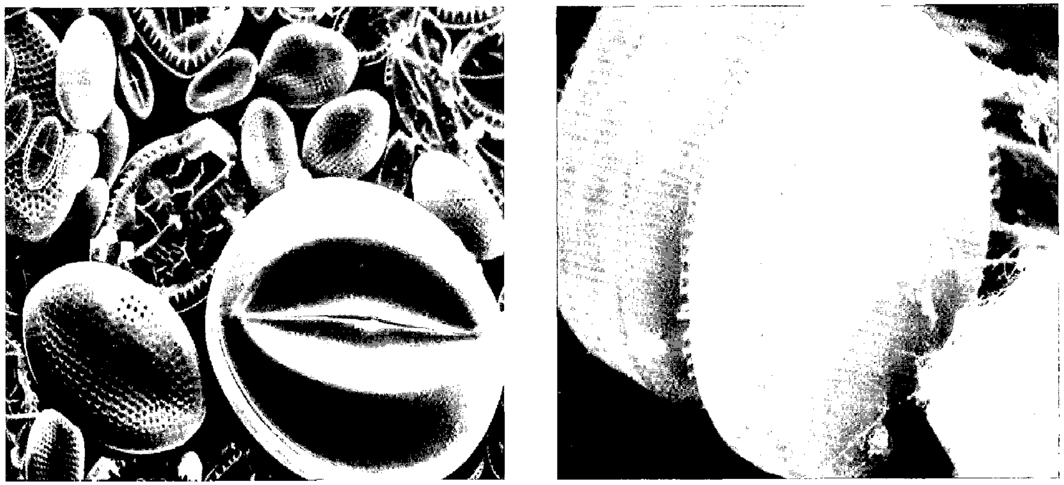


Figure 41. Electron Micrographs of Phytoplankton

Phtographs made with the powerful scanning electron microscope reveals the shape, structure, and surface texture of diatoms. On the left, diatoms on eel grass are shown 1000 times life size (photograph by Michael Eng). On the right, diatoms on a squid are shown 1600 times larger than life (photograph by Carla Stehr). These photographs, called electron micrographs, were made at the Electron Microscopy Unit, National Marine Fisheries Service Northwest and Alaska Fisheries Center in Seattle, Washington, and are courtesy of Carla Stehr.

Of the many nutrients needed by plants to grow, inorganic nitrogen is the one which is usually in shortest supply. It is therefore a limiting factor which may place a ceiling on plant growth. As phytoplankton grow, inorganic nitrogen is removed from the surrounding water. To sustain growth, nitrogen and other nutrients must be continually supplied to the euphotic zone. The most important mechanism for replenishing inorganic nitrogen to the euphotic zone is upwelling (see "Oceanography: The Water"). Dead and decaying matter (detritus), fecal pellets, and dissolved waste products drift down through the water column and are eventually remineralized by marine bacteria into a form that can be used once again by the phytoplankton.

Upwelling areas, like the coast of Oregon, are regions of high production as compared to the open ocean (18). Annual primary production on the Oregon continental shelf is typical of that found in many other upwelling locations, with values ranging between 200 and 300 grams of carbon per square meter (2, 22). In waters west of the shelf, total yearly production has been estimated to be 125 grams of carbon per square meter, a value considered typical of temperate oceanic regions (2, 17, 18).

Nearshore phytoplankton growth is closely tied to seasonal fluctuations. During the winter, surface wind-driven mixing produces sufficient nutrients, but light and temperature levels are too low for plant growth. Mixing disperses many plant cells below the euphotic zone. In spring, however, nutrients remaining from the winter are present at the surface, and phytoplankton growth increases as the days lengthen and temperatures warm.

The onset of upwelling replenishes the surface waters with nutrients depleted by spring phytoplankton growth. Phytoplankton populations respond to increased nutrient availability by producing outbursts of growth called blooms. Phytoplankton growth and subsequent grazing by herbivores again reduce nutrient levels, and by fall, shortening day length and colder temperatures set in. Periodic upwelling events at this time of year, however, can lead to small increases in phytoplankton. The highest concentrations of phytoplankton during an upwelling event are often found in bands lying parallel to the coast. The position of the bands depends on the intensity of upwelling and the width of the continental shelf (see Figure 42).

Few studies have been made of Oregon's phytoplankton populations west of the continental shelf. However, the species composition of phytoplankton in oceanic waters differs from that of the coastal zone and diatoms are much less important as primary producers. Phytoplankton abundance offshore is much lower than in coastal waters and, rather than being concentrated in the upper 20 meters as in coastal waters, reaches a maximum during the summer around the seasonal pycnocline at 60 meters (2). Because many phytoplankton species are adapted to certain light intensities, a chlorophyll layer at this depth may indicate an assemblage of diatoms able to photosynthesize in the presence of adequate nutrients at much lower light intensities than at the surface (2).

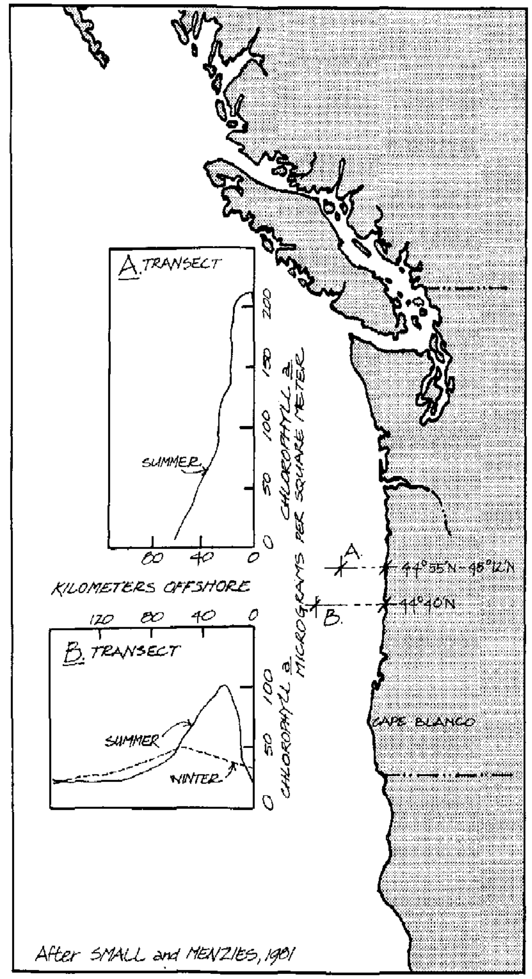


Figure 42. Phytoplankton Concentrations over the Continental Shelf

Samples taken along two transects over the Oregon continental shelf near Newport show phytoplankton concentrations per square meter to be twice as great over the narrow shelf (Transect A) as over the wider shelf (Transect B), but total abundance is approximately the same.

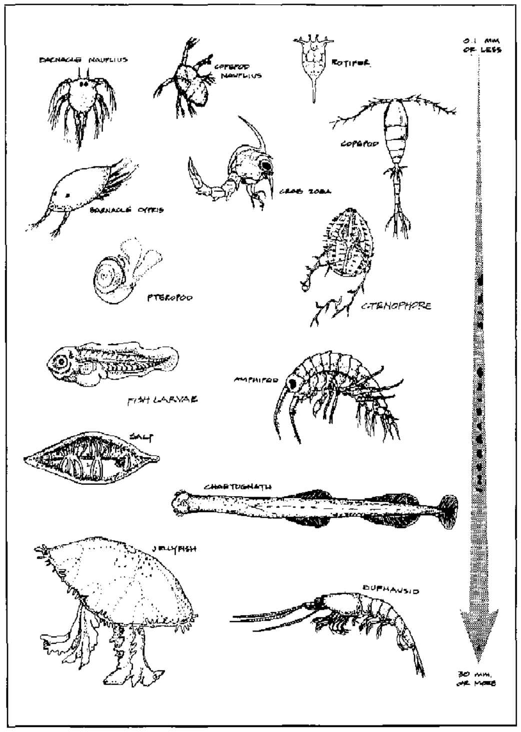


Figure 43. Zooplankton off the Oregon Coast

Many different animal groups are represented among zooplankton samples taken off the coast of Oregon. These drawings are not drawn to the same scale but are arranged from top to bottom by increased size.

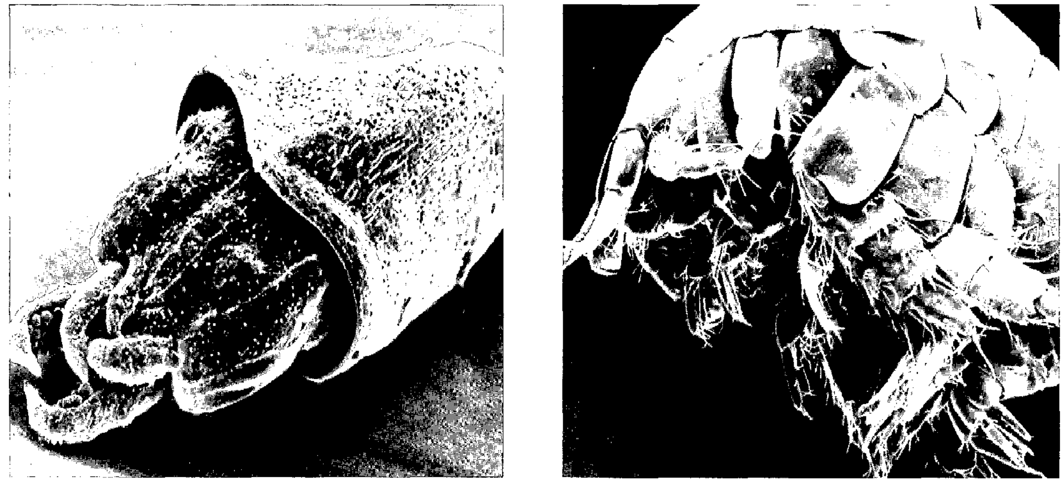


Figure 44. Electron Micrographs of Zooplankton

Zooplankton, while typically much larger than phytoplankton, are none-the-less very tiny. The scanning electron microscope gives marine scientists a valuable look at surface details which aids in understanding how organisms develop at an early stage. On the left, a newly hatched squid, shown 50 times life size, displays many of the features of an adult, including tiny suckers on its not-yet-developed tentacles (photograph by Carla Stehr). At right, a marine amphipod, Rhepoxynius abronius, *is magnified 40 times to reveal a body with segmented plates (photograph by Caron Stehr). (Photographs courtesy of Carla Stehr.)*

Beyond the shelf, winter mixing increases nutrient concentrations at the surface. In summer a thin layer of Columbia River plume water (see "Oceanography: The Water") begins to spread over the region, surface waters warm, and the water column stabilizes. Conditions are ready for phytoplankton production, which then begins to deplete the supply of nutrients within the surface layer. Consequently, production decreases throughout the summer. A slight increase in production can occur in fall, when stratification breaks down because of the onset of surface wind mixing, and nutrients return to the surface (1, 2).

ZOOPLANKTON

Nearly all groups of marine animals have at least one developmental stage when they can be considered zooplankton. The young of most nekton (animals that can swim) are planktonic, and many benthic organisms release planktonic larvae to the water column. That larvae can drift can be both an advantage, as when the larvae of attached bottom-dwelling organisms are dispersed widely to find suitable environments, and a disadvantage, as when currents carry the young beyond their range of environmental tolerance.

Zooplankton lifestyles are far more varied than those of phytoplankton. Zooplankton have developed ways of pursuing and apprehending food. Most are multicellular, not unicellular. Reproduction is sexual rather than asexual, and the advanced zooplankton have more carefully programmed behavior for bearing young to increase their odds for survival (20).

Many groups make up the zooplankton, including chaetognaths, larvaceans, ctenophores, medusae, pteropods, amphipods, euphausiids, and the larval stages of many fish and benthic invertebrates (see Figure 43). Of these groups, the copepods, jellyfish, and euphausiids make up over one-half of the animal biomass of the pelagic habitat; copepods are the most abundant life form in the waters of this region (6).

Zooplankton occupy the first few levels of the trophic pyramid above the primary producers (see also Figure 3 in "Marine Ecology: Life and the Environment"). Some are herbivores, grazing on phytoplankton, whereas others are voracious carnivores, preying on other zooplankton. Eleborate food-gathering mechanisms have evolved to capture the variety of food items consumed by the zooplankton.

Although zooplankton are not restricted to the euphotic zone as are marine plankton, many of them live by grazing and must remain in the surface waters. However, zooplankton are less affected by sinking, since they have more swimming ability. Many groups of zooplankton migrate vertically in the water column, surfacing at night to feed and spending the daylight hours in the dimly lit water 100 to 200 meters below (see Figure 45).

Zooplankton are an important link in the marine food web, converting plant material to animal tissue. Although the specific food habits of most animals off Oregon are unknown, it is likely that most fish and larger pelagic invertebrates feed on zooplankton at some time during their life history. Numerous species of fish, including juvenile salmonids, myctophids, Pacific herring, and northern anchovy, as well as squid and shrimp, are known to eat zooplankton (11, 19).

The pelagic food web is based primarily on grazing, that is, zooplankton eating phytoplankton. A large portion of the energy produced by phytoplankton flows through the zooplankton to the higher trophic levels as indicated by a consumer-to-producer biomass which approaches one-to-one (6).

DIEL VERTICAL MIGRATION

Many groups of marine organisms move vertically within the water column each day. Migrating species typically spend the daylight hours at depths below 100 meters. During the early evening, individuals swim to the surface and feed. Before sunrise, these species again move downward to spend the day at depth.

Off Oregon, the most common vertical migrators include myctophid fishes, pelagic shrimps, and euphausiids (6, 8, 5, 9, 23). Pictured below are the day and night abundance patterns for two dominant species, the myctophid fish *Stenobrachius leucopsarus* and the shrimp *Sergestes similis*, and typical euphausiids. The movement of individuals to surface waters at night is readily apparent.

Few generalizations can be made concerning the relationships between species which migrate and those which do not. Both herbivores and carnivores demonstrate migratory behavior. Within any one animal group or within any one genus there is considerable variability in the number of species which migrate vertically. Even members of the same species may or may not move vertically within the water column on a daily basis. For example, a portion of the *Stenobrachius* population fails to migrate to the surface at night. Those which do not migrate remain below 400 meters after sunset.

Several hypotheses have been proposed to explain why marine organisms migrate vertically. The dark provides relative safety from predators; cooler water in the deeper layers lowers metabolic rates so that less energy is expended; and currents running counter to each other at the surface and at various depths can cycle these organisms away from and back to their preferred daytime location.

The vertical migrations of zooplankton have been monitored with echo sounders. Certain of these organisms form a sound-reflective layer at middepth known as the "deep-scattering layer." This layer has been detected at less than 200 meters at night and as deep as 800 meters by day (4).

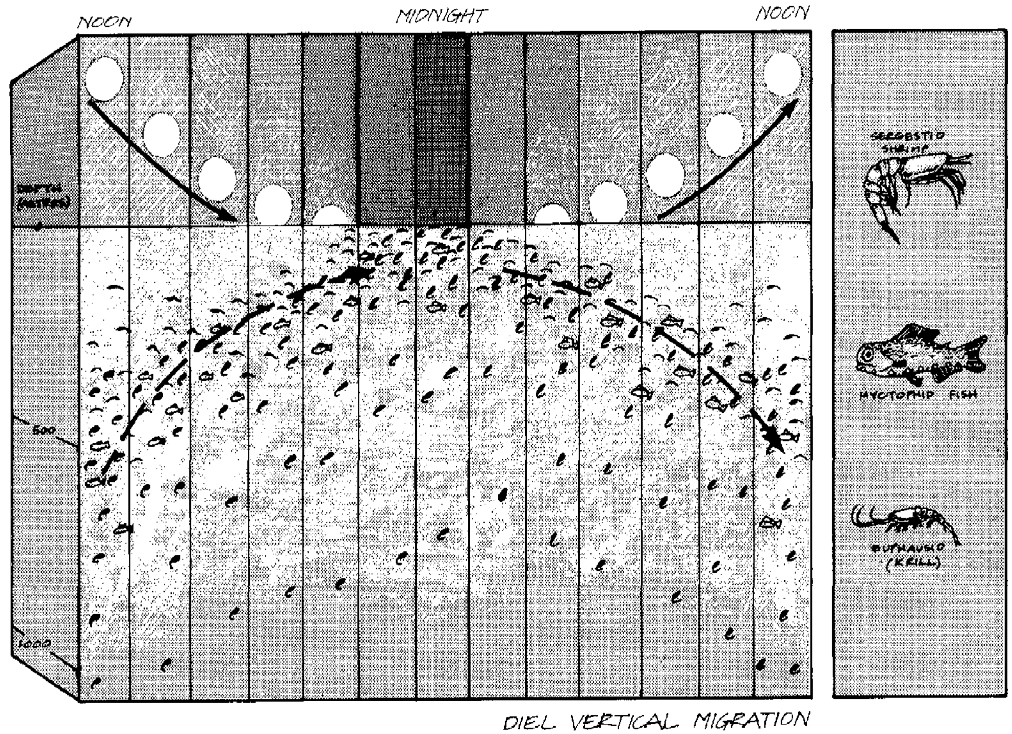


Figure 45. Diel Vertical Migration

The daily cycle of ascent and descent of marine organisms in response to variations in sunlight intensity, such as shown in this diagram, is referred to as diel vertical migration. Across the top of the diagram is the approximate position of the sun, beginning on the left with a high at noon, dipping to a low below the horizon at midnight, and rising again to another noon high. Marine organisms, represented here by three common species, follow a reverse pattern; they are lowest in the water when the sun is highest and rise toward the surface as the sun sinks. Some, like the sergestid shrimp, do not necessarily come to the surface but merely rise some distance before descending again.

Zooplankton Production

Since herbivorous zooplankton depend on phytoplankton for food, their distribution is closely tied to the seasonal and spatial changes in the marine phytoplankton community. Zooplankton populations experience a burst in production during the spring in response to phytoplankton growth, but lag somewhat behind, until sufficient numbers of prey are available to exploit. In the summer, coastal zooplankton abundance is approximately five times that found during the winter (9).

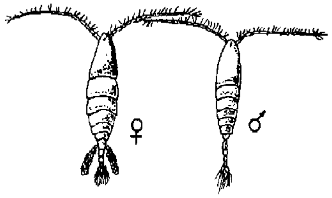
Zooplankton are most numerous within a few kilometers of the Oregon shoreline and then decrease rapidly farther west. Typical abundance 1.6 kilometers (1 mile) off Newport during the summer is from 5,000 to 15,000 individuals per cubic meter of sea water. At 16 kilometers (10 miles) west of Newport, the average abundance in the summer decreases to roughly 1,000 individuals per cubic meter of sea water (12, 14, 15). The highest concentrations of continental shelf zooplankton are found in the upper 20 to 30 meters of the water column.

Over the continental slope and in oceanic waters, copepod density in summer is approximately twice that of winter. Although the highest concentration of copepods occurs in the upper 39 meters of water, many individuals live below 40 meters in the offshore zone (10, 11).

Distinct changes in the species composition of the zooplankton also occur seasonally. During the winter, northerly currents bring many species with southern affinities into the Oregon coastal zone. When the direction of the predominant surface current reverses in the spring and summer, many copepods typical of more northern habitats occur off the coast.

IMPORTANT ZOOPLANKTON—COPEPODS AND EUPHAUSIIDS

Copepods

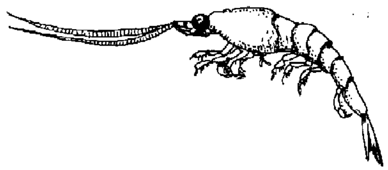


Copepods are the most numerous zooplankton group on the continental shelf. Most zooplankton samples collected off Newport have contained more than 90 percent copepods. They are also an extremely diverse group; fifty-eight species of copepods have been identified from Oregon's shelf waters (13).

The copepod *Calanus marshallae* is a common species along the Oregon coast. Its body is composed of segments, with each segment bearing a pair of appendages. The appendages surrounding the mouth are used to gather and ingest phytoplankton, while those located at midbody function much like oars, propelling the animal through the water. Although copepods cannot swim effectively against ocean currents, many species are capable of daily vertical migrations.

Development of copepods from eggs to adults is a complex process. A copepod molts a total of 11 times before becoming an adult. In the case of *Calanus marshallae*, this molting process leads to more than just morphological changes. Accompanying development are habitat changes within the coastal zone. Adults and the oldest juveniles are found west of the summertime upwelling front, eggs occur within the upwelling front, and the youngest juveniles live east of the front (14).

Euphausiids



Euphausiids, large zooplankton closely resembling shrimp, reach a maximum length of 22 to 24 millimeters (about one inch). They are larger and more complex and pass through more stages of development than copepods. Over a dozen species of euphausiids live off the Oregon coast; *Euphausia pacifica* is the dominant species in offshore waters (19), while *Thysanoessa pacifica* is the most abundant species over the shelf (7).

Euphausia pacifica migrates vertically in the water column to feed (see Figure 45) and is both herbivorous, grazing extensively on phytoplankton, and carnivorous, preying on small zooplankton. In turn, these euphausiids are the most important food source for many nektonic species, including herring, Pacific sardine, jack and Pacific mackerel, rockfishes, salmon, shrimps, myctophids, and baleen whales. Other zooplankton, including other euphausiids, also prey on *E. pacifica* (3, 15, 19).

The Antarctic species *Euphausia superba*, also known as "krill," occurs in large swarms and is the principal food for baleen (filter-feeding) whales. Recently, the Japanese and Russians have shown an interest in commercially fishing the abundant stocks of the Antarctic region.

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Note: References are cited in text by number. References marked with an asterisk (*) are recommended because they are comprehensive, easily understood, and accessible.

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CHAPTER FIVE
NEKTON
The Swimmers

INTRODUCTION

Tuna, salmon, perch, anchovies, herring, squid, and other familiar marine animals are classified by marine biologists as nekton because of their ability to outswim the ocean currents. Unlike the passively drifting plankton, nekton swim widely throughout the ocean to feed and reproduce. The nekton inhabiting Oregon's ocean include two major groups of marine animals: invertebrate squids and vertebrates fishes. Sea birds and marine mammals are often classified as nekton since they too pursue a swimming mode of life (see "Marine Birds and Mammals: Residents and Visitors" for a discussion of these two animals groups).

Nekton occupy a variety of niches within the marine ecosystem, both as predator and as prey. These niches change as individual fish mature from tiny, free-drifting larvae to mobile juveniles, and finally to predatory adults. Increased physical size and improved swimming abilities permit nekton to capture increasingly large bundles of food and thus gradually progress from herbivores to first-, second-, and third-order carnivores. Although less vulnerable as they grow larger and develop mobility, maturing nekton nonetheless continue to be prey to larger nekton.

Nekton are important to oceanic food webs and ecosystems as well as to human populations. Throughout history, two major nekton groups, squid and fish, have been valued as an important food source. Many cultures developed around the opportunity to seek, catch, and process fish. Indeed, Oregon's coastal economy has been anchored in the commercial and recreational fishing industries supporting fishermen and the onshore network of processors, marine supply dealers, and boatyards.

This chapter of the *Oceanbook* describes a few general characteristics of nekton and then provides more detailed information on important species found off Oregon. The *Oceanbook* is not intended as a complete guide to the nekton of the Oregon coast; rather, it is limited to the most abundant prey species and the most important commercial species. And because the fishing industry is so important to Oregonians, the chapter includes a brief overview of commercial fishing.

NEKTON CHARACTERISTICS

Endowed with an ability to swim, nekton roam the ocean, especially as part of the cycle of spawning, rearing, and feeding. Many species migrate long distances throughout their life history. The Pacific whiting, for instance, spawns off southern California in winter and then moves northward over 1,300 kilometers to summer feeding areas off the Oregon and Washington coasts (see Figure 46). Salmon, steelhead, and sea-run cutthroat trout are anadromous fish; that is, they begin their migration in fresh water, spend most of their lives at sea, and return to fresh water to reproduce. Albacore tuna migrate across the North Pacific Ocean to feed in summer off the Oregon continental shelf. In general, larger fish tend to travel farther than smaller ones (11).

