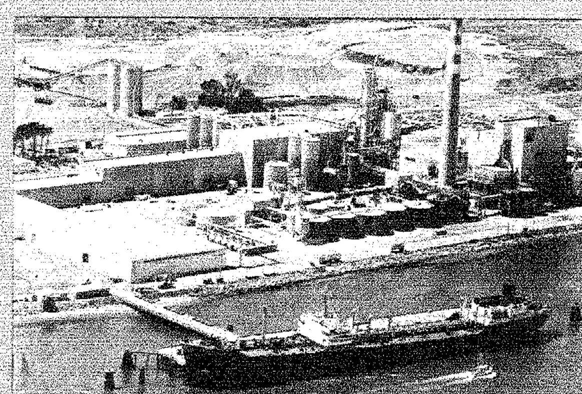
Biological Report 1
January 1992

The Ecology of Humboldt Bay, California: An Estuarine Profile



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The Ecology of Humboldt Bay, California: An Estuarine Profile

By

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Preface

This estuarine profile is one of a series of profiles that synthesize current ecological and other pertinent information on selected estuaries of the United States. The data in this profile on Humboldt Bay provide a scientific reference on the bay's natural resources and will aid in the management and protection of the estuary. Humboldt Bay is one of the most valuable coastal resources on the west coast of the United States.

The profile provides current and historical information on the geographic setting of Humboldt Bay; describes geological, climatological, hydrological, and physicochemical aspects of the bay environment; describes the biotic communities and their relationships; compares and contrasts other west coast estuaries to Humboldt Bay; provides management considerations in terms of procedures, socioeconomic factors, and environmental concerns; and identifies research and management information gaps important to proper management and protection of the bay.

The information in this profile should also be useful to educators, students, and interested laypersons. The style and format are designed to make the profile useful to many different interests.