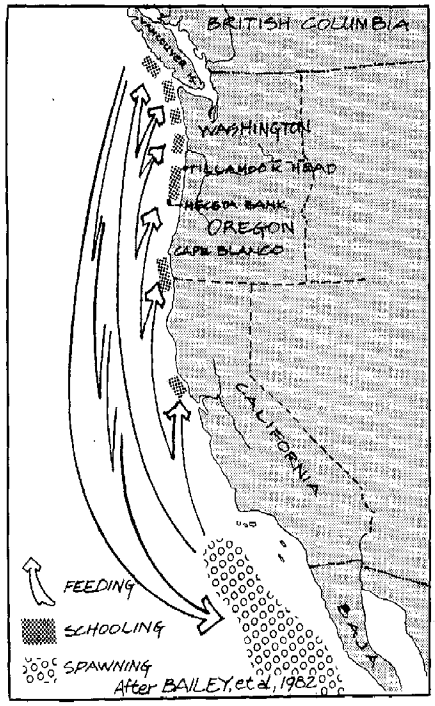


Figure 46. Migration Route of Pacific Whiting off the U.S. West Coast

Adults spend the summer feeding on the mid- and outer continental shelf of Oregon and then migrate south to southern California and Baja to spawn.

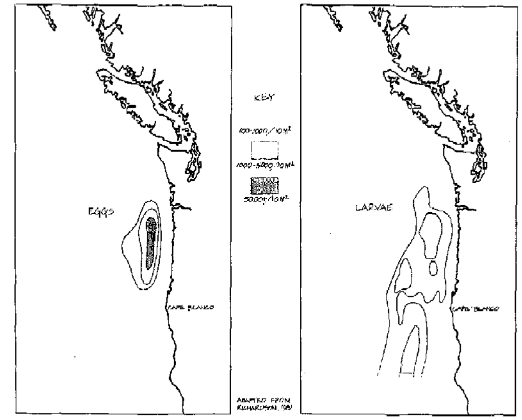


Figure 47. Northern Anchovy Egg and Larvae Distribution off Oregon (July 1976)

The spawning and release of eggs occur west of the Columbia River. During summer, the Columbia River plume carries the planktonic eggs and larvae south and offshore. The mechanism by which these larvae return to the continental shelf and estuaries where they are later captured as juveniles is unknown. Reversal of the current and onshore flow in the summer or fall may play a role in this process.

The depth of the sun's penetration into the ocean influences the vertical distribution of nekton, most of which ultimately depend on food produced in the euphotic zone. Many of the larger nekton are known to live in deeper water during the daytime and rise to the surface at night, following their prey, which are in turn rising to the surface to feed on phytoplankton in the ocean's upper layers. This vertical movement in the water column, often extending over several hundred meters, is known as diel vertical migration (see "Plankton: The Drifters").

Many nekton have developed adaptations for concealment based on the depth of light penetration. Epipelagic species, those living in the upper 200 meters of the ocean, are usually countershaded, silver or gray above and light below. Such cryptic coloration allows the fish to blend with its environment. Below 200 meters, bioluminescence is a common adaptation of nekton. For instance, myctophids can match the ambient light of the environment through control of ventral light-producing organs, which make the animal difficult to discern against the dimly lit background. Likewise, because all red light is filtered out at these depths, the red pigmentation of the sergestid shrimp and other nekton appears black and thus aids concealment.

Body shapes vary widely but are adaptive to the needs of animals in the ocean environment. Tuna, with their streamlined bodies, are rapid swimmers and can migrate many hundred kilometers. Sole, a kind of flatfish, lie on the bottom, both eyes on the top side of the head. Rockfish, round-bodied and relatively slow swimmers compared to the tuna, are nonetheless quite maneuverable as they graze around their rocky home.

Feeding behavior is extremely varied among the nekton. Some, like sharks, are rapid-swimming midwater predators that pursue and overtake their prey. Others pluck their prey off the bottom. Still others, like the large clumsy sunfish *Mola*, float at the surface and feed on small gelatinous zooplankton.

The vast majority of nekton produce small eggs which are nearly always laid in midwater and drift with ocean currents (see Figure 47). Although most nekton species produce tremendous numbers of eggs (an exception is the shark, which produces approximately 12 per year), mortality is high. Fertilization is external in most nekton and eggs develop externally. However, notable exceptions exist. Salmon deposit their eggs on well-prepared gravel beds in freshwater streams, and Pacific herring affix eggs to the rocks and vegetation in bays and estuaries in gooey mats. In other nekton species, like rockfish and sharks, fertilization is internal. The eggs mature within the female's body cavity and the young are born alive.

In general, egg production off Oregon coincides with the season of peak food abundance in the spring and summer. Since the eggs are characteristically small, with little yolk, the larvae must feed themselves. The tiny larvae (3 to 10 millimeters) drift in ocean currents from the spawning area to the nursery area, usually in shallow water. Here they feed on zooplankton and grow rapidly until at the end of the larval stage they develop fins, scales, and other features of the adult. The young adult fish then move from the nursery grounds to the feeding grounds, which are often in deeper water. Fishery biologists believe that adult fish may make use of subsurface countercurrents to move from the feeding grounds to the spawning grounds (11).

Oregon's estuaries play an important role in the life histroy of many nekton species. Salmon use estuaries for migration, food, shelter, and physiological acclimatization prior to moving into the ocean. Several flatfish species, especially English sole, use estuaries as nursery grounds during their first year of life. Pacific herring lay their eggs in the intertidal zone of Yaquina Bay and continue to use it as a nursery and feeding ground.

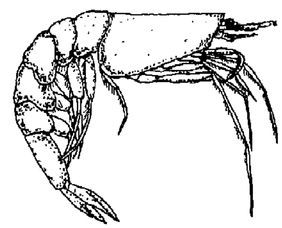
Harvesting fish stocks is still one of the major uses of the ocean, and many of the nekton living off the Oregon coast are important to Oregon's commercial fishing industry. These fish are harvested as two major groups: groundfish (those living on or near the seafloor) and midwater species (those living higher in the water column). Groundfish include flatfishes (halibut, sole, flounder), rockfishes (many species), sablefish, Pacific whiting, Pacific cod, and lingcod. Important commercial species living higher in the water include albacore tuna, coho salmon, and chinook salmon.

Many important commercial fish species, like salmon and rockfish, are also caught in the recreational fisheries. Other species frequently caught by recreational fishermen are redtail surfperch, lingcod, surf smelt, kelp greenlings, and cabezon (25, 26).

IMPORTANT NEKTON SPECIES OFF OREGON

Information on the distribution, migration, reproduction, and trophic relationships of the major nekton species in Oregon is summarized below. These species represent the most abundant and important prey species within the pelagic ecosystem as well as the most important species harvested for human consumption.

Invertebrates



SERGESTID SHRIMP *Sergestes similis*

SHRIMP *Sergestes similis*

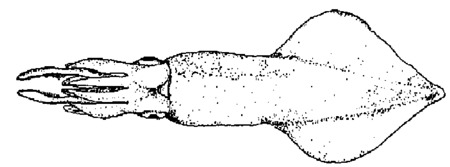
Range. *S. similis* ranges from Japan eastward to the west coast of North America.

Migration and Vertical Distribution. Off Oregon, the distribution of *S. similis* changes seasonally. The center of maximum abundance moves from the continental slope in the summer onto the continental shelf during the winter (69). *S. similis*, like several other common pelagic animals, migrates vertically each day. At night, most sergested shrimp can be found in the upper 100 meters of water. At dawn, the bulk of the population migrates to depths greater than 200 meters where they will remain until dusk (69).

Reproduction and Early Life History. Off Oregon, *S. similis* lives just over one year. Spawning occurs throughout the year, but only a few individuals reproduce during the summer (69).

Trophic Relationships. Sergestid shrimp feed on copepods, euphausiids, chaetognaths, and amphipods (32). Among the predators of these shrimp are fish such as albacore and Pacific whiting (55, 3) and baleen whales (55).

Fishery. Although abundant, this species of shrimp is not harvested commercially.



MARKET SQUID *Loligo opalescens*

SQUID *Loligo opalescens*

Range. More than a dozen species of squid live off the Oregon coast (30). One of these, the market squid *L. opalescens*, is common in coastal waters between Baja California and southern Alaska.

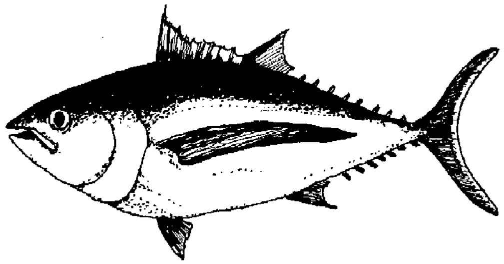
Age/Maturity. Squid live one to two years and mature eight to ten months after hatching (49).

Reproduction and Early Life History. Following mating, which occurs from April through August, female squid attach several dozen egg clusters to the bottom. Adults die after spawning. Larvae hatch after three to five weeks. Spawning grounds off Oregon are located in water less than 60 meters deep between Bandon and Cape Arago, off the Coos Bay North Spit, in the vicinity of Heceta Head, off Newport, and in the area surrounding Cape Lookout (23).

Trophic Relationships. Squid eat euphausiids, copepods, shrimp (*Sergestes*), crustacean larvae, northern anchovy, and other cephalopods (34). Predators include coho and chinook salmon, rockfish, sanddabs, lingcod, petrale sole, seabirds (arctic loon, cormorants, sooty shearwater, short-tailed shearwater, northern fulmar, gulls, rhinoceros auklet, common murre), and marine mammals (elephant, fur, and harbor seals; California sea lions; porpoises) (51).

Fishery. Although the presence of squid has been known for years, a strong fishery in California held down the price. The aftermath of the 1982-83 El Nino and low production in California made it profitable to fish for squid in Oregon (33). Squid have been recently landed in small quantities in Newport. Market squid are harvested when they form spawning schools in shallow water. Shrimp nets, bottom trawls, purse seines, and lampara nets have been used to catch the market squid. Efforts are currently underway to assess the biomass of the Oregon squid resource. It is unknown what level of fishing intensity can be sustained by the present stock.

Vertebrates



ALBACORE TUNA Thunnus alalunga

ALBACORE *Thunnus alalunga*

Range. Albacore tuna are distributed throughout the North Pacific Ocean. Two separate groups seem to exist within this range, each having different migratory behavior (39). A northern substock, representing albacore caught off Oregon and Washington, migrates between the eastern and western North Pacific. A southern substock, encompassing fish caught off southern California, does not make trans-Pacific migrations. During the summer fishing season, no exchange of fish is known to occur between the California and Pacific Northwest substocks (38).

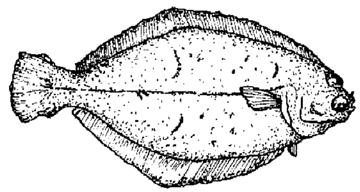
Migration and Vertical Distribution. The seasonal migration of albacore into the waters of the Pacific Northwest is thought to begin in late May and June when fish move from the central North Pacific into waters located 1,000 to 1,600 kilometers (625 to 1,000 miles) off the coast (39, 92). They then migrate eastward as surface waters begin to warm. Albacore first appear off northern California and southern Oregon in midsummer. While off the coast, these fish tend to aggregate in the vicinity of upwelling fronts or at the edge of Columbia River plume water (38, 64). By late fall, albacore have left Oregon and moved into oceanic waters. Physical factors such as water temperature and the structure of oceanic fronts can affect the timing of this migration as well as the distribution of albacore (39, 63, 31, 9).

Rather than spending most of their time in surface waters, as was previously thought, albacore are frequently found within and below the thermocline (38). Fish swim over a range of depths, with the range being larger during the day than at night. Albacore may encounter up to 7° C change in water temperature over a 20-minute period when moving vertically (38).

Reproduction and Early Life History. The spawning grounds for the northern substock of albacore are located in the central North Pacific between Hawaii and the Philippines. Spawning occurs throughout the year, with a peak in summer. Albacore found off Oregon are sexually immature three- and four-year-old fish (92).

Trophic Relationships. Albacore feed on juvenile stages of anchovies, rockfishes, jack mackerel, and Pacific saury as well as squid, euphausiids, and amphipods (10).

Fishery. Commercial fishing for albacore by U.S. vessels takes place from the continental shelf to over 1,600 kilometers (1,000 miles) offshore. Most of these fish are harvested by trolling with jigs. The albacore which belong to the northern substock are also fished off Japan. The annual landings of albacore in Oregon are shown in the Table: "Commercial Fish and Shellfish Landings 1970-1983."



DOVER SOLE Microstomus pacificus

DOVER SOLE *Microstomus pacificus*

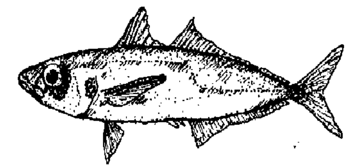
Range. Dover sole range in distribution from Baja California to Alaska. Areas of major abundance in Oregon are off Coos Bay and the Columbia River. Dover sole prefer mud and muddy-sand bottoms on the outer shelf and slope (19, 66). Figure 48 shows locations where Dover sole are caught.

Migration and Vertical Distribution. Younger fish live in shallower water than adults. Seasonal changes in depth distributions also occur. Females migrate into shallower water during the summer, whereas males remain in deeper areas all year (2).

Reproduction and Early Life History. Spawning occurs during the winter in areas deeper than 400 meters (74). Larvae live in the uppermost 50 meters of water for at least one year. They are distributed over and beyond the continental slope. Off the Columbia River, Dover sole eventually settle to the bottom near the edge of the continental shelf (12).

Trophic Relationships. Pelagic larvae eat zooplankton. Adult Dover sole feed on benthic invertebrates such as polychaete worms, ophiuroids (brittle stars), crustaceans (amphipods), and molluscs (14, 71).

Fishery. The Dover sole has been the most important flatfish landed in Oregon since the trawl fishery began in 1973 (12). Despite yearly fluctuations in landings, Dover sole has consistently remained the dominant flatfish. It is also one of the few groundfishes present in sufficiently high concentrations beyond the continental shelf to support a deepwater commercial fishery.



JACK MACKEREL Trachurus symmetricus

JACK MACKEREL *Trachurus symmetricus*

Range. Jack mackerel range from Baja California to Alaska. They were especially abundant off Oregon in 1983 and 1984, possibly as a result of the 1982-83 El Nino event (67).

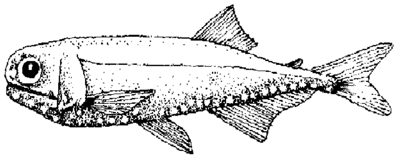
Migration and Vertical Distribution. Most data about *T. symmetricus* are from California waters where commercial and recreational fishing is common. They live in the uppermost 100 meters of water and frequently form dense schools. Small individuals are most abundant near the coast and islands of southern California. Larger fish school offshore over the continental slope along the west coast of North America. Adults migrate northward and westward from their wintering range off Washington, Oregon, and California (49). As surface temperatures decrease, fish may descend into warmer, deeper waters.

Age/Length/Maturity. Jack mackerel are long-lived and may reach 30 years and a maximum length of 76 centimeters (approximately 30 inches). They mature between two and three years of age (49).

Reproduction and Early Life History. Mackerel spawn in areas from 150 to 450 kilometers (approximately 281 miles) offshore (45). The center of peak spawning moves northward during spring, summer, and fall. Mackerel off Baja California spawn in March and April, whereas off Oregon peak spawning occurs during the fall (36). It is not known if the seasonal shift of spawning results from later maturation of the more northern individuals or if spawning adults migrate north as surface waters warm (61). Jack mackerel eggs and larvae have been found 160 to 1,600 kilometers (100 to 1,000 miles) off the Oregon and Washington coasts in August (1). Maturing fish move onshore for the first three to six years and then move to deeper water and further offshore (49).

Trophic Relationships. Jack mackerel off southern California feed on copepods, pteropods, and euphausiids (8). There are also reports of juvenile squid, northern anchovies, and myctophid fish being eaten (14). Jack mackerel are generally not an important food source for other marine life (61).

Fishery. If an expanded, open-ocean purse-seine fishery develops off Oregon, jack mackerel may become a significant commercial species (44).



MYCTOPHIDS

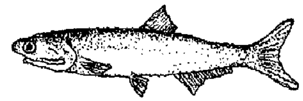
MYCTOPHIDS

As a group, the myctophid fishes are the most abundant of all midwater fishes. One of them, *Stenobrachius leucopsarus* (northern lampfish), is the single most abundant species off the Oregon coast (75). Moreover, myctophids are the dominant fish larvae between 27 and 111 kilometers (62 to 185 miles) offshore (86). A distinguishing feature of myctophids is the presence of many photophores, small, light-producing organs located on the body's surface.

Length. Myctophids are small fish, usually 10 centimeters (4 inches) or less in length.

Migration and Vertical Distribution. Myctophids are mesopelagic; that is, they live below 200 meters depth during the day. Some myctophid species migrate to the sea surface at night. During the summer, the largest concentrations of myctophids are found over the continental slope. When the southerly winds of winter produce an onshore flow of near-surface water, these small fish become most numerous on the outer continental shelf (65).

Trophic Relationships. Myctophids eat copepods, euphausiids, and amphipods. Important predators on myctophids are albacore, rockfish, and sablefish (94, 75).



NORTHERN ANCHOVY *Engraulis mordax*

NORTHERN ANCHOVY *Engraulis mordax*

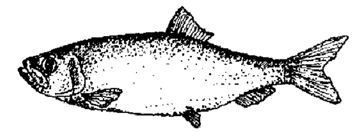
Range. Northern anchovies live along the west coast of North America between Baja California and British Columbia. Three distinct subpopulations of anchovies are found within this range. Individuals off of Oregon belong to the northernmost group. The central subpopulation is centered off southern California and is harvested for fish meal.

Age/Maturity. Adult northern anchovies in the northeast Pacific mature at two years of age and reach a maximum age of seven years (49).

Migration and Vertical Distribution. During winter, adult and juvenile anchovies live in nearshore areas. Some of the juveniles move into bays and estuaries (Tillamook, Yaquina, and Coos bays) when spring arrives. From June through August, juveniles remain in nearshore and estuarine habitats while adults migrate into Columbia River plume water to spawn. Mature adults are typically found from 65 to 157 kilometers (40 to 100 miles) off the northern Oregon coast at this time. By fall, adults have returned to the nearshore habitat where they are joined by juveniles which have left the bays (37).

Reproduction and Early Life History. Fertilization of eggs occurs in near-surface waters. The eggs are pelagic. Following spawning, eggs and larvae are carried even farther offshore (see Figure 47).

Trophic Relationships. Northern anchovies feed on phytoplankton and zooplankton (for example, copepods, pteropods, and dinoflagellates) (42, 4). Northern anchovy are eaten by other fishes (Pacific whiting, salmon, rockfishes, jack mackerel, and albacore), many marine birds, squid, and many marine mammals (seals, sea lions, dolphins, porpoises, and small whales) (94). With the exception of occasional harvesting for use as bait, the 100,000 to 1 million metric tons of anchovies off the Oregon and Washington coast remain unexploited (81, 84).



PACIFIC HERRING *Clupea harengus pallasi*

PACIFIC HERRING *Clupea harengus pallasi*

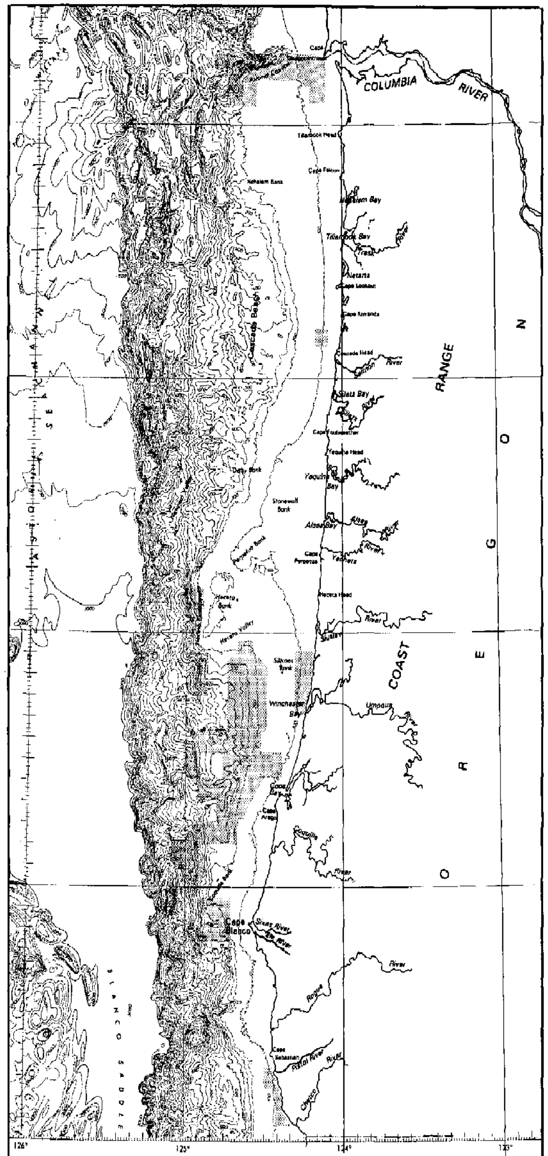
Range. Pacific herring are widespread throughout continental shelf waters of the North Pacific. Although distribution near North America extends from Baja California to the Beaufort Sea, herring are more abundant off Washington and British Columbia than Oregon.

Age/Length/Maturity. The maximum age reached by Pacific herring in the northeast Pacific is eight years, and the maximum length is 23 centimeters (approximately 9 inches). Pacific herring mature between two and four years of age (49).

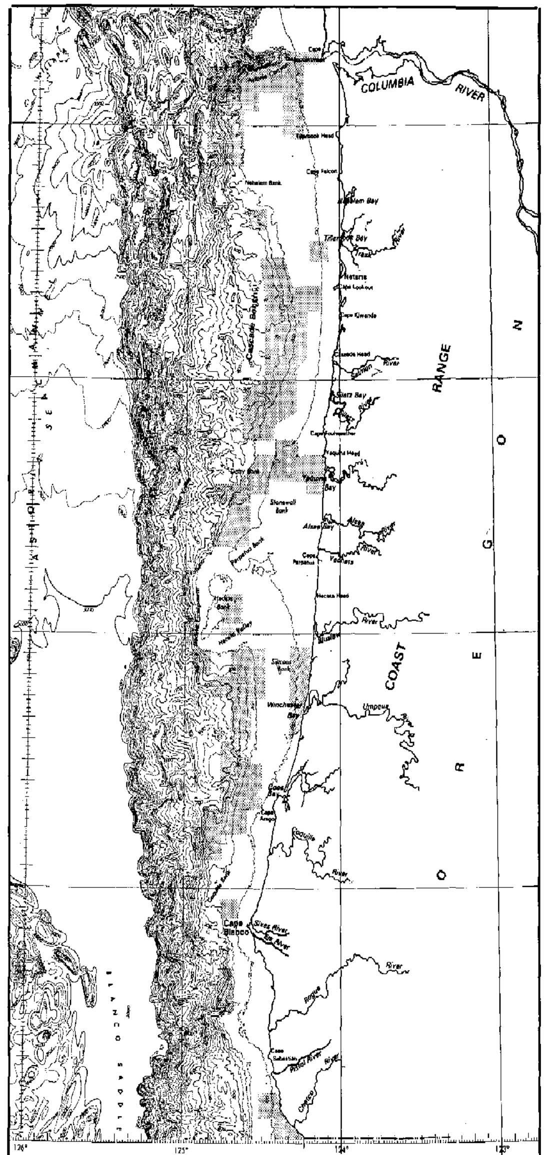
Migration and Vertical Distribution. Adults migrate seasonally from the continental shelf into shallow water.

Reproduction and Early Life History. Spawning occurs during late winter and spring (49). Pacific herring lay their eggs in the intertidal areas of Yaquina Bay. The sticky eggs are frequently found attached to kelp, rocks, and pilings. After the eggs hatch in about ten days, the larvae subsist on the food reserves of their yolk sac for another two weeks before they begin feeding. At the end of their first summer, young fish move into deeper water on the continental shelf (20).

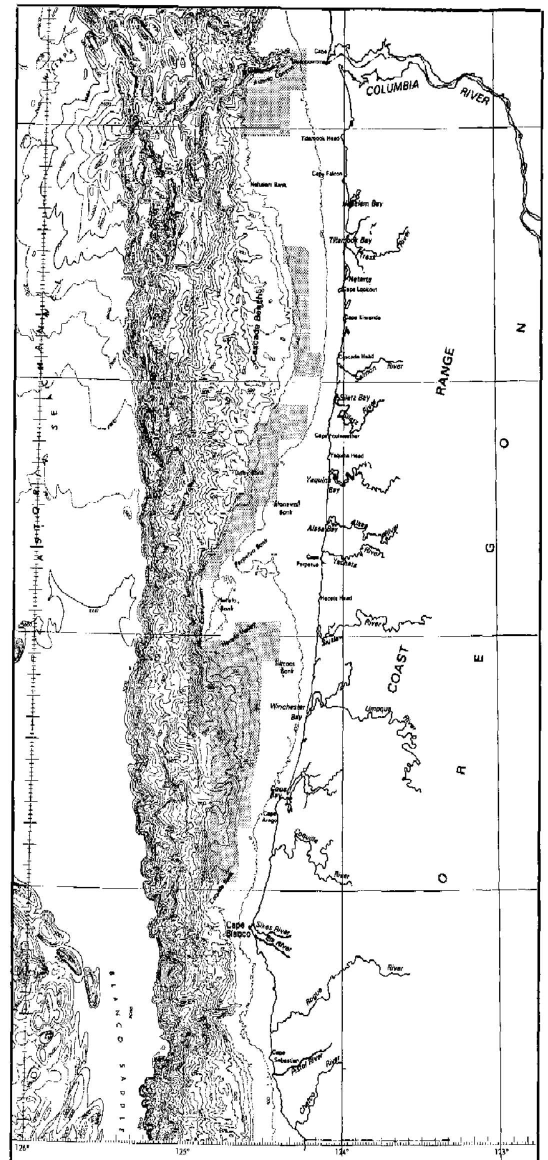
Trophic Relationships. Pacific herring feed on zooplankton such as copepods, amphipods, and euphausiids, although food habits may change seasonally. Herring consume large quantities of food during the spring and summer. Many predators, including sharks, salmon, lingcod, seabirds, and marine mammals (sea lions and whales) rely on Pacific herring for food.



DOVER SOLE COMMERCIAL CATCH AREAS
Data from ODF&W, 1977, in Stander & Holton, 1978



ROCKFISH COMMERCIAL CATCH AREAS
Data from ODF&W, 1977, in Stander & Holton, 1978



SABLEFISH (BLACK COD) COMMERCIAL CATCH AREAS
Data From ODF&W, 1977, in Stander & Holton, 1978

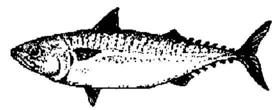
Figures 48, 49, and 50. Fishing Grounds for Selected Groundfish Species.

This series of three maps shows areas of the continental shelf where three species of groundfish were caught by commercial fishermen. A comparison among the maps will reveal areas where species catch overlap. In Figure 48, Dover sole data are based on log records for 1973 and 1975. Figure 49 displays data on rockfish, including Pacific ocean perch, and is based on log records for 1973, 1975, and 1976. Figure 50, Sablefish, is based on data from Oregon Department of Fish and Wildlife research trawls from 1971 to 1974 (after 89).

COMMERCIAL FISH AND SHELLFISH LANDINGS (POUNDS ROUND) IN OREGON 1970-1983

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
FISH:														
Anchovy, northern	[1]	[1]	[1]	[1]	[1]	39002	1500	200	300	700	0	0	200	0
Bass, striped	50051	67084	54449	39517	35151	18019	[2]	[2]	[2]	[2]	[2]	[2]	[2]	[2]
Bonito, Pacific	0	0	0	0	0	0	0	0	0	0	0	0	0	1462
Cabezon	0	0	0	0	0	0	0	0	0	0	0	299	142	702
Cod, Pacific	76397	483147	1075675	466186	700607	588029	628939	846913	931676	931704	356522	116947	260319	196644
Flounder, arrowtooth	865[3]	2078[3]	50903[3]	73159[3]	34060[3]	101812[3]	71280[3]	194708[3]	380564	745000	438774	1311268	1617209	1191733
Flounder, starry	585038	613714	521900	463583	613504	887588	1754995	746795	1211186	645989	426768	888441	481812	432560
Grenadier	0	0	0	0	0	0	0	0	0	0	0	0	0	798
Hake, Pac. (Whiting)	0	5935	0	62013	36416	6320	471987	974687	858049	304700	605298	360251	3316	142536
Halibut, Pacific	95170	71601	68571	51601	67630	57878	58149	78500	62998	43448	176684	150396	234730	579560
Herring, Pacific	47933[4]	43728[4]	38726[4]	49218[4]	65629[4]	70867	83613	54874	137231	175448	140723	148410	144970	145915
Lamprey, Pacific	3771	3000	1273	0	4000	3138	865	1481	9090	8935	3233	4686	39169	4482
Lingcod	1121325	1534302	1663760	2312925	2167563	1664442	1116570	996228	1180735	1605165	1662778	2307361	3213736	3830684
Mackerel	0	0	0	276	473	5080	2987	3613	810	5231	20	26	83	18253
Opah	0	0	0	0	0	0	0	0	0	0	0	0	0	448
Pollock, walleye	0	0	0	0	0	0	0	0	0	0	0	0	0	348
Prickleback, monkeyface	0	0	0	0	0	0	0	0	0	0	0	0	0	302
Pac. Ocean Perch[5]	1612600	1738991	588244	570145	887044	921419	2332603	1446010	1934061	4193424	3615284	4350997	5508130	5192175
Rockfish, widow	0	0	0	0	[6]	[6]	[6]	[6]	[6]	[6]	[6]	31768970	19198987	[6]
Rockfish (misc. spp.)	4238572	4198673	5283943	488304	4022363	3256941	5714320	6457698	11559767	19194651	35173303	18321418	22031780	30291426
Sablefish	161845	274570	449010	1298098	601181	728981	1060658	921098	3816029	17024760	6025840	5166329	11220816	10234762
Salmon, chinook	6311491	5013543	5086474	9586654	4911284	6534955	4820004	6953526	4543434	4804950	3954327	2439675	4365148	1287328
Salmon, chum	4863	3050	9960	11788	3272	4625	10111	810	13086	338	1824	11118	13964	1100
Salmon, coho	13084479	11774660	6482926	7305423	10054741	5823540	11413708	3291276	4148041	6160328	3256659	4156442	4204763	1300319
Salmon, pink	1004	10412	132	18363	81	1041	6376	455566	281	122324	1805	372605	0	269
Salmon, sockeye	40875	153440	153722	10944	21	7	399	210	50	10	0	0	472	2998
Sanddab, Pacific	63049	60164	114467	183872	245392	365095	326950	243560	227027	453383	356592	293589	526000	531280
Shad, American	598248	473822	640844	450747	264505	456758	412635	369780	671598	703166	291414	117477	435351	359719
Shark, soupfin	0	0	3755	343	1010	856	2982	1805	856	3049	1791	3585	11081	13905
Shark, spiny dogfish	17280	4115	514	906	12701	19367	13330	56090	160326	65446	56305	10608	2090	2581
Shark, other	0	0	0	0	0	0	0	0	0	0	0	1293	8213	7100
Skates and Rays	1137	707	1037	7477	13989	18180	254044	255298	401579	480573	183873	85861	63889	159640
Smelt	146105	134246	133403	62244	424627	9147	19761	956275	7100	791228	328762	24013	55346	40343
Sole, butter	0	0	0	2842	3411	22962	14588	48558	63498	44244	28713	22463	19178	12075
Sole, curlfin (turbot)	[7]	[7]	[7]	[7]	[7]	[7]	[7]	[7]	10087	2532	1016	5105	9793	9489
Sole, Dover	5606116	5718550	6014291	4572561	5714525	4886918	5018116	4075203	7546417	11226910	9080509	11672995	17951407	18698513
Sole, English	1887586	1804012	2195609	2378570	1786406	2173321	3602638	2171203	2283864	2390661	1584178	1600095	2187335	2014645
Sole, flathead	0	0	0	0	0	33351	59968	22814	18127	31165	7035	11111	6524	17105
Sole, petrale	2151452	2290871	2206880	2244005	2746087	2654859	1764712	1818942	2246190	2330293	1890934	1948665	3323843	2435788
Sole, rex	1076279	862727	1324442	1268203	1311021	1010607	1078871	952756	1431578	1638048	1175957	1346409	1865611	1426686
Sole, rock	4488	32495	2425	388	3549	26212	14230	20360	20164	20301	28729	19871	66543	9278
Sole, sand	578476	465245	444261	401791	313835	470267	847841	466900	569098	769564	564653	735458	856930	696583
Sole, slender	0	0	0	0	0	0	0	0	64	0	25	0	0	0
Sole, miscellaneous	3337	198	0	2030	2	13017	70492	16595	19252	39777	0	0	0	0
Steelhead	186370	313129	457276	461329	129414	26529	33548	73000	74900	41193	29772	61060	53564	80487
Sturgeon, green	40017	39920	33823	22247	85771	32974	40945	16721	34995	22243	23240	9990	21219	18970
Sturgeon, white	172631	201708	202665	268582	271203	301284	483895	240962	181219	312161	183927	280123	236691	296648
Sunfish, ocean	0	0	0	0	0	0	0	0	0	0	0	0	0	244
Surfperch	4838	5994	0	1572	6769	0	39	0	288	2487	121	167	342	2421
Tomcod, Pacific	0	0	0	0	0	0	0	0	0	0	0	0	0	46
Tuna, albacore	21797708	8419585	23056004	16338827	25224720	17165537	5933617	4420159	11285419	3106607	3504715	7726890	1913063	3410429
Tuna, other	5139167	4672582	6177711	8086658	7815206	6418872	11415793	5478762	7112254	5713979	1006	0	580	177
Walleye	0	0	0	0	0	0	0	0	0	396	0	0	0	0
Wolf-eel	4137	0	0	0	0	505	285	145	688	253	690	1435	2348	6747
Miscellaneous[8]	2051413	1825248	750068	612377	742556	994620	631019	552768	122328	97253	227422	335370	1219	53
CRUSTACEANS:														
Crab, box	0	0	0	0	0	0	0	0	0	0	0	0	502	16207
Crab, Dungeness	14929347	14875849	6762259	2349645	3917625	4026937	8134065	19902419	12501274	15631877	18650635	6984025	7035245	5350560
Crab, rock	0	0	0	0	0	0	0	0	883	2333	1788	7	0	0
Crab, Tanner	0	0	0	0	0	0	0	0	0	0	0	0	65	1338
Crayfish	39019	39537	8730	9942	12094	26559	11916	32494	11286	20663	78359	83904	155231	125519
Shrimp, brine	0	0	0	0	0	0	0	0	0	278	3125	3935	7100	12402
Shrimp, ghost (sand)	6349	6002	10082	12753	14628	19533	27303	33097	57325	46546	57888	55499	68749	69905
Shrimp, pink	13572174	9075006	20731151	24517194	20313760	24083568	25456007	48580070	56666109	29586586	30152030	25923589	18461988	6547073
MOLLUSKS:														
Clams, bay	40690	58753	74130	34452	24956	27780	88029	75758	215031	9412	80467	74707	131989	136185
Clams, razor	[9]	[9]	[9]	[9]	[9]	40465	118016	45781	41455	36228	20291	22516	26528	100
Mussels, ocean	0	0	588	0	0	728	666	312	818	19068	60629	17866	18372	28267
Mussels, freshwater	0	0	0	0	0	0	0	0	0	0	0	0	0	2485
Octopus	3048	2796	2886	11095	0	7244	14538	4049	16122	24187	14013	14082	18597	16780
Scallop, weathervane	0	0	0	0	0	0	0	0	0	3434	0	16853845	1487941	2648965
Squid	0	0	0	0	0	0	0	0	0	0	0	225	113138	297410
Oysters	306810	278904	175720	198072	233528	213136	166128	233736	241168	222048	234784	269840	296484	247136
TOTAL	**97965370**	**77666113**	**93053689**	**91736521**	**95838310**	**86258871**	**95626041**	**114590565**	**135027755**	**132089781**	**124742030**	**148494292**	**129979815**	**100608098**

[1] INCLUDED IN PACIFIC HERRING.
[2] NO COMMERCIAL SEASON.
[3] INCLUDES CURLFIN SOLE (TURBOT).
[4] INCLUDES NORTHERN ANCHOVY
[5] INCLUDES ROCKFISH SIMILAR IN APPEARANCE TO PACIFIC OCEAN PERCH.
[6] INCLUDED IN ROCKFISH (MISC. SPP.).
[7] INCLUDED IN ARROWTOOTH FLOUNDER.
[8] INCLUDES MINK FOOD, CARP, WALLEYE AND INCIDENTAL SPECIES
[9] INCLUDED IN BAY CLAMS



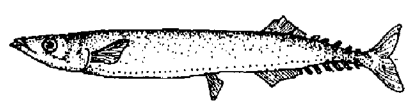
PACIFIC MACKEREL *Scomber japonicus*

PACIFIC MACKEREL (CHUB) *Scomber japonicus*

Range. Pacific mackerel, a highly migratory species, range throughout the North Pacific.

Trophic Relationships. Pacific mackerel feed on crustaceans, squid, and small fish.

Fishery. A commercial fishery exists for this species in California. Although not of commercial importance in Oregon, Pacific mackerel were the most abundant fish caught by Oregon State University researchers in purse seines off the Oregon coast in the summers of 1983 and 1984. As with jack mackerel, the recent intrusion of warm water from California associated with the 1982-83 El Nino event may account for this abundance.



PACIFIC SAURY *Cololabis saira*

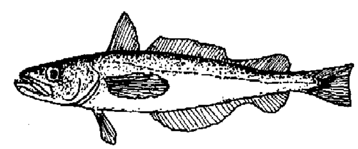
PACIFIC SAURY *Cololabis saira*

Range. Pacific saury is a common epipelagic fish off of Oregon.

Vertical Distribution. Saury are known to congregate around oceanic fronts such as upwelling regions, which are distinguished by marked thermal gradients (29). During daylight hours, saury are found feeding at depths of 30 to 70 meters. At night, saury migrate to the surface and stop eating. Large schools sometimes form at this time.

Trophic Relationships. They feed on copepods, amphipods, euphausiids, fish eggs and larvae (for example, northern anchovy), and crustacean larvae (29, 27). Saury are an important food for many commercially important fish. Off Oregon, saury is one of the main prey of albacore (64). Salmon and sablefish also rely on this abundant fish as a food source (17). In addition, marine mammals such as sei whales and northern fur seals are known to feed on saury (29).

Fishery. Japan, South Korea, and the Soviet Union have developed large fisheries for this species in the eastern Pacific, but the saury off the U.S. west coast are not exploited. In 1968, saury biomass in the eastern North Pacific was estimated at 450,000 tons (29).



PACIFIC WHITING *Merluccius productus*

PACIFIC WHITING (HAKE) *Merluccius productus*

Range. Pacific whiting are very abundant between Baja California and British Columbia.

Migration and Vertical Distribution. Pacific whiting migrate annually from spawning grounds off southern California to feeding grounds off northern California, Oregon, and Washington (see Figure 46). During winter, adults form spawning schools in midwater over the continental shelf of southern California. Following spawning, fish migrate northward, first appearing off Oregon in April. By mid-June, large numbers have moved inshore to depths of less than 100 meters. During the remainder of the summer, whiting gradually move back into deeper water, and by fall, move southward again (5).

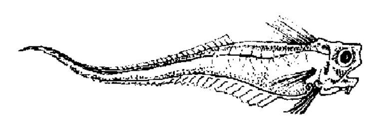
Adult whiting off Oregon also vertically migrate within the water column. At night, fish are at the surface feeding on euphausiids (3). During the day, whiting migrate downward and form large schools near the bottom. Schools can vary in size from 0.5 to 20 kilometers (approximately 0.3 to 12.5 miles) long and 0.25 to 3 kilometers (approximately 0.16 to 1.9 miles) wide.

Age/Length/Maturity. Pacific whiting reach a maximum age of 13 years and a length of 79 centimeters (approximately 32 inches). Maturity is reached at 4 years (46).

Reproduction and Early Life History. The eggs are pelagic and are found considerably offshore. The larvae and juvenile fish are pelagic for one to two years in shallow areas of the continental shelf and then join the adult population in deeper water (49).

Trophic Relationships. Pacific whiting eat a variety of food items. Euphausiids, shrimp, Pacific herring, northern achovy, eulachon, flatfish, rockfish, and smelt have been reported from the stomachs of whiting. Seasonal and year-to-year changes in the diet are known to occur (16, 41). Predators on whiting include fish (sharks, rays, albacore, rockfish, sablefish, lingcod, and arrowtooth flounder) and marine mammals (California sea lion, northern elephant seal, Steller's sea lion, northern fur seal, killer whale, sperm whale, dolphin, and porpoise) (5).

Fishery. The most productive fishing grounds for Pacific whiting off Oregon are the areas around Heceta Bank, Yaquina Head, and Cape Blanco. Most fish are caught at between 100 and 200 meters (5). Recent political sanctions against Poland and Russia have essentially stopped the direct harvest of whiting by foreigners. Joint-venture operations have continued, though, with U.S. vessels catching and selling 72,000 metric tons of Pacific whiting to foreign interests during 1983 (59). However, foreign interest in the Pacific whiting fishery may be changing since recent claims have been made that the fish are too heavily parasitized for consumption (33).



RATTAILS

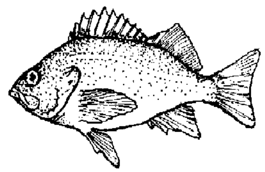
RATTAILS *Family Macrouridae*

Abundance. Off Oregon, rattails are the most numerous benthic fish in water deeper than 1,000 meters (76).

Reproduction and Early Life History. Little is known about the biology of this family (91). Larvae and juvenile are rare, only occasionally being captured in midwater trawls (90).

Trophic Relationship. Members of this family Macrouridae off Oregon are known to feed on epifauna and pelagic organisms (70).

Fishery. Two species in this family are an incidental commercial catch off northern California. They are marketed in the Eureka, California, area under the name "grenadier."



CANARY ROCKFISH *Sebastes pinniger*

ROCKFISH *Sebastes spp.*

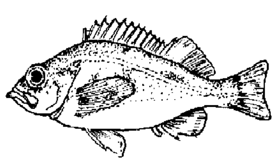
The term "rockfish," or "red snapper," is applied to any one of the many species in the genus *Sebastes*. Over 60 species of *Sebastes* occur off the U.S. West coast.

Range. Figure 49 shows where rockfish are caught off Oregon.

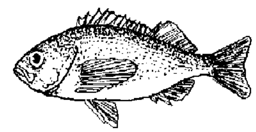
Migration and Vertical Distribution. Rockfish larvae are abundant in surface waters beyond the continental shelf (84, 86). As juveniles, they move in shore, settle to the bottom, and spread over the continental shelf, where they are associated with rocky bottoms as adults (7).

Reproduction and Early Life History. Reproduction in many rockfishes of the genus *Sebastes* differs from that of other groundfish. Fertilization is internal and precedes release of larvae by one to four months. Young are born live rather than released as eggs into the water. Commercial catch rates may be high during both the mating and spawning periods (60).

Trophic Relationships. Young rockfish feed on planktonic crustaceans. Adults are known to consume euphausiids, squid, copepods, amphipods, and fish (7). Important predators on juvenile rockfish include other fish (for example, halibut and albacore), marine birds, and marine mammals.



PACIFIC OCEAN PERCH *Sebastes alutus*

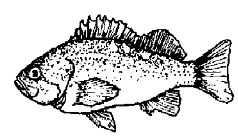


WIDOW ROCKFISH *Sebastes entomelas*

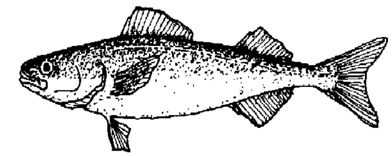
Fishery. Prior to 1960, flatfishes were the most important group of groundfish landed in Oregon. Since 1960, rockfish have increased in importance. Among the most important commercial species in Oregon are the Pacific ocean perch, *Sebastes alutus*, widow rockfish, *Sebastes entomelas*, yellowtail rockfish, *Sebastes flavidus*, and canary rockfish, *Sebastes pinniger*. These species are caught in the deepwater trawl fishery on the continental slope.

The widow rockfish, unlike most other species, is mainly pelagic and spends considerable time off the bottom. A midwater trawl fishery has been able to exploit the dense schooling behavior of this species, but landings of widow rockfish have been declining since 1981 (see Table: Commercial Fish and Shellfish Landings in Oregon 1970-1983).

Catches of Pacific ocean perch increased steadily throughout the 1960s until Japanese and Russian trawls caught large numbers in 1966-1967. Oregon and Washington landings decreased from 7,200 to 675 tons over this same period. Foreign fishing fleets are now prohibited from fishing Pacific ocean perch.



YELLOWTAIL ROCKFISH *Sebastes flavidus*



SABLEFISH *Anoplopoma fimbria*

SABLEFISH (BLACK COD) ***Anoplopoma fimbria***

Range. Sablefish range along the outer continental shelf and upper slope from Baja California to the Bering Sea and Japan. Figure 50 shows the locations where sablefish are commercially caught.

Migration and Vertical Distribution. Most sablefish do not migrate great distances along the coast (24), but a seasonal shift from shallow water during the summer into deeper water during the winter has been noted (6, 79, 35). They are commonly found between depths of 160 and 2,000 meters, with the larger fish found deeper.

Age/Length/Maturity. Sablefish are long-lived, with a life span that can reach 26 years. Maximum size reached is slightly greater than 90 centimeters (36 inches). Maturity is reached between 5 and 7 years (49).

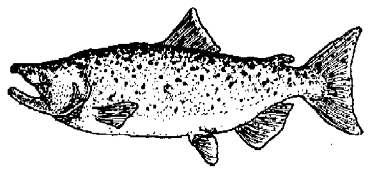
Reproduction and Early Life History. Mature sablefish spawn along the continental slope throughout their range between September and February. Locations of spawning grounds are unknown. Egg development occurs at the surface. Sablefish larvae are found at the surface during the spring as far as 290 kilometers offshore (180 miles) (6). Juveniles are also epipelagic and form schools near the surface, sometimes far offshore. By fall, juveniles have moved from offshore areas onto the continental shelf (35). Subadults eventually move to deeper water (49).

Trophic Relationships. Food items depend on life stage, geographic location, season, and time of day (49). Larval sablefish feed on zooplankton. Adults consume fish such as saury and myctophids as well as euphausiids (17, 35). Sablefish are eaten by northern sea lions, Pacific cod, and lingcod (49).

Fishery. Sablefish is a major deepwater, longline fishery.

SALMON

Five species of salmon live in the waters off Oregon: coho (silver), chinook (king), pink (humpy), chum (dog), and sockeye (red). Two of these, coho and chinook, are important to Oregon's commercial and recreational fisheries. Chum salmon, though numerous in Oregon at one time, are less abundant today. Sockeye and pink are not caught in large numbers off Oregon, but are abundant in areas farther north.



CHINOOK SALMON Oncorhyncus tshawytscha

CHINOOK SALMON *Oncorhynchus tshawytscha*

Range. The distribution of North American chinook salmon is somewhat broader than for coho salmon, with individual stocks ranging from southern California to the Gulf of Alaska, the Aleutians Islands, and the Bering Sea. They are also found off the coast of Asia.

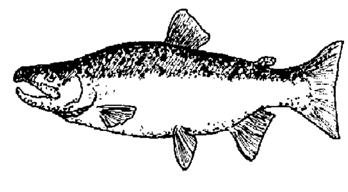
Reproduction and Early Life History. Many chinook stocks reproduce in the upper sections of large rivers such as the Columbia, Sacramento (California), and Fraser (British Columbia), as well as in streams near the coast. Chinook also demonstrate far more variability in the time they enter fresh water on their spawning migrations. Rather than having just one spawning run in the fall, chinook return to spawning rivers throughout the year. Spring, summer, and fall runs are found in the Columbia River. Oregon coastal streams may have both spring and fall runs or just a fall run.

Variability in the chinook life history continues after spawning. After hatching, chinook may migrate downstream to the estuarine environment, remain in fresh water for several months before moving into estuaries, or remain in fresh water for one year and then migrate to the coastal environment during their second spring (40). Typical of this variability are the fall chinook in the Sixes River, a small coastal stream in Curry County, which have five distinct life history patterns based on length of time spent in fresh water and estuaries (82).

In the Columbia River, the offspring of fall-run chinook remain in fresh water for about three months, whereas the young of spring-run fish spend one year in the river; however, there are exceptions to this pattern (83). Chinook return to fresh water after reaching an age of from two to six years. Most are three or five years old.

Migration. There are two types of ocean migrations. Spring chinook from the Umpqua River and spring and fall chinook from areas south of the Elk River remain off the southern Oregon and northern California coasts throughout their life (59). The western limit of their distribution is not clearly defined but may extend several hundred kilometers offshore. Chinook originating from coastal streams from the Elk River north, as well as from the Columbia River, tend to move northward. Most of these fish migrate as far as northern British Columbia before returning to their river of origin (21, 46).

Trophic Relationships. Chinook off the Oregon coast eat euphausiids, amphipods, crab larvae, squid larvae, and fishes (79, 80, 22). The diet of harbor seals includes adult salmon.



COHO SALMON Oncorhyncus kisutch

COHO (SILVER) SALMON *Oncorhynchus kisutch*

Range. The coho stocks of North America range throughout the eastern North Pacific from central California to Alaska. They are most abundant within this area off British Columbia, the central portion of their range. In Oregon, juveniles spending their first summer in the sea have been found within 37 kilometers (23 miles) of the shoreline (67). Older salmon can occur farther offshore, especially during the winter. Coho also live in the northwestern Pacific from Japan to the Bering Sea.

Reproduction and Early Life History. The life cycle of coho salmon is summarized in Figure 51. Spawning occurs in smaller tributaries of freshwater streams from November through February. Eggs are deposited in coarse sediments and hatch in a little over one month. (The development of salmon from egg to adult occurs in stages; the sequence is egg, fry, fingerling, smolt, adult.) Coho fingerlings remain in streams for about one year before migrating into estuaries. They then undergo dramatic physiological and morphological changes, called smoltification, in preparation for entering the ocean. Fingerlings are transformed into smolts when this process is finished. Most coho smolts are 10 to 13 centimeters long by the time they finally reach the sea.

After entering the ocean, coho grow rapidly. At the end of their first summer in the sea, they are 28 to 51 centimeters (approximately 11 to 20 inches) long. Some precocious males (called jacks) reach sexual maturity at this time, return to the stream of their birth and spawn with mature three-year-old fish. The females and nonprecocious males remain at sea for one more summer. Commercial troll and recreational fishermen harvest these three-year-old adults, but adult coho not caught return during the fall to their natal stream.

Migration. Recent studies have shown that for the first few months after reaching ocean water, juvenile coho may be distributed south of their entry river. By late summer, most have moved north of the point at which they entered the ocean. Some juveniles may remain in coastal waters in the vicinity of their release point (67).

Some Oregon coho have been known to move as far north as the Gulf of Alaska by the end of their first summer at sea (15, 21). The proportion of the Oregon coho stock that makes this extended journey is unknown. However, scientists believe that only a small number of fish, from various stocks, are involved and that the migration is tied to oceanic conditions encountered by coho smolts where they enter the ocean. Likewise, the route taken by these fish on their return migration is not well documented. Most coho stocks produced in Oregon (hatchery and wild) remain in ocean waters off California, Oregon, and Washington (56).

Trophic Relationships. Juvenile coho salmon eat primarily euphausiids, amphipods, crab larvae, and fish (77). Among the fish eaten, the Pacific sand lance, juvenile rockfishes, and juvenile flatfishes are most frequently consumed. Older coho are known to feed on euphausiids, squids, and other fishes (15, 80). Among the predators of young salmon are rockfish and other large fish, including salmon, and the common murre, a seabird which is known to eat juveniles as they migrate into the ocean. Adult coho are consumed by harbor seals, sea lions, killer whales, and sharks.

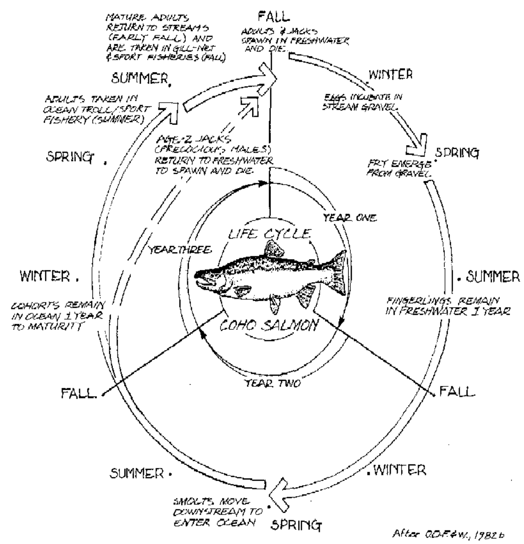


Figure 51. Coho Salmon Life History.

The life cycle of the coho salmon is similar to that of all types of salmon: birth in freshwater streams, a journey to the sea, a maturation phase at sea, and a return to the stream of birth to spawn and begin the cycle anew for the next generation of salmon.

Salmon Fishery. Salmon are harvested in the ocean by trolling with baited hooks on lines. Fishing occurs over the entire Oregon continental shelf, although activity is usually concentrated in areas less than 150 meters deep. Coho salmon are normally caught in shallower depths than are chinook.

Salmon catches off Oregon have fluctuated greatly over time. Following peak production during the early part of this century, salmon catches declined steadily until the early 1960s. This decline has been attributed to the construction of dams; the alteration of freshwater habitat by logging, pollution, gravel removal, siltation, dredging, and filling; and overfishing (52, 57).

SALMON MANAGEMENT

During their life cycle, salmon pass through very different biological environments and many political jurisdictions. Fish move from smaller freshwater streams along the Pacific Northwest coast or from the Columbia River system of Montana, Idaho, and British Columbia, through estuaries, and into the ocean to migrate as far away as the Gulf of Alaska before returning to their native streams. While completing this extensive migration, salmon are regulated by state, regional, federal, foreign, and international organizations.

Many of the problems facing salmonid management are related to the vast area traversed by migrating fish, the effect of changing environmental conditions, and the socioeconomic and political demands of all the jurisdictions through which the salmon pass. In addition, the increased use of hatchery-reared salmon in recent years to supplement depressed wild stocks presents new challenges in managing for "mixed stocks" (hatchery and wild) in ocean and inland commercial and recreational fisheries while attempting to rebuild wild stocks (33).

Oregon hatchery operations were expanded in the 1960s to counteract the decline in salmon. The number of young released to the ocean has increased steadily since that time. As an example, coho smolt releases increased from less than one million during the 1950s to 62 million in 1981 (see Figure 52). An ever-increasing number of salmon smolts has had mixed results and has not always translated into an increased number of adults. On the one hand, chinook salmon have been generally stable or increasing from 1960 to 1982, although some (for example, summer Columbia River chinook) have been on the decline. On the other hand, coho production illustrates a different trend, increasing from the early 1960s through the early 1970s and then declining from the mid-1970s until today (see Figure 53) (59).

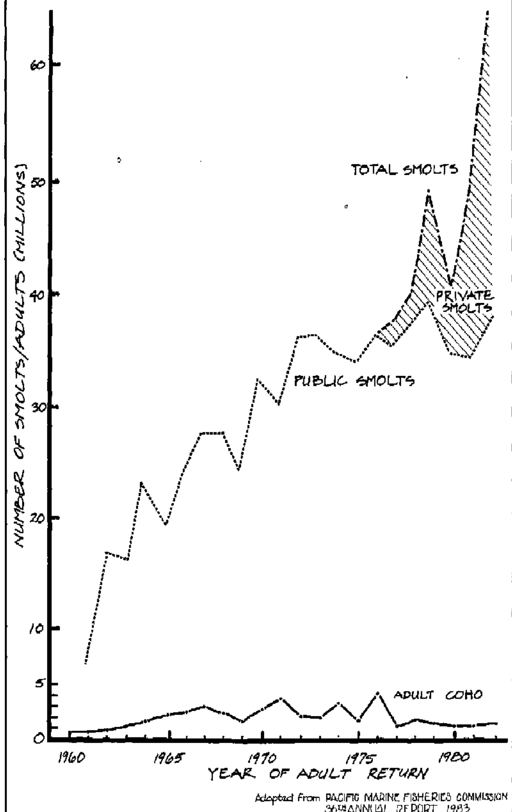


Figure 52. Coho Salmon Hatchery Releases and Adult Abundance for the Period 1961-82.

Far fewer adult coho salmon return to spawn than are released as smolts. The difference between total smolts and public smolts (smolts produced naturally or by public agency hatcheries) represents private hatchery releases (salmon ranches) (data from 62).

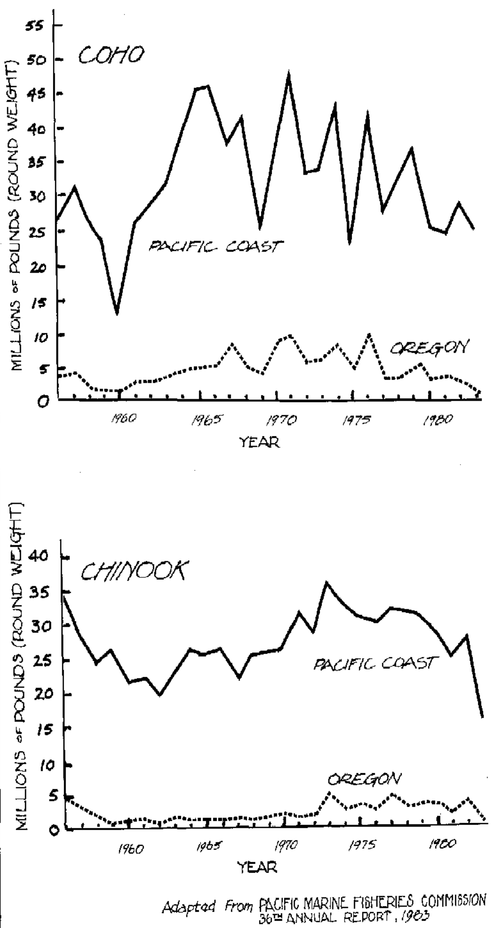


Figure 53. Pacific Coast (Alaska, British Columbia, California, Oregon, and Washington) and Oregon Landings of Troll-Caught Coho and Chinook Salmon (data from 62).

Several theories have been proposed to account for the recent coho declines. None has been proven and all are controversial. The Oregon Department of Fish and Wildlife has put forward several explanations in its 1982 Coho Salmon Plan (58). Two of them have received considerable attention recently from fisheries biologists and oceanographers.

One theory involves the importance of ocean conditions to salmon. Traditionally, the abundance of coho salmon was thought to be limited by the freshwater habitat. Streamflow, in particular, has been positively correlated with the catch of adults (53). Recent data, however, suggest that ocean conditions such as upwelling during the first year in the sea may be more important in determining year-class success and eventual adult abundance (53, 54, 88). (Factors such as ocean conditions are referred to as density-independent controls, since they operate regardless of the number of fish in the ocean).

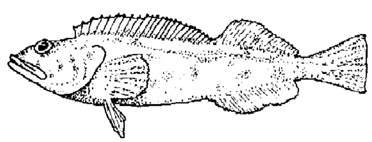
The other theory relates the increased number of young fish but low adult return to the ability of the ocean to provide food. Some fishery biologists feel that coho production has declined because too many smolts are being released by hatcheries, especially in years of low ocean production. (Regulating factors which vary proportionately with the number of fish living in the sea are collectively called density-dependent factors.) Figure 52 shows the dramatic increase in the number of young salmon released by Oregon's public hatcheries and salmon ranches. Superimposed on this figure is the abundance of coho adults over the same period. The number of adult fish produced after 1975 has declined *in spite of the continually increasing number of smolts released.* This type of relationship could indicate that there is a finite limit to the number of salmon the ocean can support and that the limit may have been exceeded (47, 48). Such a limit is called the carrying capacity.

The carrying capacity of the ocean is not fixed. Long-term changes have occurred in ocean conditions, including sea level rise and sea temperature increases associated with the most recent El Nino events. Such changes in the environmental conditions of the ocean may explain why salmon have been more abundant in the past (68). Moreover, natural salmon populations contained a combination of individual races that had adapted to various niches in the available habitat. Thus, ocean carrying capacity in the past could have been higher than today now that present populations include artificial production where ability to adapt to a wide variety of niches may be less than for natural production (56).

It is likely that a combination of factors is causing the decline of coho salmon. The identity of these factors and their degree of influence cannot be ascertained without much more information.

SOME FISH SPECIES OF MINOR COMMERCIAL IMPORTANCE OFF THE OREGON COAST

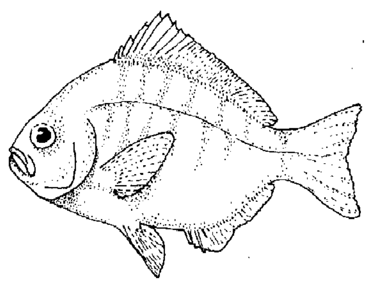
(After Miller and Lee, 1972)



LING COD Ophiodon elongatus

LINGCOD *Ophiodon elongatus*

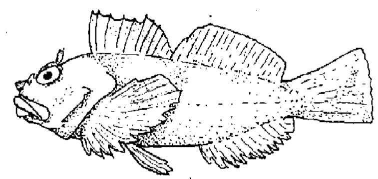
Ranges from Baja California to Kodiak Island, Alaska.
Length up to slightly over 1 meter; weight varies from up to 41 pounds off California to over 100 pounds off British Columbia.
Found at various depths by age: juveniles in shallow bays on sand and mud bottoms from beach to nearly 100 meters; adults from surface to 420 meters.



REDTAIL SURFPERCH Amphistichus rhodoterus

REDTAIL SURFPERCH *Amphistichus rhodoterus*

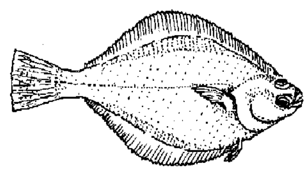
Ranges from Monterey Bay, California, to Vancouver Island, B.C.
Length to 40 centimeters.
Found from surface to 8 meters.



CABEZON Scorpaenicthys marmoratus

CABEZON *Scorpaenicthys marmoratus*

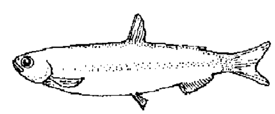
Ranges from Baja California to Sitka, Alaska.
Length up to nearly 1 meter.
Found from shallow intertidal to 75 meters.



ENGLISH SOLE Parophrys vatulus

ENGLISH SOLE *Parophrys vetulus*

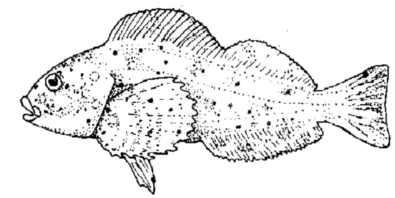
Ranges from Baja California to northwest Alaska.
Length up to ½ meter.
Found from 20 meters to 300 meters.



SURF SMELT Hypomesus pretiosus

SURF SMELT *Hypomesus pretiosus*

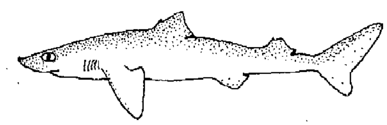
Ranges from Long Beach, California, to Prince William Sound, Alaska.
Length to 25 centimeters.
Spawns in surf in daytime.



KELP GREENLING Hexagrammos decagrammus

KELP GREENLING *Hexagrammos decagrammus*

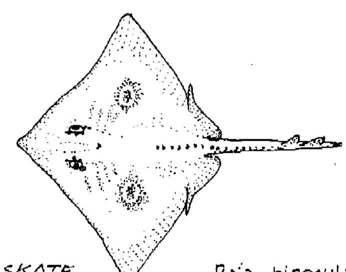
Ranges from La Jolla, California, to Aleutian Islands, Alaska.
Length up to ½ meter.
Found from intertidal zone to 45 meters; common in kelp beds but taken in deeper waters over sandy bottoms.



SPINY DOGFISH Squalus acanthius

SPINY DOGFISH *Squalus acanthias*

Ranges from central Baja California to Alaska.
Length to 1½ meters.
Found from shallow waters to 360 meters.



BIG SKATE Raja binoculata

BIG SKATE *Raja binoculata*

Ranges from Baja California to Bering Sea.
Length to 2½ meters, but rarely over 2 meters.
Found from 3 meters to slightly over 100 meters.

COMMERCIAL AND RECREATIONAL FISHING: Where the Fish Are and How We Know

An ancient industry, the harvesting of fish stocks is still one of the most important uses of the ocean. Yet basic data about fish distribution and abundance is difficult for scientists to obtain. Fisheries biologists and oceanographers depend on catch data supplied by commercial fishermen because going to sea is expensive and making quantitative observations once there is difficult. Thus, commercial fishermen provide important information on the kinds of species caught in a particular area—their size, sex, age, and community composition.

Nevertheless, commercial fish catch data, though valuable, is used within limits by biologists. Catch statistics do not reveal information about species not caught or individuals too small to be netted. Some species may be fished with more intensity than other species, so catch data may show a disproportionate amount of the target species or show them in greater numbers in a particular area. Catch statistics reveal where fish are caught, not necessarily their distribution.

Improvements in fishing technology have affected the catch data supplied to scientists. Larger boats with more powerful engines can stay at sea longer and range farther in search of fish. Improved nets increase the efficiency of the catch. Echo sounders are now used to locate fish, which appear as little dots on a screen. Infrared satellite images reveal upwelling areas where fishing success could be higher. Together this increased fishing power has changed the numbers and kinds of fish caught and thus the information available to biologists.

Fishermen have long known that fish distribution usually coincides with specific environmental conditions to which a species has adapted. Water temperature and salinity, depth, sediment type, and other bottom conditions combine to create unique conditions attractive to certain fish. Many species have overlapping habitat requirements so that several fish types may inhabit a given area (see Figure 54). These areas of high fish concentration have been traditional fishing grounds, such as the area between the mouth of the Columbia River south to Tillamook Head and the Stonewall Bank-Heceta Bank areas off the central coast.

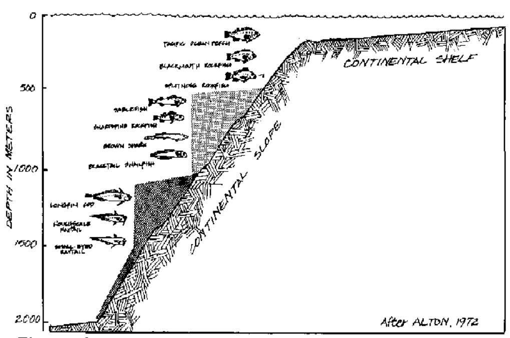


Figure 54. Benthic Fish Assemblages on the Outer Continental Shelf and Slope off Northern Oregon.

The distribution of fish species changes with depth. Rockfish are the most numerous fish on the upper continental slope, whereas rattails begin to dominate in deeper water and become the most abundant fish below 1,000 meters.

The commercial catch off Oregon is made up of many nekton species, as well as several important benthic species (see "Benthos: The Seafloor" for a discussion of Dungeness crab, Tanner crab, pink shrimp and weathervane scallops). This variety is reflected in the accompanying table, "Commercial Fish and Shellfish Landings in Oregon 1970-1983," which lists all commercial fish catches from 1970 to 1983. On the basis of pounds landed, however, rockfish, salmon, lingcod, Dover sole, and sablefish have been the most important. Pacific whiting, though not landed in Oregon, has been important until recently as a foreign and U.S.-foreign joint-venture fishery.

Most of the groundfish species caught in the commercial and recreational fisheries live over the continental shelf, although some are abundant over the continental slope (sablefish, Dover sole, rex sole, and some rockfishes). Many of the species associated with the bottom exhibit distinct preferences for water depth (2) and bottom type—rock, sand, mud (12, 66). Figures 48, 49, and 50 map the commercial catch of three species with differing environmental preferences over the continental shelf and slope off Oregon.

Commercial landings for Oregon have varied greatly, from approximately 90 million pounds in 1973 to almost 84 million pounds in 1984 (see Table: "Commercial Fish and Shellfish Landings in Oregon 1970-1983" and Figure 55). The fluctuation in landings can be influenced by a variety of factors, including abundance of fish, weather, market conditions, improvements in fishing gear, shifts in species targeted for harvesting, and governmental regulations. An increase in landings during the mid- to late 1970s resulted from several factors, including an increase in the number of vessels (most of which were large trawlers) in the fishing fleet, a peak in the cyclical productivity of shrimp and Dungeness crab, and favorable weather and ocean conditions for fishing (43).

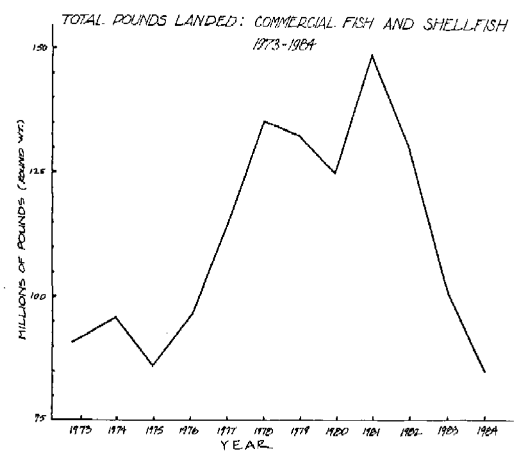
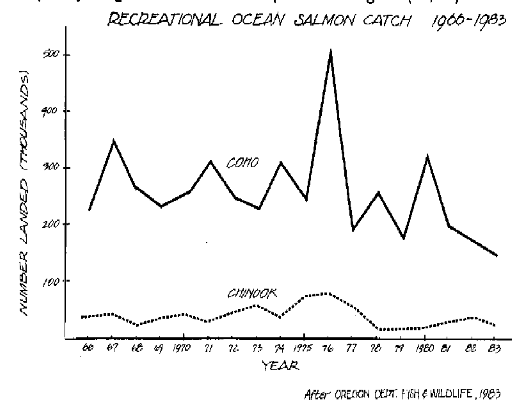


Figure 55. Twelve-Year Trend in Oregon Commercial Landings.

(ODF&W data). The increase in landings from 1976 to 1978 reflects increased fishing effort, favorable environmental conditions, and peak cycles in the life history of key species. Catch statistics for specific fish are shown by year in the accompanying table.

Recent declines in traditionally important fisheries such as salmon have increased interest in the commercial harvest of alternative species. Squid, skate, northern anchovy, Pacific saury, sergestid shrimp, Pacific mackerel, and jack mackerel are abundant, but markets have not yet been developed for these species. At present, many of these species are hauled in with other commercial target species but are tossed back over the side. It has been estimated that these discarded species may account for between one-third to one-half of the total commercial catch (68).

Several fish species important to commercial fishermen are also important to recreational fishermen as sport fish. Rockfish and salmon dominate the ocean sport catch (see Figure 56), but other species frequently sought include redtail surfperch and lingcod (25, 26).



SURVIVAL IN THE OCEAN

Fishermen and biologists have often wondered why some fish species are abundant in some years and scarce in others. One approach to this problem has been to determine the point in some animal's life history when it is most vulnerable (18, 11). The first months of life are a critical period in determining the abundance of an animal since the youngest stages of fish and invertebrates experience the highest rates of mortality. If larvae and juveniles experience favorable environmental conditions, then there will usually be a correspondingly higher number of mature adults available for a commercial or recreational fishery.

Survival through the first few months of life depends upon both physical and biological factors. Adequate supplies of food are central to survival. Off Oregon, upwelling produces phytoplankton blooms which in turn provide many animals with food. In the absence of upwelling, not only is food less available and mortality increased, but individual growth is also slowed. The slower a species grows, the more time it is exposed to possible predation from larger individuals. An adequate food supply and the availability of species to the fishery have been correlated with the intensity of upwelling (78, 28) and abundance of food such as pink shrimp (87, 53).

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CHAPTER SIX

BENTHOS

The Sea Floor

INTRODUCTION

Far below the wave-tossed ocean surface, the floor of the ocean provides a surprisingly diverse habitat for marine life. Referred to as the benthos, this bottom environment includes the rocky intertidal zone near the coast, the gently sloping mud- and sand-covered flats of the continental shelf, and the steeply dipping, mud-covered continental slope leading down to the deep ocean abyssal plains.

The ocean floor is home to nearly all major invertebrate groups (animals without backbones) but only a fraction of them—such as clams, crabs, and scallops—are harvested by humans. Far more abundant off Oregon are nematodes, polychaetes (marine worms), molluscs (snails and clams), crustaceans (shrimp, copepods, amphipods, isopods), and echinoderms (sea urchins, starfish, brittle stars).

Life on the seafloor also includes a variety of vertebrate animals. Bottom-dwelling fishes, such as sole, flounder, skate and cod, inhabit this benthic environment. Several of these benthic fishes are described in Chapter Five, "Nekton: The Swimmers." In addition to the animal life found on the ocean bottom, a few marine plants live attached to the seafloor (see sidebar: "Seaweeds").

This chapter of the *Oceanbook* describes general characteristics of benthic organisms, their diversity, habitat preferences, feeding, and life cycle. Several species important to commercial and recreational use off the Oregon coast are highlighted. In addition, the unique benthic life of deep-sea hydrothermal vents is discussed.

BENTHIC CHARACTERISTICS

Environmental Opportunity

Sediments covering the seafloor vary in composition. This diversity creates a variety of environmental opportunities for benthic organisms. Mud is composed of extremely fine particles of sediment which pack tightly together. Sand particles, on the other hand, are larger and leave larger spaces between them. Mixtures of sand and mud yield a variety of grain spaces. Organic material may be present on the ocean floor and mixed into the sediment spaces in varying quantities. Many benthic animals are very small and burrow into the sediments. They have particular likes and dislikes about the kinds of sediments in which they will live. Thus, just as the composition of the seafloor itself changes over an area, so too does the community of animals populating that area.

A small proportion of the sea bottom consists of rocky habitat around nearshore sea stacks, banks of the continental shelf, and recently erupted volcanic rocks on the midocean ridges. These rocky areas also provide habitat different from the sediment-covered bottom.

Nearshore, the ocean floor of the continental shelf is affected by a constantly changing physical environment. Bottom-dwelling species must contend with wave action, currents, turbidity, and daily and seasonal changes in light and temperature. In addition, marine life of the nearshore intertidal zones has adapted to alternating periods of exposure to air and tidal inundation.

Bottom-dwelling creatures have developed a variety of methods to take advantage of the diversity in bottom habitats and environmental conditions. Some, like the giant kelp and barnacles, live attached to a firm surface. Others, like clams and worms, burrow freely through soft sediments or, like crabs and sea cucumbers, roam the sea floor. Those benthic species living on the surface are referred to as epifauna; infauna refers to animals that conceal themselves below the surface (see Figure 57).

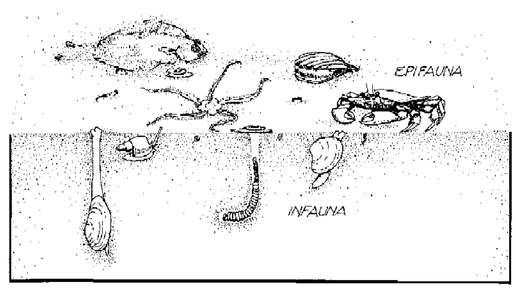


Figure 57. Examples of Epifauna and Infauna

Benthic animals living on the surface of the ocean floor are referred to as epifauna. These include crabs, brittle stars, and scallops. Those which live below the surface, such as clams and burrowing worms, are known as infauna.

Size Range of Benthic Animals

Bottom-dwelling animals are frequently grouped in three size categories: macrofauna, meiofauna, and microfauna (see Figure 58). The largest are the macrofauna, those organisms long enough to be retained on a seive with a mesh of 0.5 millimeters. This group is perhaps the best known since their size makes them easy to sample and sort. Some of these macrofauna are gastronomic delicacies of the sea world: crabs, lobsters, oysters, and sea urchin roe.

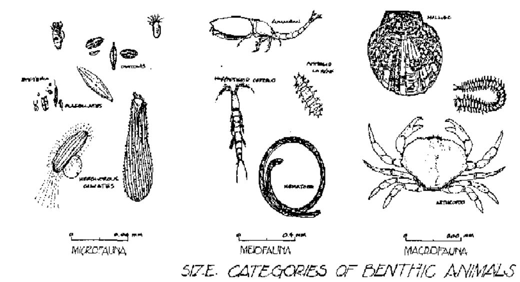


Figure 58. Size Categories of Benthic Animals

Benthic animals are classified into three major groups based on size. Representative examples within each group are shown. The scale of the drawings is approximate.

Meiofauna are small organisms (retained on sieves of 0.063 to 0.5 millimeters) that cannot be seen without the aid of a microscope and are difficult to count and identify. Primarily multicellular animals, meiofauna live in the spaces between sediment particles and include free-living nematodes (round worms) and copepods as well as the younger, smaller life stages of many macrofaunal animals.

Microfauna, such as bacteria and protozoans, are the smallest forms of life (less than 0.063 millimeters). Little is known about the role of this group in the marine ecosystem, though bacteria are important in breaking down organic compounds and returning nutrients to the water in a form usable by other species.

Food Sources and Feeding Methods

Most of the seafloor lies below the euphotic zone. As a result, bottom-living animals ultimately rely upon food falling from the ocean's upper layers or brought in by ocean currents (see Figure 59.). (Animals living around deep-sea hydrothermal vents are an exception to this generalization and are discussed elsewhere in this chapter.)

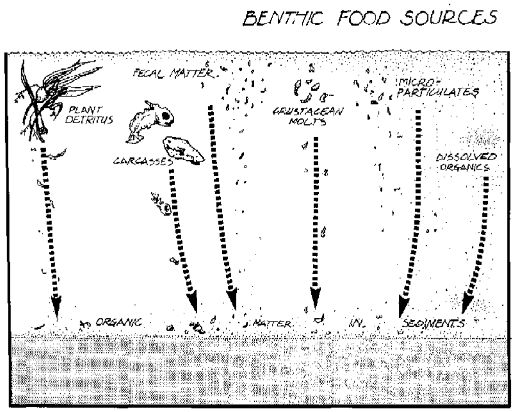


Figure 59. Benthic Food Sources

Benthic animals depend on a slow, sparse rain of organic debris drifting to the bottom from the surface layers. This debris ranges from microscopic particles to entire fish carcasses.

The amount of organic material reaching the bottom is greater near the coast than at distances farther from shore. Two important factors contribute to this: higher phytoplankton production in the nearshore surface layer and a shorter journey downward through the water column. Thus, more downward-drifting food reaches the bottom before being intercepted and consumed.

Feeding habits of benthic animals vary greatly and generally relate to the type of sediment in which a species is found. Common feeding modes are filter feeding, deposit feeding, and predation. Filter or suspension feeding is most prevalent in nearshore, sandy environments where food is abundant. Scallops and mussels remove food particles from the water by pumping water past filtering mechanisms which extract small plant and animal plankton.

Deposit feeders, which prefer fine muddy sediments rich in organic material, have developed several methods of recovering detritus as they roam the ocean bottom. Some, like shrimp, swim just above the bottom and make short excursions to the bottom to feed. Others, such as brittle stars and isopods, ingest the sediment particles around them, gleaning the organic detritus. Some burrowing clams use siphons to scoop up surface deposits. Benthic predators, such as the voracious crab, actively search out and prey upon other benthic animals (8).

SEAWEEDS

Marine algae include not only microscopic floating plants, but large attached species as well. Because plants depend on the sun's energy, these attached seaweeds are confined to relatively shallow waters nearshore where sunlight penetrates the water to the bottom or where the seaweed leaves can float in the sunlight while the plant is anchored to the dimly lit bottom.

Marine algae can be distinguished in part by their pigmentation, hence the names red algae, green algae, and brown algae. Most of the large seaweeds belong to the brown algae group and frequently form dense beds around rocky outcrops.

Seaweeds contribute little to the overall production of food on the continental shelf or waters farther offshore, but can be a factor in the high productivity of coastal areas. Off central and southern California, seaweed is particularly important in the diet of sea urchins, which in turn are a major food source for sea otters.

The bladder or bull kelp, *Nereocystis luetkeana*, the most common large kelp in Oregon, serves as a particularly important habitat for many species of coastal fish and invertebrates. A branched "holdfast" anchors it to the bottom and a long stalk leads to a bulbous, gas-filled float at the surface (see Figure 60). Attached to this bulb are four broad leaves which capture solar energy as they float just below the surface. Bull kelp may grow to 20 meters (more than 60 feet) and may have leaves 3 meters long.

Although very numerous, *Nereocystis* beds are usually small and vary through time in size and position (24). Some beds temporarily disappear only to be re-established several years later. This huge kelp is an annual, putting on all of its growth during the spring and summer. Following the winter die-off, many of these plants are washed onto the beach. *Nereocystis* reproduces asexually by microscopic spores. These spores live through the winter to produce the next generation of kelp in the spring (14).

Another large brown algae, the California giant kelp, *Macrocystis integrifolia*, a perennial, is of commercial importance in southern California. It is found in Oregon only off Simpson Reef at Cape Arago just south of the entrance to Coos Bay (24).

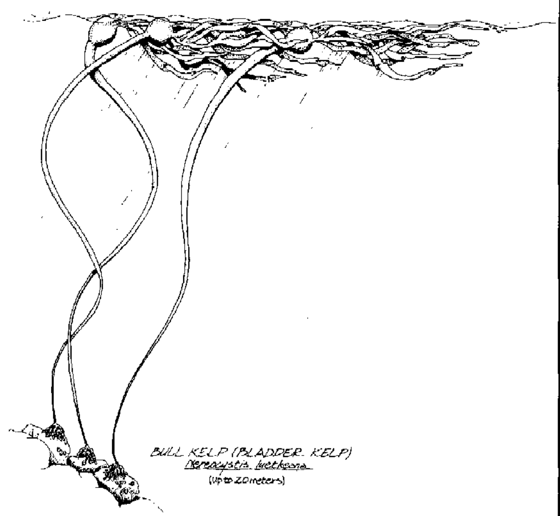


Figure 60. Bull Kelp

The leaves of the bull kelp are kept afloat at the surface by a bulbous, gas-filled float. A tough but flexible stalk terminates in a "hold-fast," which anchors the plant to the bottom. Piles of bull kelp, coiled like bull whips, litter Oregon beaches after a storm.

A "NEW" BENTHOS: Deep Ocean Ridges and Hydrothermal Vents

Since the discovery in 1977 of oceanic spreading centers and hydrothermal vents, the unique biological communities associated with them have been the subject of research by marine scientists (see also Chapter Two, "Geology: The Rocks"). Findings from this research have revealed insights into biological processes and forms of life previously unknown on modern-day earth. Animals living in these zones do not depend upon the energy of sunlight and primary production by plants for food. Instead, in a process called chemosynthesis, bacteria use the chemical energy contained in inorganic chemicals to convert carbon dioxide into organic compounds. Bacteria have thus replaced plants as the primary producers in these vent ecosystems.

In some cases the bacteria live within the bodies of animals which take advantage of the chemosynthetic ability of the bacteria. For example, vestimentiferan tube worms which are frequently seen very close to vents lack a digestive tract. This vent water contains reduced sulfur, oxygen, and carbon dioxide and is ingested by the tube worm. The bacteria within the gut of the tube worm then produce nutritious organic compounds usable by their host.

Marine biologists studying these vents have catalogued previously unknown species of marine life living near them, including mussels, clams, limpets, polychaete worms, snails, barnacles, leeches, and copepods. Although a large number of organisms are found around the hydrothermal vents, the diversity of species is much lower than in other deep-sea habitats. Furthermore, the animals living in vent communities are actually different from those of surrounding deep-water areas. Rather than growing very slowly and living for up to one hundred years or more as other deep-sea organisms have been shown to do, vent organisms seem to mature rapidly and reproduce on a time scale of less than 10 years (11).

Hydrothermal vent communities are known to exist at several locations on the Juan de Fuca Ridge and are suspected to exist on the Gorda Ridge. Recent dives of the research submersible *Alvin* have revealed that the most abundant organisms of the Juan de Fuca vent system are vestimentiferan worms, limpets, and polychaete worms, all of which live on the sulfide chimney deposits of active vents. The composition of animal communities changes very rapidly only a short distance away from the subsea oases created by the food available from the hydrothermal vents. Animal abundance decreases to the normal low levels found in the deep sea with only an occasional sponge or sea anemone seen attached to the bottom.

Life Cycle and Reproduction

Although most adult benthic animals live in a relatively cold environment, the life cycle of many benthic organisms includes a planktonic larval stage which takes advantage of higher temperatures and food available at the surface during this critical nursery period (8). In many species, the release of larvae appears to be timed to the burst of phytoplankton production, important for larvae that rely on this food resource. Crustaceans, molluscs, echinoderms, and polychaete worms are among the many invertebrate groups whose species may reproduce using a drifting larval stage. At the end of the planktonic phase, larvae settle to the bottom and select a place to live. These organisms undergo a complex metamorphosis in passing from a pelagic habitat to a bottom-dwelling existence.

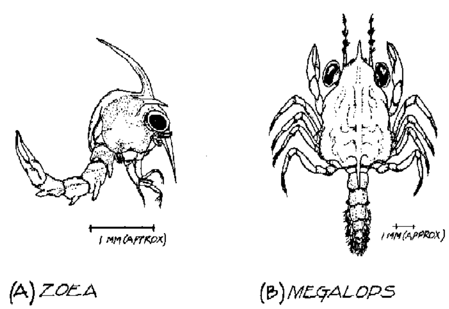


Figure 61. Planktonic Stages of the Dungeness crab

Crab zoea (A) undergo five molts before emerging into the megalops stage (B) and then spend approximately four months living in the water column before they settle to the seafloor. (Figure adapted from Reilly, 1983.)

For the tiny larvae, survival in the ocean is precarious and the chances of reaching maturity and colonizing a suitable area are slight. Larvae provide food for many larger organisms and suffer immense mortality from predators, including all filter-feeding animals which consume large quantities of pelagic larvae. In addition, some larvae may be carried far offshore by the currents and never find a suitable habitat. To overcome these odds and ensure species survival, females of many species release several thousands eggs each season.

Not all benthic organisms, however, have a pelagic larval stage. Some crustaceans, including amphipods, have brood pouches between their limbs, where the larvae are protected after they hatch. Other benthic larvae develop directly on the bottom. Although scientists know that such direct development occurs in other areas, research off Oregon is lacking.

Distribution of Benthic Animals

Although relatively few studies have been conducted on the benthic fauna of the continental margin west of Oregon, it is known that species composition changes with depths and with sediment characteristics. In very shallow water with sandy bottoms, filter-feeding amphipods, nudibranchs, and gastropods dominate benthic infaunal communities. In the deeper water, shrimp and urchins are more abundant. On the muddy bottoms of the mid- and outer continental shelf, deposit-feeding polychaete worms prevail (17).

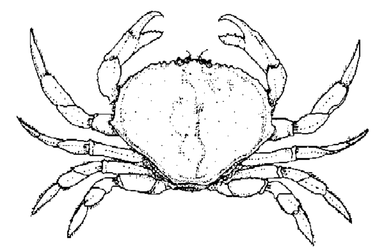
Organisms of the deep ocean basins have adapted to a fairly stable set of environmental conditions different from that of the continental margin. In this dark, cold, high-pressure environment, food drifting downward to deep-sea communities is scarce. Food items can range in size from minute particles of organic material absorbed onto sediment grains to the massive carcass of a whale. Accordingly, the numbers of deep-sea benthic animals and their growth rates are very low when compared to data from the continental shelf, yet the diversity of species living there is extremely high. Collections of several thousand macrobenthic animals from these deep waters typically will contain 200 to 300 different species (13).

Benthic animals found at water depths of 3,000 meters on the Cascadia Plain typify the life on many deep-sea plains adjacent to continental land masses. Of the larger burrowing animals, polychaete worms make up the majority of samples collected, while crustaceans are the second most abundant group. Sea cucumbers, brittle stars, and amphipods are the most frequently collected surface animals (1, 4, 5, 6, 7, 9, 12, 20, 23). No data on meiobenthos exist.

Beyond the Gorda and Juan de Fuca ridges lies the deeper (over 3,200 meters) Tufts Abyssal Plain. Studies show that whereas the number of larger infauna on the Tufts is roughly equivalent to that of the Cascadia Basin, the biomass is only half as large.

IMPORTANT COMMERCIAL BENTHIC SPECIES

Benthic invertebrates are of major importance to Oregon's commercial fishing industry. However, because these benthic animals lack the mobility of the free-swimming vertebrate fish, they are easily harvested and thus are vulnerable to fishing pressure. The life history of several important benthic species is discussed in the following section.



DUNGENESS CRAB *Cancer magister*

DUNGENESS CRAB *Cancer magister*

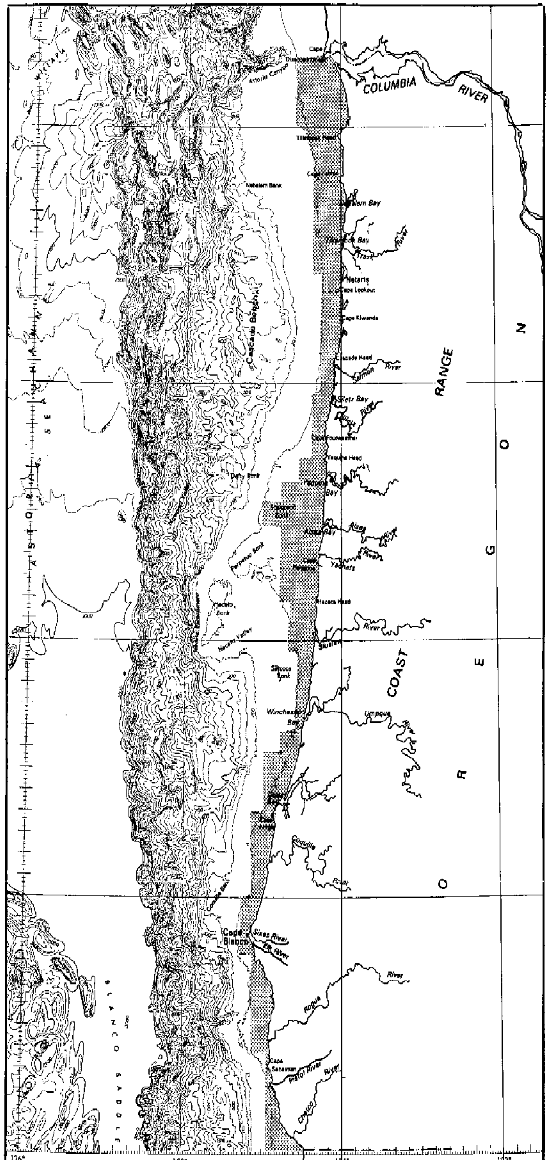
Range. The Dungeness crab ranges from Baja California to Alaska in bays and shallow coastal water to a depth of 90 meters, preferring sandy or muddy-sand bottoms, but it can be found on almost any type of substrate (18).

Distribution. Dungeness crabs tend to move seasonally from shallow water in summer to deeper water in winter.

Reproduction. Dungeness crabs mate in the spring. The female stores the sperm within her body until spawning, which takes place off Oregon from October to March (31). Eggs hatch and pelagic larvae are released during the winter. Throughout the next four months, while the larvae live as zooplankton, they undergo several transformations (see Figure 61) (15). Pelagic larvae are found up to 90 kilometers off the Oregon coast (15).

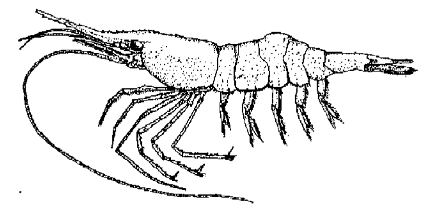
Trophic Relationships. Dungeness crabs eat a wide variety of food. Examination of stomach contents shows that they consume crustaceans, clams, fishes, snails, and polychaete worms (3, 10). Planktonic crab larvae are eaten by juvenile coho and chinook salmon and rockfishes (see also Figure 3 in Chapter One) (25). Adult Dungeness crabs are preyed upon by lingcod, wolf-eels, halibut, and rockfish (31).

Fishery. The commercial landings of Dungeness crab fluctuate greatly over time. Indeed, catch statistics show an 11-year cycle in the abundance of crabs (2). Large numbers of Dungeness crabs were caught in 1956-57, 1967-68, and 1976-77 (see Figure 62.) Dungeness crabs are harvested using baited traps. All nearshore Oregon waters less than 50 fathoms are fished except for one area near Cascade Head (see Figure 63).



DUNGENESS CRAB COMMERCIAL CATCH AREAS
Data from ODF&W, 1977, in Standar & Holton, 1978

Figure 62. Dungeness Crab Commercial Catch Areas off the Oregon Coast



PINK SHRIMP *Pandalus jordani*

PINK SHRIMP *Pandalus jordani*

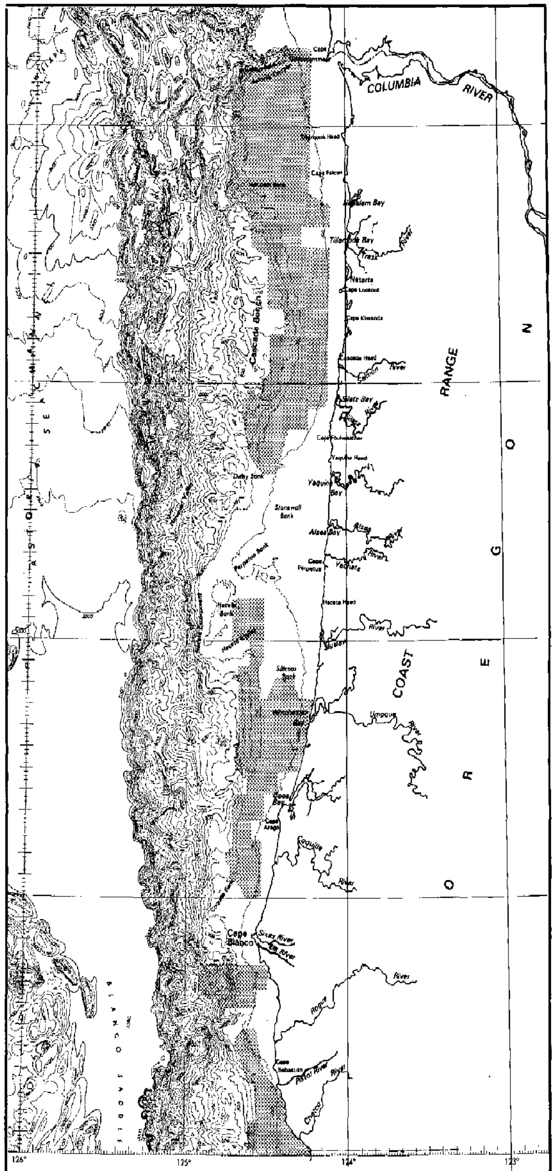
Range. Oregon pink shrimp are found along the west coast of North America. Off the Oregon coast they live in watr 70 to 180 meters deep over muddy-sand bottoms (26).

Distribution and Vertical Migration. Pink shrimp spend the daylight hours on the bottom and then migrate into the water column at night (19).

Reproduction. Pink shrimp are males for the first year of sexual maturity and then transform into females. The transformation is completed after the shrimp reach two and one-half years of age. Females carry their eggs in brood pouches between October and January; eggs hatch in late winter. From the eggs come planktonic larvae, which are most abundant on the inner shelf in February and March. As the larvae grow, they move further westward so that by June, late-stage larvae and young juveniles may be found 15 to 30 miles offshore. After settling to the seafloor, juveniles live in the same locations as the adults rather than seeking out separate nursery areas (16).

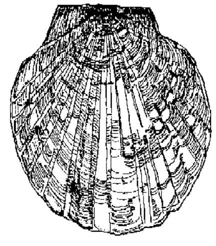
Trophic Relationships. The food habits of pink shrimp are poorly known but observations show that adults found in the water column at night eat euphausiids and copepods whereas those on the bottom feed on small benthic animals and detritus (19). Fish such as Pacific whiting eat pink shrimp and may strongly effect shrimp abundance (27).

Fishery. The fishery for pink shrimp began prior to 1955, though gear restrictions and hand-picking costs hindered this effort. Legalization of the shrimp trawl fishery in the Gulf of Mexico and development of the shrimp-packing machine allowed the industry to grow after 1957 (28). Shrimp landings increased steadily until they reached a peak harvest of 55 million pounds in 1977. Survival of shrimp is linked to upwelling; thus, the catch of shrimp increases as upwelling increases (27). Locations of commercial shrimp beds are illustrated in Figure 64.

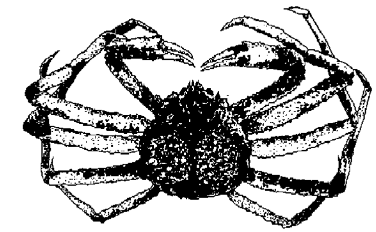


PINK SHRIMP COMMERCIAL CATCH AREAS
Data from ODF&W, 1977, in Stander & Holton, 1978

Figure 63. Pink Shrimp Commercial Catch Areas off the Oregon Coast



WEATHERVANE SCALLOP *Pecten caurinus*



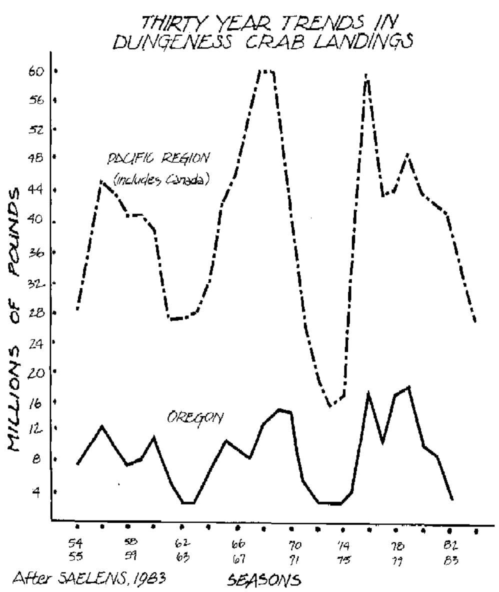
TANNER CRAB *Chionoecetes tanneri*

WEATHERVANE SCALLOP *Pecten caurinus*

Distribution. Weathervane scallops are found along the Oregon coast at depths of from 90 to 120 meters (30). Distinct beds of scallops occur off Coos Bay, the Siuslaw River, Yaquina Head, Cape Kiwanda, and Tillamook Head, although the locations of these beds may shift from year to year (30).

Reproduction. Weathervane scallops spawn from February through July. The larvae are planktonic for a four- to six-week period.

Fishery. Surveys of the Oregon coast during the 1960s revealed the presence of weathervane scallops in commercial quantities, but Oregon scallops remained unexploited until 1981, when several vessels landed large catches at Coos Bay. These beds were dominated by a single-year class (1975), indicating reproductive failure for the period 1976 to 1980. Within six months, most known scallop beds had been harvested. Only a few vessels continue to fish for scallops.



TANNER CRAB *Chionoecetes tanneri*

Distribution. Off Oregon, Tanner crabs are found on the continental slope at depths of from 500 to 1,920 meters. Adults are most frequently encountered between 500 and 777 meters and juveniles are usually caught between 640 and 1,554 meters (22). Adult males are normally found at shallower depths than adult females.

Reproduction. During winter, the male population makes a spawning migration downward toward the females. Females carry fertilized eggs from spring to late winter, at which time the larvae hatch. Following maturation within the plankton, young Tanner crabs settle to the bottom in deep water. As they continue to grow, they move into shallower water and eventually join the adult population.

Fishery. The Tanner crab is a deep-water species which may be sufficiently abundant off Oregon to support a commercial fishery (21, 22). Other species of *Chionocetes* are fished off Japan and Alaska and in the Atlantic.

Figure 64. Thirty-Year Trends in Dungeness Crab Landings

The upper figure shows total landings of Dungeness crab for the Pacific region (including Canada). A distinct 11-year cycle in crab abundance is visible. The lower figure shows the landings in Oregon for the same period.

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CHAPTER SEVEN

MARINE BIRDS AND MAMMALS

Residents and Visitors

INTRODUCTION

Silently riding the wind of an incoming storm, roosting noisily on rocky ledges, or wheeling and diving in the wake of a fishing boat, seabirds are important visual elements of the Oregon coast. Likewise, the sight of sea lions basking in the sun, seals floating lazily on the waves, or whale-spouting above distant wavetops adds to the richness of the coastal panorama.

But beyond their aesthetic appeal to coastal visitors, both marine birds and mammals are important components of the marine ecosystem. And even though they spend much time at sea, both birds and mammals are highly dependent upon the habitat provided along Oregon's coastline for breeding and rearing young or for resting and feeding during migration. The location and health of these habitat areas are vital to the breeding success and survival of various bird or mammal species.

This chapter of the *Oceanbook* discusses in detail marine birds which breed along the coast and marine mammals which either haul out (leave the water) along the coast or are commonly found in the waters off Oregon. In addition, marine bird and mammal species that only visit the coast are described.

MARINE BIRDS

Marine Bird Characteristics

Marine birds differ from other terrestrial birds in a variety of ways. First, they spend much of their lives in association with the sea. Some (for example, gulls, pelicans, and cormorants) remain close to shore throughout their lives; others (such as albatross, storm petrels and alcids) are at sea for extended periods and return to land only to breed. Of the truly pelagic seabirds, several are nocturnal on the breeding grounds, entering or leaving their colonies only at night. Marine birds commonly seen off the Oregon coast are listed in the accompanying Table.

Probably the most striking difference between marine and terrestrial birds is the longevity of marine birds. Upon reaching adulthood, many marine birds live for years. Annual mortality rates commonly run below 20 percent, whereas those for terrestrial birds can be 40 to 70 percent (12). Some banded individuals have lived for 20 to 30 years.

Marine Birds Commonly Seen off the Open Oregon Coast—Their Preferred Habitat, Seasonal Occurrence, and Abundance.

(Modified from Eltzroth and Ramsey, 1979)

Family *Gaviidae*	
Common Loon	PR Cs C
Yellow-billed Loon	VA Cs O
Arctic Loon	P Cs C
Red-throated Loon	WR Cs C
Family *Podicipedidae*	
Western Grebe	PR Cs C
Red-necked Grebe	PR Cs U
Horned Grebe	PR Cs C
Family *Diomedeidae*	
Black-footed Albatross	PR Oc,Cs C
Laysan Albatross	WR Oc,Cs R
Family *Procellariidae*	
Northern Fulmar	MI Oc,Cs C
Pink-footed Shearwater	MI Oc,Cs U
Flesh-footed Shearwater	MI Oc,Cs O
Bulleo's Shearwater	MI Oc,Cs U
Sooty Shearwater	MI Oc,Cs V
Short-tailed Shearwater	MI Oc,Cs U
Family *Hydrobatidae*	
*Fork-tailed Storm-Petrel	PR Oc,Cs C
*Leach's Storm-Petrel	PR Oc,Cs U
Family *Pelecanidae*	
Brown Pelican**	SR Cs C
Family *Phalacrocoracidae*	
*Double-crested Cormorant	PR Cs V
*Brandt's Cormorant	PR Cs V
*Pelagic Cormorant	PR Cs V
Family *Phalaropodidae*	
Red Phalarope	MI Oc, Cs V
Red-necked Phalarope	MI Oc, Cs V
Family *Laridae*	
Glaucous Gull	WR Cs R
*Glaucous-winged Gull	PR Cs V
*Western Gull	PR Cs V
Herring Gull	WR Cs U
Thayer's Gull	WR Cs U
California Gull	PR Cs V
Ring-billed Gull	PR Cs C
Mew Gull	WR Cs V
Bonaparte's Gull	MI Cs V
Heermann's Gull	SR Cs C
Black-legged Kittiwake	MI Oc,Cs C
Sabine's Gull	MI Oc,Cs U
Common Tern	MI Oc,Cs U
Arctic Tern	MI Cs U
Caspian Tern	SR Cs U
Family *Alcidae*	
*Common Murre	PR Cs V
*Pigeon Guillemot	SR Cs C
Marbled Murrelet	PR Cs U
Ancient Murrelet	WR Cs U
*Cassin's Auklet	PR Oc,Cs C
Parakeet Auklet	VA Oc,Cs O
*Rhinoceros Auklet	PR Cs C
Horned Puffin	VA Oc,Cs O
*Tufted Puffin	PR Oc,Cs U
Family *Anatidae*	
Oldsquaw	WR Cs O
Harlequin Duck	PR Cs U
White-winged Scoter	PR Cs V
Surf Scoter	PR Cs V
Black Scoter	PR Cs U
Family *Haematopodidae*	
*Black Oystercatcher	PR Sh U
Family *Charariidae*	
Semipalmated Plover	MI Sh C
Snowy Plover	PR Sh R
Lesser Golden Plover	MI Sh R
Surfbird	WR Sh V
Ruddy Turnstone	WR Sh U
Black Turnstone	WR Sh V
Family *Scolopacidae*	
Least Sandpiper	PR Sh V
Whimbrel	PR Sh C
Wandering Tattler	MI Sh U
Rock Sandpiper	WR Sh U
Dunlin	WR Sh V
Western Sandpiper	MI Sh V
Marbled Godwit	MI Sh C
Sanderling	WR Sh V
Family Stercorariidae	
Pomerine Jaeger	MI Oc,Cs U
Parasitic Jaeger	MI Oc,Cs U
Long-tailed Jaeger	MI Oc,Cs U
South Polar Skua	MI Oc,Cs R

*Breeds along open coast and on sea islands.
** Endangered species

Seasonal Occurance:
- PR - Permanent resident
- SR - Summer resident
- WR - Winter resident
- MI - Migrant
- VA - Vagrant

Abundance (during peak period):
- V - very common (50 or more birds/day/observer)
- C - common (10-49 birds/day/observer)
- U - uncommon (0-9 birds/day/observer)
- R - rare (5 or less birds/year/observer)
- E - extremely rare (5 or less birds/year/all observers)
- O - occasional (not seen every year but occasionally present)

Preferred Habitat on Open Coast (some species also live in bays, estuaries, and further inland):
- Sh - Shore (sandy beach and rocky intertidal)
- Cs - Continental Shelf
- Oc - Oceanic (beyond Shelf)

Other important differences are the age of first reproduction and clutch size (the number of eggs in a single nest). Many seabird groups have extended juvenile periods, becoming sexually mature after three to seven years. These birds typically lay small clutches of only one or two eggs per year. Marine birds, therefore, maintain their numbers by producing relatively few young per year over a long lifetime.

Seabirds are well adapted to exploiting the ocean's resources, having evolved a remarkable variety of specialized beaks, feet, and body shapes for feeding and breeding. A rhinoceros auklet snaps up fish with a heavy, bony bill and holds them with its tongue while continuing to catch more fish. A black oystercatcher can pry limpets off rocks with its long, stout bill. A brown pelican plunges into the surface waters, scooping up prey with the pouchlike extension of its lower mandible. Figure 65 summarizes the variety of feeding methods of marine birds found off the Oregon coast.

A webbed foot provides an advantage in the aquatic environment. Diving birds such as cormorants and murres are well endowed for pursuing their underwater prey with short legs and large webbed areas between their toes. However, because their legs are positioned farther back on the body, diving birds are less adept onshore and sway from side to side as they amble over land. The legs and feet of shorebirds, on the other hand, are better suited to life ashore. Some possess short legs for dashing to and from the water's edge; others can wade atop long, spindly legs while searching for small fish in shallow bays.

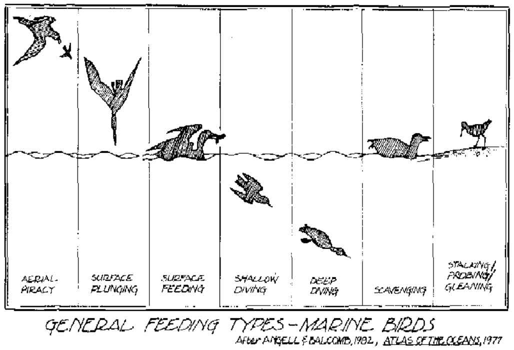

Figure 65. Feeding Stategies of Open Coast Marine Birds.

Marine birds use a variety of feeding methods to capture the many food resources of the ocean. Each feeding method, or combination of methods, allows that species to exploit a particular niche in the food supply and thus improve its chances of survival and reproduction.

A streamlined body like that of the cormorant is most useful in propelling the bird efficiently through the water. The wings of the alcids, large in proportion to a small body size, are used like paddles to maneuver the bird quickly and powerfully in search of prey.

Most birds have a gland situated at the base of the tail which secretes oil. Continual preening spreads the oil over the birds' feathers and makes them waterproof. Seabirds repeat this routine several times a day. Some species are not so well endowed; cormorants need to leave the water to spread their wings to dry after diving.

Seabirds are most abundant along the shore and over the continental shelf where prey is plentiful. Prey is known to accumulate in frontal regions, which are boundaries between oceanic water masses such as the zone where cool, upwelled nearshore water meets warmer offshore water. A rich supply of nutrients at the surface in these regions permits abundant plant growth, which in turn supports zooplankton and small fish. Petrels, terns, and shearwaters occur on the warm side of the fronts and murres and auklets on the cold side of the fronts (13).

Birds in the Marine Ecosystem

Birds are an important component of marine communities in that a significant proportion of the energy passing through the Oregon coastal ecosystem is channeled into their survival. Small pelagic fish are the principal food of many marine birds. Northern anchovy, Pacific herring, rockfish, smelt, sculpin, and cod are all eaten by seabirds in great numbers.

Computer simulation models have been used to estimate how many of these fish are consumed each year by four species of Oregon seabirds: sooty shearwaters, Leach's storm petrel, Brandt's cormorant, and the common murre (18). Results have shown that about 125 million pounds of pelagic fish may be eaten annually by these four species (18). This catch approximates that landed annually by commercial fishermen in Oregon and is estimated to be nearly 22 per cent of the annual production of small pelagic fish. The northern anchovy is particularly important as a food source, providing approximately one-half of all prey consumed.

Shearwaters play an important role in the flow of energy from fish to birds. Estimates indicate that for a few brief months during their fall migration off Oregon, shearwaters consume seven times as much food as either common murres, Brandt's cormorants, or storm petrels (18). However, when computed on an annual basis, the total energy demand of common murres exceeds that of the other three species.

Oregon Marine Bird Populations

The total number of breeding seabirds in Oregon is estimated to be 450,000 (15). Year-to-year fluctuations in the number of breeding birds can often be attributed to oceanographic conditions. The intensity and duration of upwelling, for example, may influence both the number of birds that breed and the survival of offspring (12).

Most seabirds are colonial nesters; consequently, colony sites are critical areas for marine birds. Large numbers of birds aggregate within these nesting areas, using the social stimulation of the colony to synchronize hatching, to ward off predators, and to forage for food in waters close to the colony. Both human and natural disturbances around seabird colonies can severely affect the survival and reproductive success of a species. Figure 67 shows the locations of known seabird colonies along the Oregon coast.

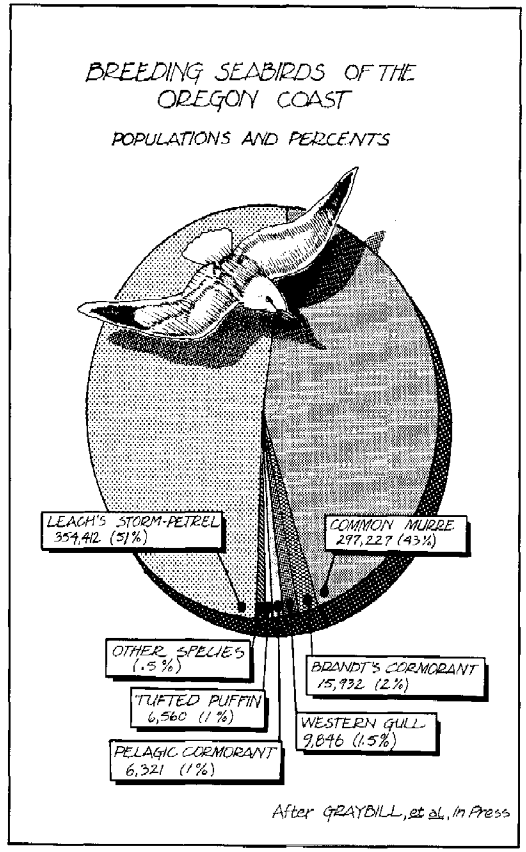

Figure 66. Populations of Breeding Seabirds and Proportion of the Total Seabird Population of Each Species in Oregon

Oregon's seabird population is dominated by two species, the common murre and Leach's storm petrel. All other species combined, including the familiar Western gull, account for less than ten per cent of the total population.

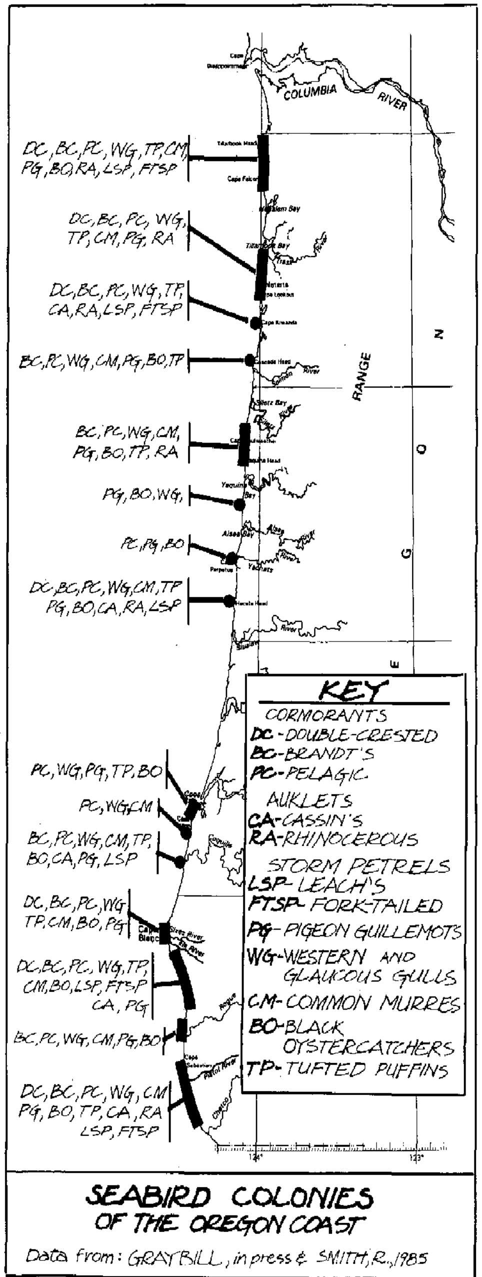

Figure 67. Colonies of Breeding Seabirds in Oregon

Twelve species of seabirds breed along the Oregon coast, nesting on offshore islands and on the mainland where the interference from humans and predators is minimized.

LIFE HISTORIES OF OREGON'S BREEDING SEABIRDS

Thirteen species of seabird breed along the Oregon coast. Their life histories are briefly discussed in this section (5, 1, 10, 12). As illustrated in Figure 66, common murres and Leach's storm petrels account for approximately 94 per cent of Oregon's breeding seabirds while the other twelve species combined, including gulls, total only 6 per cent.

CORMORANTS *Family Phalacrocoracidae*

Three species of cormorants live in Oregon year-round. All are blackish, with slender, hook-tipped bills, and the adults often have colorful face skin and gular pouch. The Brandt's cormorant *(Phalacrocorax penicillatus)*, the most common cormorant of the Oregon coast, has a blue throat pouch during the breeding season. It is also the largest of the species, up to 74 centimeters (approximately 30 inches). Double-crested cormorants *(Phalacrocorax auritus)* range to nearly 70 centimeters (27 inches) and have an orange-yellow throat pouch. They are the only species to regularly occur in freshwater habitats. Pelagic cormorants *(Phalacrocorax pelagicus)* are the smallest (56 centimeters or approximately 22 inches) of the three cormorant species. They have a white patch on each flank and a dull red throat pouch during the breeding season. Although they are the most widespread, they are the least gregarious of the three species.

Range. Brandt's cormorants reside from Vancouver Island to Baja California. Double-crested cormorants are found from Alaska to northern Mexico. Most widespread are the pelagic cormorants, whose breeding range extends from Baja California northward along the Pacific coast, across the Bering Sea, and south to Japan.

Breeding. The breeding seasons of the three species are staggered, a fact that reduces competition for food among the birds. Brandt's cormorants usually nest on flat tops of offshore islands and, less frequently, on inaccessible mainland bluffs and cliff ledges. Nests are generally made of seaweed, but uprooted plants may also be used, which can cause significant impact to local plant ecology. Clutch size is three to six eggs.

Double-crested cormorants nest in a variety of habitats from offshore rocks to abandoned timbers in estuaries and even inland locations. Nests, built primarily by males, are large twiggy masses, built up year after year. Nests typically contain three to five eggs, but as many as nine have been reported.

Pelagic cormorants build nests on inaccessible cliff faces using seaweed and other vegetation plastered together with guano. From three to seven eggs are laid in the nest.

Feeding. Strong swimmers, cormorants pursue small fish such as herring and shrimp and are capable of swimming to depths of more than 20 to 50 meters. These birds lack water-repellent plumage, however, and must occasionally leave the water to dry.

STORM PETRELS *Family Hydrobatidae*

Leach's storm petrels, *Oceanodroma leucorhoa*, are small (approximately 19 centimeters, or 7.5 inches) and black with a white rump patch. They are the most abundant member of this family in Oregon. Fork-tailed storm petrels, *Oceanodroma furcata*, are small (approximately 19 centimeters, or 7.5 inches) and grey, with a forked tail.

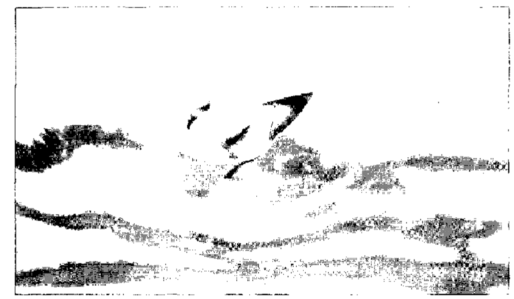

Figure 68. Fork-tailed Storm Petrel

(photo by Ron LeValley)

Although present along the Oregon coast, these small birds are not frequently seen. They seek food far at sea and come ashore at night to nest in burrows away from gulls and other predators.

Range. Leach's storm petrels are found off Oregon only during the summer breeding season; they migrate to the tropics during winter. Fork-tailed storm petrels remain off Oregon year-round.

Breeding. The breeding range of both species overlaps across the North Pacific Ocean to northern California. Both species of storm petrels mate, brood, and feed their young at night to avoid predation by gulls that are often nesting in the immediate area. Breeding occurs during the spring, and only a single egg is produced. Leach's storm petrels prefer rocky crevices on offshore rocks for their nest site. Fork-tailed storm petrels nest underground in burrows. Nocturnal activity by storm petrels makes them difficult to detect and study.

Feeding. Storm petrels range well offshore from their breeding grounds to forage. Leach's storm petrels prefer offshore waters and in winter off California, for example, are uncommon within 30 kilometers of shore. They feed on zooplankton, small fish, and crustaceans. Fork-tailed storm petrels also search the open waters over the continental shelf for food but tend to stay nearer shore than the Leach's storm petrel. They feed on shrimp, zooplankton such as euphausiids, and small fish.

MURRES, GUILLEMOTS, MURRELETS, AUKLETS, AND PUFFINS *Family Alcidae*

Alcids, the northern counterpart of the penguin family, are small, torpedo-shaped seabirds with short, broad wings well suited as much for underwater swimming as for flying. Six species of alcids breed on small islands or on rocky outcrops of the mainland along the Oregon coast.

The Common murre, *Uria aalge,* is 36 centimeters (14 inches) long, with a slender, pointed bill. In breeding plumage, its head, neck, back, and wings are dark with white underparts.

The pigeon guillemot, *Cepphus columba,* is a small bird, 27 centimeters (10.5 inches) long. Typical coloration is black with large white shoulder patches and red feet.

Figure 69. Tufted Puffins

(photo by Ron LeValley)

Although best adapted to "underwater flying", the puffin's wings none-the-less function well enough in air to allow the bird to nest on rocky cliffs high above the water.

The Cassin's auklet, *Ptychoramphus aleuticus,* is dark with a white belly. It is a small seabird, 18 centimeters (7 inches) long.

The rhinoceros auklet, *Cerorhinca monocerata,* has a keratinous "horn" at the base of the upper bill, from which the species derives its name, but this and the narrow white plumes behind the eye are present only during the breeding season. It is 29 centimeters (11.5 inches) long.

The tufted puffin, *Lunda cirrhata,* is one of the most unusual-looking seabirds, black with a triangular-shaped, bright orange beak and white eyebrow plumes, both of which are lost after the breeding season.

Differences in the beaks of alcids and in their feeding habits tend to separate individual species and reduce competition for food. Some feed in shallow nearshore water, while others feed much further offshore in deeper water.

Range. These alcids share a breeding range that extends from central Alaska to central California. For a few, the breeding range spans the north Pacific basin: north to the Kurile Islands for the pigeon guillemot and to northern Japan for the tufted puffin. The southern breeding range of the Cassin's auklet extends to central Baja California.

Breeding. Common murre colonies are often extremely large and dense with tens or hundreds of thousands of individuals packed shoulder-to-shoulder during the breeding season. Nest sites are usually flat rock surfaces on island tops or ledges. Murres lay a single egg, whose pear shape keeps it from rolling too far away. Both parents feed the chick until it is ready to leap from the colony and swim away with the male parent.

Pigeon guillemots nest in loosely scattered pairs on offshore islands and rocks but may also occur on precipitous headlands and structures such as pier pilings. The two-egg clutch is laid in rock crevices directly on the ground. They are one of the few alcids that can raise two chicks.

Figure 70. Common Murre

(photo by Tish Parmenter)

From the tip of its sharp, tapered beak to its webbed feet set well rear of its streamlined body, the common murre is a superb diver and swimmer.

Cassin's auklets nest on offshore islands, laying a single egg in burrows excavated with sharp toenails. Because their small size makes them likely prey for gulls, they are nocturnal breeders.

Rhinoceros auklets lay a single egg at the end of a burrow up to six meters (19.8 feet) long, on grassy slopes and forested areas mostly on offshore islands. Typically, the nest site is visited only at night.

Tufted puffins nest in deep burrows, which they excavate with their beaks and sharp claws, and lay a single egg. Nesting sites are generally on offshore islands. Activity at the nest can occur during the day since their large size keeps them from being harassed by gulls. During the breeding season, they are very conspicuous around nesting colonies, but during the winter, disperse over the open ocean and are rarely seen over continental shelf waters.

Feeding. Common murres prey on small fish which are brought back to the chick one at a time. Murres are deep divers, up to 200 meters, and can remain submerged for up to four minutes (16). Murres have been observed feeding on salmon smolts off the mouths of Oregon's estuaries where salmon hatcheries release large numbers of fish.

The guillemots' diet consists of small fishes. Equipped with a narrow bill, like the murre, they can carry only a single fish to their young.

Cassin's auklets feed in shallow water on small fish and planktonic invertebrates far from the nest site. Adults store food in a pouch beneath the tongue and regurgitate it for the young.

Rhinoceros auklet tongues are modified with teethlike structures so that more than one prey item can be held in its mouth at a time. These auklets feed on small fish and crustaceans.

The tufted puffin's tongue is modified like that of the rhinoceros auklet, enabling it to transport fish on both sides of its beak. In addition to small fishes, tufted puffins consume crustaceans, cephalopods, sea urchins, and molluscs.

Figure 71. Pigeon Guillemots

(photo by Ron LeValley)

Like common murres, tufted puffins and other members of the family Alcidae, the pigeon guillemot is well adapted to diving and pursuing small fish. One of this group of six has indeed just caught lunch.

BLACK OYSTERCATCHER *Family Haematopodidae*

The black oystercatcher, *Haematopus bachmani*, is a stout, black shorebird, 38 centimeters (15 inches) long, inhabiting the intertidal zone along rocky shores. It possesses a long, flat, orange-red bill and pale legs.

Range. Black oystercatchers are found from central Baja north through the Aleutian Islands.

Breeding. During the breeding season, oystercatchers are usually paired, but often single. They lay three eggs in nests of small pebbles and shell fragments built just above the splash zone in rocky areas along the entire Oregon coast. Young oystercatchers are precocious, leaving the nest within a few hours of hatching.

Feeding. The heavy bill is used to pry mussels, limpets, and chitons from the intertidal zone.

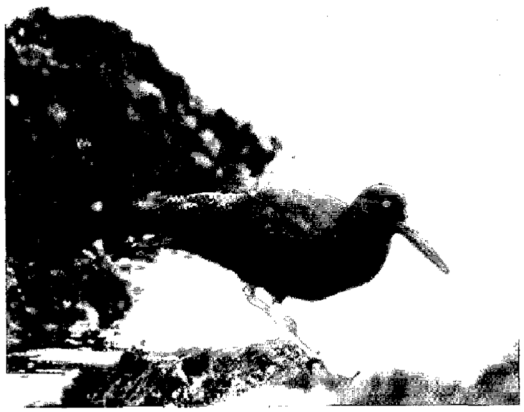

Figure 72. Black Oystercatcher

(photo by P. LaTourrette, courtesy of Richardson Bay Audubon Center)

A well-balanced body and stout beak allow the black oystercatcher to pry food from the rocks along the shore at low tide.

GULLS *Family Laridae*

Gulls are highly visible members of the nearshore bird community, frequently forming large groups on beaches and jetties. Although many species can be found on the coast, few are year-round residents. Only the glaucous-winged gull, *Larus glaucescens*, and western gull, *Larus occidentalis*, breed on the open Oregon coast. Both are large birds, 54 to 56 centimeters (21 to 22 inches) long. The western gull has a very dark back and wings, a light underside, and pink feet, while the glaucous-winged gull has a pale gray back, a gray wing pattern on the wing tips, and pink feet. Because the distinguishing colors of the feet, bill, and wing of the adult are usually not well defined until the third year, juvenile gulls are extremely difficult to identify.

Range. Western gulls reside from Baja California to northwest Washington. The glaucous-winged gull breeds farther north, from the Bering Sea and Gulf of Alaska to the northern coast of Oregon.

Breeding. The nests of these two species are usually placed on offshore islands and rocks, but small colonies can also be found at mainland sites that are free from predators and human disturbance. The average clutch is three eggs. Like most seabirds, gulls remain faithful to their nest site and their mate throughout their lifetime.

Feeding. Gulls are opportunistic feeders, including many different items in their diet: small fish, the young of other birds, squid, euphausiids, cannery waste, and garbage. Like jaegers, they sometimes steal the food of other birds. Gulls are one of the few seabirds that may have benefited by human activity, increasing in number possibly because of additional food resources made available by the widespread use of open landfills.

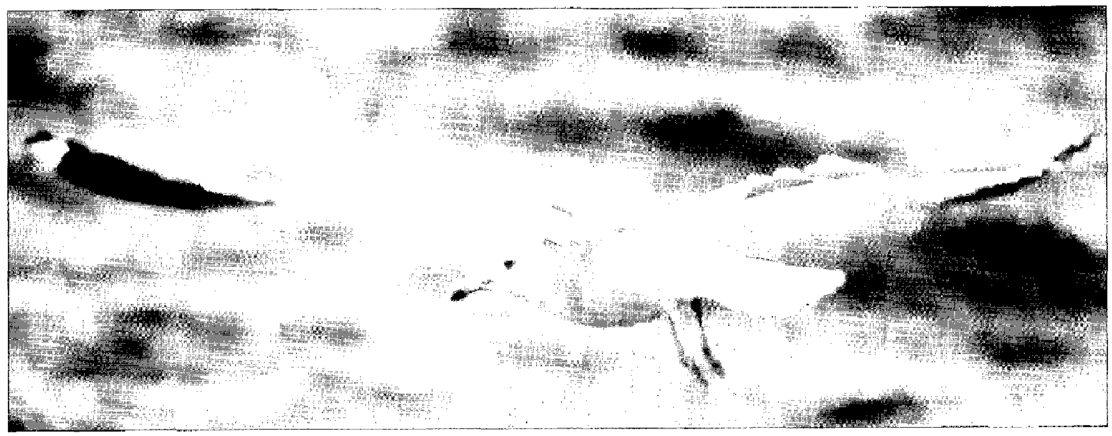

Figure 73. Western Gull in Flight.

(photo by Ron LeValley)

A large wing span and a nearly constant breeze allow the western gull to cruise the wind in search of food while conserving body energy. This method carries the gull effortlessly over a broad area and is appropriate to the gull's scavenger feeding habits. Although the western gull is the bird most often associated with the coast, it is far from the most numerous. Gulls comprise only one and one-half per cent of all marine birds on the Oregon coast.

Common Nonbreeding Seabirds of the Oregon Coast

Ten families of seabirds found along the Oregon coast are common visitors but do not breed here.

LOONS *Family Gaviidae*

Loons are diving birds with a ducklike body and a long, heavy, pointed bill. Unlike most birds, they have solid bones which allow them to submerge easily. Some dive as deep as 60 meters in pursuit of small fish and shrimp. Loons eat amphipods, crabs, and molluscs. The common loon, *Gavia immer*, is found throughout the year on the Oregon coast, whereas other species of this family are winter residents.

GREBES *Family Podicipedidae*

Grebes are also diving birds. While swimming at the surface, grebes frequently dip their heads below the water to look for food. Shrimp and small fish are important to their diet. Several species of grebes live in Oregon estuaries and bays, but the western grebe, *Aechmophorus occidentalis*, is the most abundant species on the open coast. Western grebes breed on inland lakes.

ALBATROSS *Family Diomedeidae*

Albatross are among the largest of all seabirds. The black-footed albatross, *Diomedea nigripes*, has a wingspan of 205 centimeters (80 inches), enabling it to glide long distances over the surface of the water without flapping. The black-footed albatross can be found off Oregon in greatest numbers through the summer months. Breeding occurs on the northwestern Hawaiian Islands. Males and females generally pair for life. The black-footed albatross feeds on squid, pelagic crab, and surface fish.

SHEARWATERS AND FULMARS *Family Procellariidae*

Shearwaters and fulmars, like albatross, travel long distances over the open ocean. They are seen off Oregon while in transit between southern hemisphere breeding and subarctic feeding grounds. The sooty shearwater, *Puffinus griseus*, abundant along the Oregon coast between spring and fall, breeds in New Zealand and off Cape Horn.

Northern fulmars, *Fulmarus glacialis*, occasionally seen off Oregon between fall and spring, breed on islands in the Gulf of Alaska and the Bering Sea. No member of this family breeds in Oregon. Shearwaters and fulmars feed on squid, sand lances, anchovies, and euphausiids.

BROWN PELICAN *Family Pelecanidae*

Brown pelicans, *Pelecanus occidentalis*, are summer residents of Oregon's coastal zone where individuals are commonly found in bays and nearshore waters. Breeding occurs on islands off southern California and Mexico. Pelicans plunge into the water from heights of 10 meters (33 feet) or less when diving for shallow-dwelling food. Small fish such as northern anchovies are important prey.

The brown pelican was placed on the list of endangered species in 1970 following a rapid decline in its abundance. Studies of nesting populations in California revealed that this decline was caused by pesticides present in the pelican's diet. As the levels of these chemicals increased within the bird, its eggshells thinned and hatching success decreased. Because the use of these pesticides is now banned or restricted, the brown pelican, is making a strong recovery.

Figure 74. The Brown Pelican

(photo by Dean Jue, courtesy Richardson Bay Audubon Center)

The familiar large pouch under the pelican's lower mandible is folded neatly out of the way when not in use. Scarce along the Oregon coast over the past few decades, the brown pelican is now seen more frequently in summer months as the breeding population in California increases.

DUCKS *Family Anatidae*

Sea ducks dive for fish, crustaceans, and molluscs, propelled by webbed feet larger than freshwater ducks. Their legs are positioned well to the rear of their bodies, increasing the efficiency of their kick.

Scoters are the dominant sea duck of Oregon. Three species are very common: the white-winged scoter, *Melanitta fusca*, the surf scoter, *Melanitta perspicillata*, and the black scoter, *Melanitta nigra*. Although present year-round in Oregon, most individuals fly north in summer to breed in Canada and Alaska. They are commonly observed resting on open water.

Oldsquaw ducks, *Clangula hyemalis*, and harlequin ducks, *Histrionicus histrionicus*, are also winter inhabitants of the Oregon coast.

PLOVERS *Family Charadriidae*

Members of the Charadriidae family of shorebirds have compact bodies with thick necks and short bills. Plovers stalk their prey, stopping occasionally to probe beach sands or kelp. Their food consists of common intertidal animals: crustaceans, worms, and molluscs.

Semipalmated plovers, *Charadrius semipalmatus*, are most abundant on sandy beaches during the summer as they migrate from their winter feeding grounds (southern California to South America) to their breeding grounds (northern Canada and Alaska). Snowy plovers, *Charadrius alexandrinus*, breed on sandy beaches in Oregon and are potentially threatened by human disturbance (15).

SANDPIPERS, TURNSTONES, AND SURFBIRDS *Family Scolopacidae*

Most of the shorebirds belong to the Scolopacidae family. The most abundant species, the surfbird, *Aphriza virgata*, and the black turnstone, *Arenaria melancephala*, spend most of the year on rocky shorelines and then migrate to Alaska for the summer breeding season. The wandering tattler, *Heteroscelus incanus*, and rock sandpiper, *Calidris ptilocnemis*, are also found along rocky shores. The other species frequent sandy beaches. Western sandpipers, *Calidris mauri*, and sand sanderlings, *Calidris alba*, are often seen feeding on the edge of the surf zone, where they move up and down the beach with the advance and retreat of breaking waves. Sandpipers eat amphipods and marine worms.

PHALAROPES *Family Phalaropodidae*

Phalaropes are relatively small seabirds with slender, pointed bills. Two species, the red phalarope, *Phalaropus fulicarias*, and the red-necked phalarope, *Phalaropus lobatus*, pass along the Oregon coast in the spring and fall. Both species breed in Alaska. Most red-necked phalaropes winter south of the equator; red phalaropes winter south of California. The red-necked phalarope uses its feet to stir the water surface while feeding. Presumably the small fish and euphausiids fed upon by this bird are attracted or concentrated by the stirring activity.

JAEGERS *Family Stercorariidae*

Jaegers are uncommon along the Oregon coast. The three species which have been observed breed on arctic tundra in the summer and migrate southward to spend winters south of California. Jaegers obtain food by harassing gulls and terns until the gull has either dropped or disgorged its meal. They also prey on fish and scavenge on floating refuse.

MARINE MAMMALS

The cold waters of the Pacific Ocean off Oregon are home to a variety of marine mammals. Like their terrestrial counterparts, these warm-blooded, air-breathing animals give birth to young live and nurse them until they are able to fend for themselves.

Whales, dolphins, and porpoises, together known as cetaceans, are among the most ancient marine animals. Approximately 65 million years ago, their terrestrial ancesters ventured into the sea to take their place alongside the fishes and reptiles as they adapted to a strictly oceanic existence. A second group of mammals, known as pinnipeds and including seals and sea lions, embarked on an oceanic way of life long after the cetaceans made the sea their home.

Cetaceans

Cetaceans are easily distinguished by their horizontal tail flukes, the absence of hind limbs, and nostrils modified as blowholes on top of the head. These holes close when the animal submerges so that water is not inhaled. The spout seen when a whale exhales is the water vapor from the lungs condensing as it enters the air.

Cetaceans have a thick layer of fat beneath the skin which assists in regulating the body's temperature. Their sense of hearing is well developed. Many rely on echolocation (reflected soundwaves) for orientation and finding food. Because most cetaceans are gregarious, some establishing complex social organizations, sound is also important in communication between individuals.

Cetaceans belong to two major groups: the mysticetes, filter-feeding whales, and the odontocetes, toothed whales. Mysticetes lack teeth and have instead sheets of comblike plates, called baleen, hanging from the roof of their mouth. The baleen sieves organisms low on the trophic ladder of the sea: copepods, euphausiids, amphipods, and small fish. Most baleen whales migrate from temperate and tropical breeding grounds to northern feeding grounds where production is most abundant during the spring and summer.

The mysticetes are made up of three families, but only two are common off the Oregon coast. The first and most frequently observed is the gray whale, the only living representative of its family, Eschrichtiidae. A second family, Balaenopteridae, or rorquals, including the minke whale, the humpback whale, and the blue whale, are seen infrequently in waters well offshore (9). Rorquals, also known as "gulpers," have long throat and chest pleats that expand like an accordian during feeding.

The toothed odontocetes, well represented off the Oregon coast, include the commonly observed harbor porpoise and the Pacific white-sided dolphin. The differences between porpoises and dolphins are few. Porpoises have short, round snouts and spade-shaped teeth whereas dolphins have beaklike snouts and round teeth.

Other odontocetes, sperm whales and Dall's porpoises, are seen far offshore, but sightings are rare. Killer whales are usually seen several times a year, both near the shore and in coastal rivers (9).

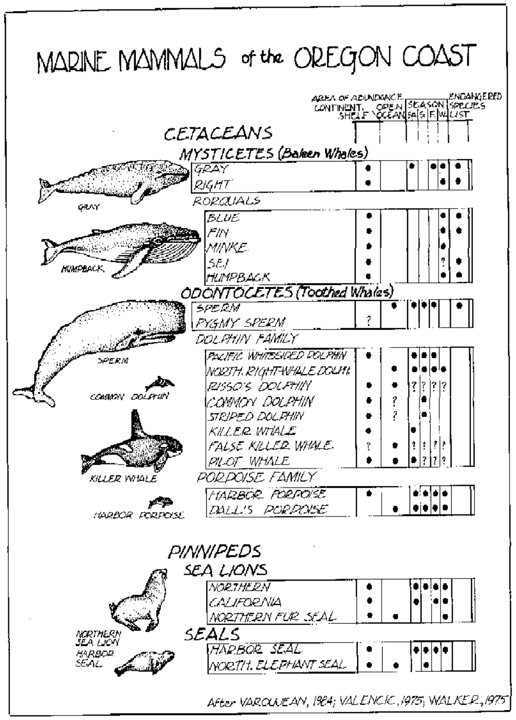

Figure 75. Marine Mammals of the Oregon Coast—Their Area of Highest Abundance and Seasonal Occurrence.

This chart shows marine mammals organized by major groups as noted in the text. Species whose numbers have been severely depleted are considered threatened or endangered under the Endangered Species Act of 1973. Seven such species are listed for Oregon and are thus eligible for special protection under U.S. law. The drawings show approximately correct size proportions among cetaceans and between pinnipeds. Not all members are shown. Much research is needed to resolve questions about the presence of some marine mammals.

Pinnipeds

Unlike cetaceans, pinnipeds have preserved the ability to move about on land. In the water the body is streamlined and torpedo shaped and all four limbs are modified into paddle-shaped flippers for mobility. The four major groups of pinnipeds are the true seals (harbor seals and elephant seals), sea lions (sea lions and fur seals), walruses, and sea otters. Seals, sea lions, and fur seals are found along the Oregon coast while walruses are confined to the Arctic. The sea otter was abundant in Oregon before its exploitation by hunters.

Seals and sea lions can be distinguished by their different behavior and physical characteristics (see Figure 76). Seals are smaller than sea lions, with flippers which cannot be rotated and hind legs which cannot reverse for locomotion on land. Thus, they can only wiggle along on their bellies when out of the water. Harbor seals, perhaps the best-known species of this group, are often seen in typical repose, bobbing lazily at the surface. While on land, seals are notably silent, except for an occasional wheeze.

Sea lions are large and have external ear flaps. Their front flippers are larger than the back ones, and, unlike those on seals, the hind flippers can rotate forward, allowing the animals greater movement on land. While out of the water, sea lions are extremely vocal.

Although pinnipeds spend much of their life at sea feeding on fish and invertebrates, they must return to land to breed and bear young. Harbor seals copulate in the water, but they, too, come ashore to give birth. Breeding grounds are known as rookeries. The adult male sea lion and the elephant seal—a true seal, in that it does not have external ears—establish a harem of many females, which they defend vigorously against intruders. At times other than the breeding season, pinnipeds often return to protected shore areas and offshore rocks, known as haul-out sites, to rest.

Pinnipeds generally abound off the Oregon coast. Depending on the time of year, the populations of California sea lions, northern sea lions, and harbor seals can each reach approximately 4,000 animals (9). The California sea lion is a migrant, but a small population of northern sea lions (also known as Steller's sea lions) breeds on the southern coast. Harbor seals are nonmigratory, though their home range is fairly large. Northern sea lions are found in the near to offshore region. Harbor seals and California sea lions are found in coastal rivers and the nearshore ocean, though California sea lions go farther offshore (9).

A few hundred northern fur seals and northern elephant seals are seen on a seasonal basis. Fur seals are difficult to keep track of since they stay well offshore. Sightings of the animals usually occur during the winter migration from their Bering Sea rookeries, and most are females. Young elephant seals commonly appear at a few haul-out sites in the summer (9).

COMMON MARINE MAMMALS OF THE OREGON COAST

This section includes descriptions of marine mammals commonly observed off the Oregon coast such as harbor porpoises, Pacific white-sided dolphins, gray whales, northern and California sea lions, and harbor seals. Also noted are other species of marine mammals less frequently seen in the waters off the coast—humpback whales, blue whales, minke whales, sperm whales, killer whales, Dall's porpoises, northern elephant seals, and northern fur seals. These species descriptions have been compiled primarily from references 8 and 1.

HARBOR PORPOISE *Phocoena phocoena*

Harbor porpoises are found throughout the cooler regions of the North Pacific. On the west coast of North America they range from Alaska south to San Diego, California.

The harbor porpoise is the smallest cetacean in the eastern North Pacific (1.3 meters long) and perhaps the most abundant. The breeding season is in late summer with a 9- to 10-month gestation period. Harbor porpoises are most common nearshore and less frequent in bays and estuaries.

They feed on bottom fish, cod, herring, squid, clams, and crustaceans.

PACIFIC WHITE-SIDED DOLPHIN *Lagenorhynchus obliquidens*

Pacific white-sided dolphins are among the most abundant of all eastern Pacific cetaceans. They range primarily along the continental shelf from Baja California to Alaska in the northeastern Pacific and from Japan to the Kuril Islands in the northwestern Pacific. Individuals are found throughout the year off California and Washington. Abundance in California peaks in the fall and reaches a minimum in the spring. Seasonal changes in distribution have been observed, with these dolphins being found closer to shore in the winter than in the summer.

White-sided dolphins form large pods numbering more than a thousand individuals and are often seen riding the bow wake of a vessel at sea. Mating takes place from late spring through autumn, with birth occurring after a 10-month gestation period.

White-sided dolphins feed on squid, herring, sardines, anchovy, saury, and jack mackerel.

NORTHERN (STELLER'S) SEA LION *Eumetopias jubatus*

Northern sea lions range from the Channel Islands off southern California north along the coast to the Bering Sea and south again along the western Pacific to the Sea of Okhotsk.

It is a nearshore species although sightings have been made 160 kilometers offshore. Figure 78 shows haul-out areas on the Oregon coast. Approximately 3,000 of the world population of 300,000 individuals (6) breed in Oregon on rock outcrops and rocky or coarse sand beaches. At the end of the mating season in July, some males migrate northward from these breeding locations to British Columbia and Alaska. Most Oregon females and pups remain off the coast throughout the winter.

This species can be distinguished by a tawny pelt and the thick mane which the male develops around its oversized neck. Size varies greatly between the sexes; males may grow to four meters (13 feet) and weigh 900 kilograms (2,000 pounds), whereas females grow to approximately half that length and weight.

Among the many types of food found in the stomachs of northern sea lions are squid, Pacific whiting, herring, and rockfish.

CALIFORNIA SEA LION *Zalophus californianus*

California sea lions have a more southerly distribution compared to that of the northern sea lion. They range from British Columbia to Mexico with all breeding occurring south of Oregon.

When mating is concluded in mid-July, some males migrate northward to overwinter as far as British Columbia. Populations in Oregon reach a peak of 3,500 individuals during the early fall. Males move southward again in the spring to breed. Figure 78 identifies sites along the Oregon coast where California sea lions are known to haul out. Although the length of both sexes is quite similar—males are 2 meters (seven feet) and females 1.8 meters (six feet)—the males weigh more than the females, 270 kilograms (594 pounds) to 90 kilograms (198 pounds).

Food for this sea lion includes hake, herring, rockfish, and sculpins. Observers have seen California sea lions eating large salmonids and lampreys around the mouth of rivers.

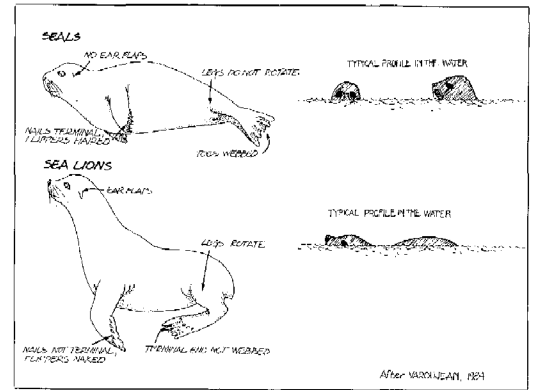

Figure 76. Distinguishing Characteristics of Seals and Sea Lions

Figure 77. California Sea Lions at Simpson Reef, Near Coos Bay

(photo by Bruce Mate, OSU Marine Science Center)

Nearly 80 sea lions have hauled out of the water on this rock at Simpson Reef, at Cape Arago. Although located well offshore away from human interference, the reef is visible from a lookout just north of the Cape Arago State Park entrance. Ideally situated for easy access to and from the water, the reef is composed of eroded, gently sloping sedimentary rocks just above sea level. At low tide, sandy beaches surrounding these rocks facilitate exit from the water. Other haul-out rocks just above the surf may be seen at the foot of the cliff within the park. Farther north, near Florence, sea lions have colonized caves eroded into the base of steep basalt cliffs. These caves are a popular tourist stop.

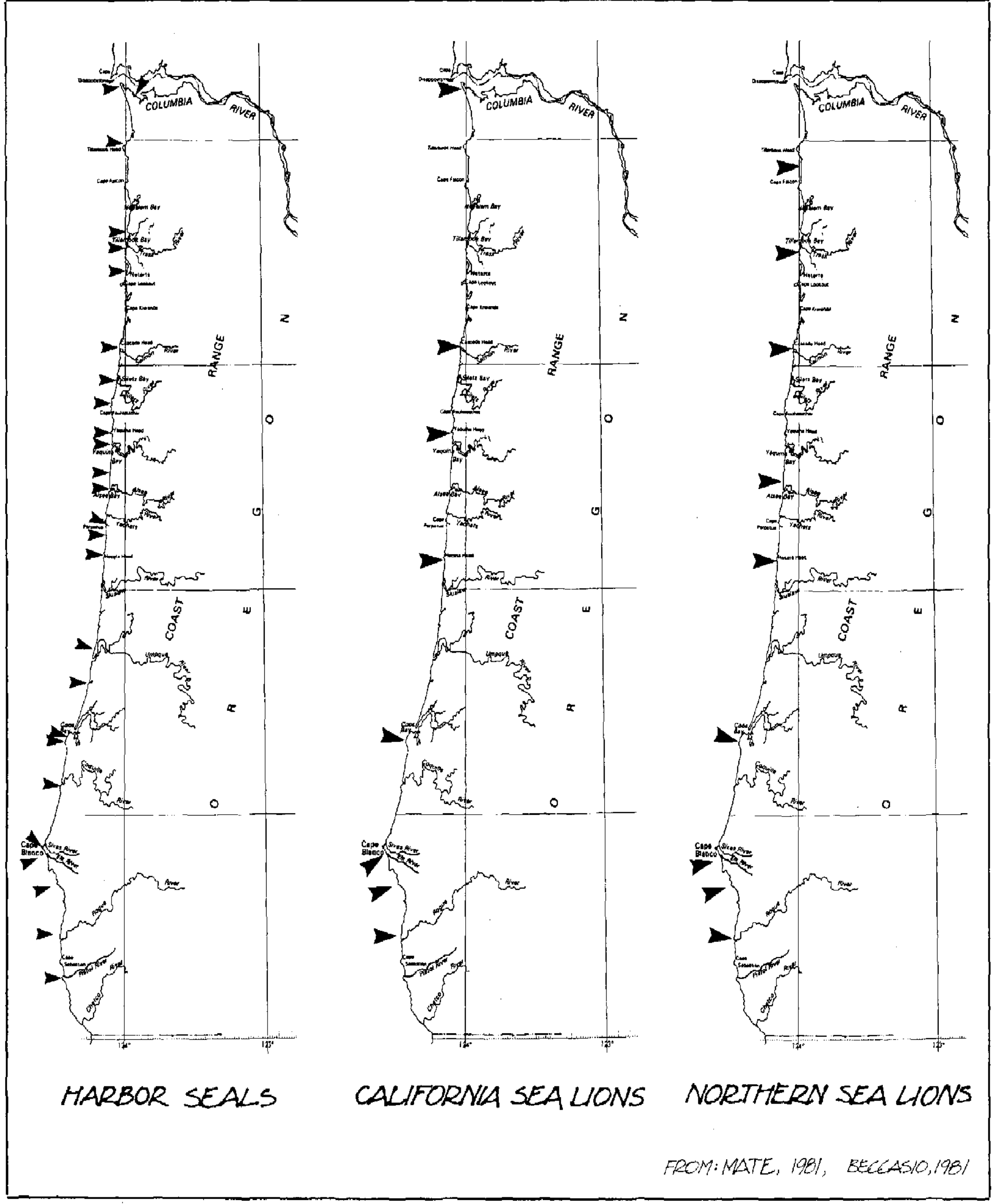

Figure 78. Coastal Haul-Out Sites for Harbor Seals, California Sea Lions, and Northern Sea Lions.

Figure 79. Harbor Seal Basking on Rocks

HARBOR SEAL *Phoca vitulina*

Harbor seals are year-round residents of the Oregon coast. They are not migratory, although seasonal movements into bays and estuaries are common. Around 300,000 harbor seals are thought to live in the eastern Pacific. Estimated abundance off the Oregon coast is 5,200 (3). Over 1,500 are found in the Columbia River; 800 in the Umpqua River; 1,200 in the Coos bay and Cape Arago region; 600 around Tillamook bay; 300 around the Rogue River; and more than 200 in Netarts Bay, 100 in Siletz Bay, 300 in Alsea Bay, and 200 near Bandon.

These animals use sand bars, mud flats, small rocks, islands, and reefs as hauling out areas. Harbor seals are shy and will abandon their haul-out area if approached. They are more gregarious during the late spring when pups are born and during the fall. Sexes are approximately the same size, ranging in length from 1.2 to 1.8 meters (four to six feet) and from 45 to 105 kilograms (99 to 231 pounds).

Harbor seals eat bottom fish, rockfish, herring, and some salmon.

NORTHERN FUR SEAL *Callorhinus ursinus*

Northern fur seals breed on islands in the Bering Sea and on San Miguel Island in Baja California during the summer. Those which breed in the Bering Sea migrate as far south as California during the winter.

All individuals spend at least eight months on the open sea and are pelagic while in Oregon. They are usually seen from 16 to 160 kilometers (10 to 100 miles) from shore with most sightings during the winter and fewest in the summer.

Fur seals feed from evening until early morning and then rest during the day. They may dive to 190 meters while feeding. The diet off Oregon includes anchovy, hake, saury, and rockfish.

NORTHERN ELEPHANT SEAL *Mirounga angustirostris*

The largest of the pinnipeds, the northern elephant seal breeds range from central Baja California to the Farallon Islands near San Francisco. Some animals have been observed to the north during the nonbreeding season. Small groups of northern elephant seals are found at haul-out areas along the Oregon coast in summer.

Male elephant seals grow to 4.9 meters (over 16 feet) and weigh between 1,800 and 2,300 kilograms (roughly two and one-half tons). Females may attain 3.3 meters and 800 kilograms. The adult male has a pronounced proboscis which begins to develop at about five years of age. It is used during trumpeting vocalizations to establish and maintain dominance among males during the breeding season.

Elephant seals feed in both nearshore and offshore waters on bottom and midwater fish, squid, small sharks, and skates.

KILLER WHALE *Orcinus orca*

Killer whales are found throughout the Pacific Ocean. Subarctic concentrations include those in the inland sounds of Alaska, British Columbia, and Washington. Also known as orcas, they travel in small groups or pods, although larger pods of 50 or more have been observed.

Breeding may occur throughout the year but is apparent in the spring and summer off the Washington coast. Orcas feed primarily on fish and marine mammals.

The largest member of the dolphin family, orcas are distinguished by their striking coloration; their backs are black and their bellies white from the lower jaw to the anal region, extending up the flank behind the large dorsal fin. On males, this dorsal fin may reach two meters (over six feet) in height, but on females and immature males it is less than one meter.

DALL'S PORPOISE *Phocoenoides dalli*

The Dall's porpoise is the most common porpoise in southeast Alaska and British Columbia. It is a year-round resident of both California and British Columbia, and individuals have been found off the Oregon coast.

The Dall's porpoise is larger and more conspicuous than the harbor porpoise. Unlike many other porpoises, Dall's porpoises do not form large schools; sightings are usually made of fewer than 24 individuals traveling together.

Dall's porpoises eat squid, Pacific whiting, herring, jack mackerel, saury, and some deepwater benthic fish.

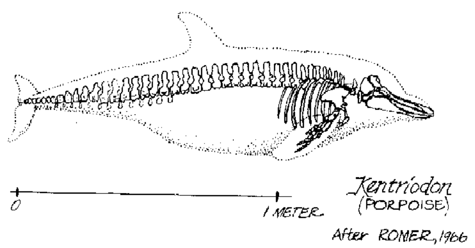

Figure 80. Ancestral Porpoise

The skeleton and form of this 30-million-year-old porpoise is very similar to the modern porpoises found in the Pacific Ocean off Oregon. Propulsion is provided by the horizontal tail flukes and steering by the short, broad front flippers.

MINKE WHALE *Balaenoptera acutorostrata*

Minke whales are small; the adult female averages eight meters (roughly 26 feet) in length. Minkes are cosmopolitan in their distribution, and at least three stocks are recognized in the North Pacific. In the eastern Pacific, minke whales are found from the Chukchi Sea to central Baja California. Their winter range extends from the central California coast to near the equator with the greatest abundance around the Channel Islands near Santa Barbara, California.

As with most cetaceans, minkes reach sexual maturity relatively late, at about seven to eight years of age. Females give birth every other year.

Minkes feed primarily on euphausiids and small fishes. Killer whales are common predators on minkes in the North Pacific.

SPERM WHALES *Physeter catadon*

Sperm whales are the largest of the odontocetes. They spend the summer in the Bering Sea and migrate south for the winter. They usually travel well offshore Oregon between March and September; however, forty-one sperm whales were stranded on the beach at Florence, Oregon, in July 1979 (see Figure 81).

The sperm whale has a huge head with a large frontal area, and only its narrow lower jaw has teeth. It feeds on bottom and in midwater on squid. This whale is perhaps best known for ambergris, a material produced in its digestive tract, which was once highly valued for use in perfume.

Figure 81. Beached Sperm Whales, June 17-18, 1979, Near Florence, Oregon

(photo courtesy Bruce Mate, OSU Marine Science Center)

Scientists remain unsure why whales occasionally stray onshore. The death of this pod of sperm whales, stranded in the dry sand of the Oregon Dunes National Recreation Area near Florence, posed a large cleanup problem for officials.

BLUE WHALES *Balaenoptera musculus*

In the eastern North Pacific, blue whales range from the Aleutian Islands to the central California coast during summer and from central Baja California south to near the equator in winter. They are most likely to be seen off the Oregon coast from late May through June and from August to October.

Females give birth to a single calf once every two to three years. Prior to and during the peak of the whaling industry in the 1930s, females matured at ten years of age. In response to this exploitation, the age of sexual maturity dropped to six or seven years.

The principal food of the blue whale is euphausiids (krill). Estimates from the Antarctic indicate that each blue whale consumes 4,000 kilograms (over four tons) of krill per day.

HUMPBACK WHALE *Megaptera novaeangliae*

The humpback whale migrates from its major breeding grounds off Hawaii and both coasts of Baja California to summer feeding grounds which range from Southern California as far north as the Chukchi Sea in the Arctic Ocean. The humpback was once caught off the Pacific Northwest coast during the summer months.

Humpbacks mate during the winter; gestation is 12 to 13 months. Calves are born the following year. Sexual maturity is thought to occur between 6 and 12 years of age. They are probably best known for their aerobatics and underwater vocalizations.

Their diet consists of benthic and pelagic euphausiids and small schooling fish. While feeding off southeast Alaska, humpbacks have been observed using a technique called "bubble net feeding." The whale swims in increasingly tighter circles around its prey releasing bubbles of air. Their prey, confined by the bubbles, concentrate in a ball. The whale then rises through the center of the ball of fish with its jaws wide open to emerge with its throat grooves bulging with water and fish.

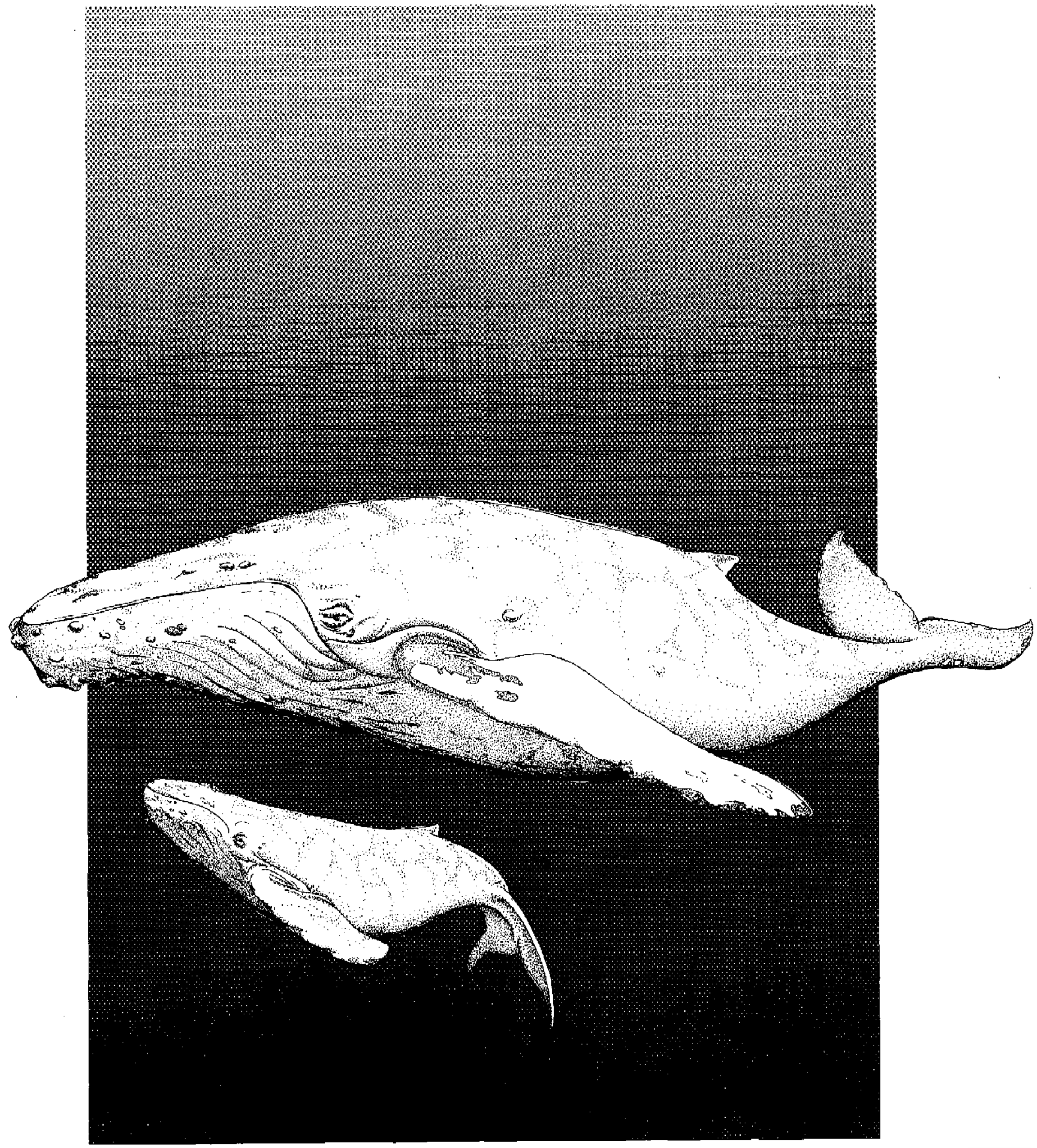

Figure 82. Humpback Cow and Calf

The body of the highly nomadic humpback whale is built for cruising long distances. Calves stay close to the mother during these long journeys. Comparison among photographs of the characteristic markings and shapes of individual tail flukes photographed in Alaska, Hawaii, and Baja California, allow scientists to determine the range of migration. Nineteenth and twentieth century whaling brought the humpback close to extinction but an international treaty in 1966 banned commercial hunting of humpbacks. Scientists report that numbers of humpbacks are now increasing.

GRAY WHALE *Eschrichtius robustus*

Gray whales undertake the longest known migration of any marine mammal, traveling from feeding grounds in the Chukchi, Beaufort, and Bering Seas to calving lagoons of Baja California.

The southern migration takes place from November through February; the northern portion occurs from February through May. The gray whale travels in slow-moving pods of several animals. While off the Oregon coast, most gray whales travel within 10 kilometers (6 miles) of the shoreline. Gray whales may reach lengths of up to 14 meters (45 feet). Females calve every other year in the winter following a gestation period of 13 months. The gray whale population in the eastern Pacific is estimated to be 17,000, close to its prewhaling number (7). Although it is currently on the U.S. endangered species list, an annual commercial quota of approximately 300 has been established. Some are taken by Soviets in the Bering Sea and some are taken for subsistence purposes by native Alaskans in the Bering and Chukchi Seas.

Unlike other baleen whales, the gray whale is a bottom feeder, consuming amphipods, mysids, molluscs, and polychaete worms. These whales use their tongue to suck bottom sediments into their mouth, trapping the small benthic animals in the baleen and expelling the sediments. Occasionally gray whales may feed in the nearshore area along the coast.

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APPENDIX

WEIGHTS AND MEASURES

LENGTH

1 micrometer (um) = 0.000001 meter (m)
1 millimeter (mm) = 0.001 meter
1 millimeter = 0.0394 inch (in)
1 centimeter (cm) = 0.01 meter
1 centimeter = 0.3937 inch
1 meter (m) = 3.281 feet (ft)
1 kilometer (km) = 3,281 feet
1 kilometer = 0.6214 miles (mi)
1 inch = 25.40 millimeters
1 inch = 2.54 centimeters
1 foot = 0.3048 meter
1 mile = 1.609 kilometers
1 mile = 0.869 nautical miles
1 fathom (fm) = 6 feet
1 fathom = 1.829 meters

AREA

1 square meter (m) = 10.765 square feet (ft)
1 hectare = 10,000 square meters
1 hectare = 2.471 acres
1 square kilometer (km) = 0.386 square mile
1 square kilometer = 247.1 acres
1 square kilometer = 100 hectares (ha)
1 square foot = 0.0929 square meter
1 acre (ac) = 4,047 square meters
1 acre = 0.4047 hectares
1 acre = 0.00156 square mile
1 square mile = 640 acres
1 square mile = 2.59 square kilometers
1 square mile = 259 hectares

VOLUME

1 cubic meter (m) = 35.31 cubic feet (ft)
1 cubic meter = 264.2 gallons (gal)
1 liter (1) = 0.03531 gallon
1 liter = 0.001 cubic meter
1 cubic foot (ft) = 0.0283 cubic meter
1 cubic foot = 7.48 gallons
1 gallon = 0.003785 cubic meter

MASS

1 milligram (mg) = 0.000035 ounce (oz)
1 gram (g) = 0.0353 ounce
1 kilogram (kg) = 2.205 pounds (lb)
1 metric ton (MT) = 1,000 kilograms
1 metric ton = 2,205 pounds
1 metric ton = 1.1 tons
1 pound = 0.454 kilogram
1 ton (t) = 907 kilograms

FLOW RATES

1 cubic meter/second (m/s) = 35.31 cubic feet/second (cfs)
1 cubic meter/second = 15,852 gallons/minute (gpm)
1 cubic foot/second = 0.0283 cubic meter/second
1 cubic foot/second = 448.8 gallons/minute

TEMPERATURE

C = degrees Celcius or Centigrade
C = (F − 32) x 5/9

On the Celcius scale, water freezes at 0° and boils at 100°.

F = degrees Farenheit
F = C x 9/5 + 32

On the Farenheit scale, water freezes at 32° and boils at 212°.

MORE INFORMATION

The interested reader may want to track down additional detail on a particular subject presented in the *Oceanbook* or may want to expand into an area not covered here. The references at the end of each chapter should help provide direction to specific literature. However, it may be appropriate to contact some experts in the field of interest to clarify a point or to provide additional information. The following list will assist those interested in making contact with such experts.

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Sea Grant College Program:	754-2714
Mark O. Hatfield Marine Science Center, Newport	(503) 867-3011

University of Oregon

Institute of Marine Biology, Charleston, Oregon 97420

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University of Washington, Seattle, Washington 98195

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Sea Grant Program	543-6600

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