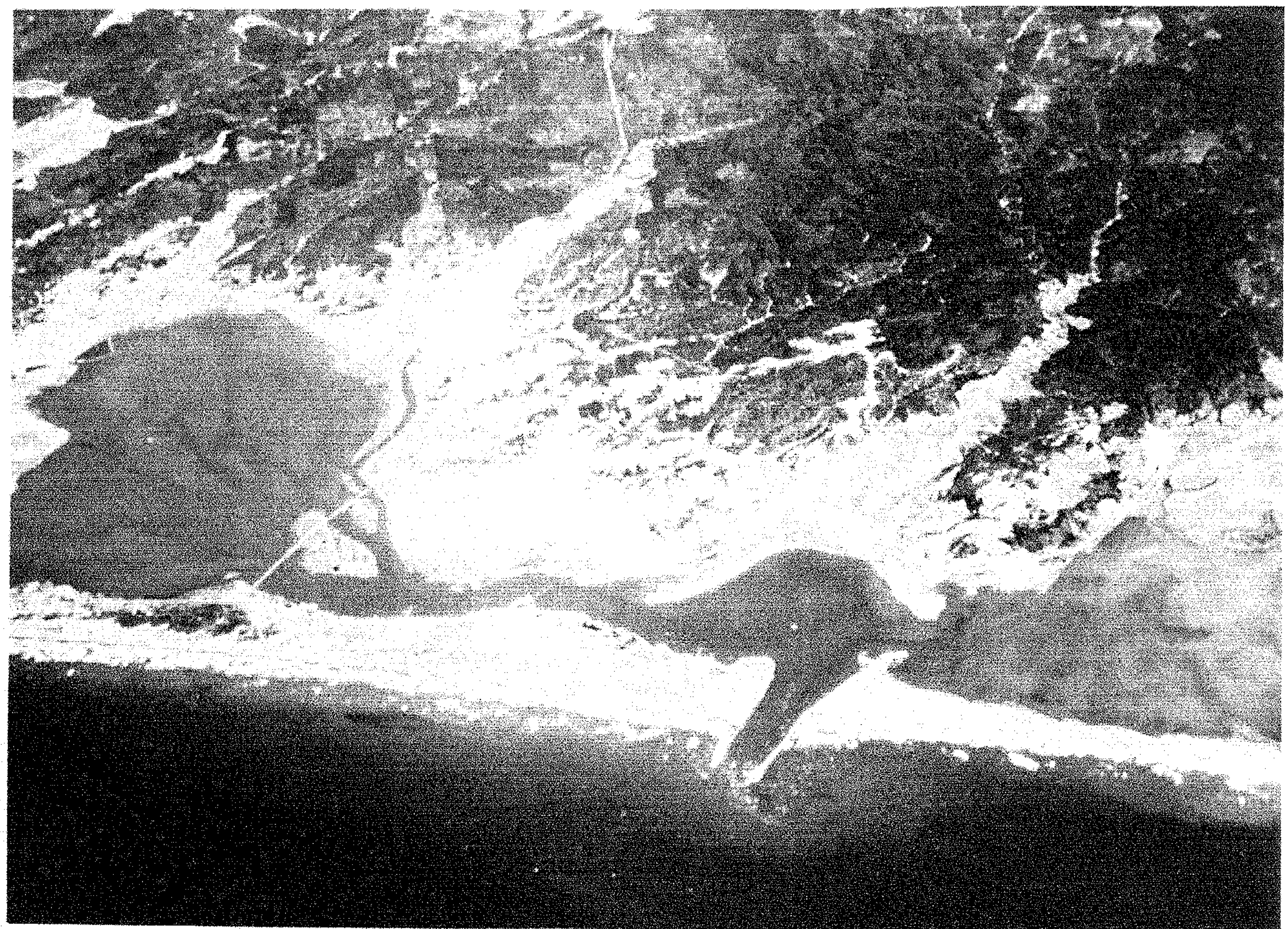
Conversion Table

Metric to U.S. Customary

Multiply	By	To obtain
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
meters (m)	0.5468	fathoms
kilometers (km)	0.6214	statute miles
kilometers (km)	0.5396	nautical miles
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
hectares (ha)	2.471	acres
liters (L)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters (m^3)	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (t)	2205.0	pounds
metric tons (t)	1.102	short tons
kilocalories (kcal)	3.968	British thermal units
Celsius degrees (° C)	1.8 (° C) + 32	Fahrenheit degrees

U.S. Customary to Metric

inches (in)	25.40	millimeters
inches (in)	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
statute miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet (ft^2)	0.0929	square meters
square miles (mi^2)	2.590	square kilometers
acres (a)	0.4047	hectares
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28350.0	milligrams
ounces (oz)	28.35	grams
pounds (lb)	0.4536	kilograms
pounds (lb)	0.00045	metric tons
short tons (ton)	0.9072	metric tons
British thermal units (Btu)	0.2520	kilocalories
Fahrenheit degrees (° F)	0.5556 (° F -32)	Celsius degrees



Humboldt Bay estuary, California, looking east from the Pacific Ocean (from an infrared color photograph).

The Ecology of Humboldt Bay, California: An Estuarine Profile

by

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Abstract. Humboldt Bay is one of California's largest coastal estuaries, second only to San Francisco Bay in size. The bay is important ecologically, serving as habitat for many invertebrates, fishes, birds, and mammals. The bay attracts many recreational users and because it is an important shipping port also attracts industry, particularly that related to forest products. This report summarizes and synthesizes scientific data on the ecological relationships and functions of the estuary, including information on geological, climatological, hydrologic and physical-chemical aspects of the bay environment; describes the biotic communities and their relationships; compares and contrasts other west coast estuaries to Humboldt Bay; provides management considerations in terms of procedures, socioeconomic factors and environmental concerns; and identifies research and management information gaps. Portions of the bay are managed as a national wildlife refuge. Management issues for this ecosystem include loss of habitat and degradation of the environment by additional industrial development and nonpoint source pollution.

Key words: Estuaries, wetlands, ecology, geology, hydrology, nekton, benthos, plants, invertebrates, vertebrates, contaminants.

Chapter 1. Introduction: The Ecology of Humboldt Bay

Humboldt Bay is one of California's largest coastal estuaries and is the only harbor of commercial importance for major shipping between San Francisco Bay, 372 km south, and Coos Bay, Oregon, 335 km north. The bay, located at latitude 40°46'N and longitude 124°14'W, consists of three arms: South Bay, a wide, shallow southern arm; Entrance Bay, a relatively narrow, deeper central area; and Arcata Bay, the largest arm to the north, also wide and shallow (Fig. 1.1). Humboldt Bay is 22.5 km long and 7.2 km wide at its widest point; its area is 62.4 km^2 at mean high tide (MHW) and 28.0 km^2 at mean low tide (MLLW), according to Proctor et al. (1980).

Both South and Arcata bays consist of extensive mud flats interlaced with drainage channels. More than half of the surface area of these two bays is exposed at low tide. Arcata Bay has a total of six islands: Indian (Gunther), Woodley, and Daby islands are in the southwest corner, just north of the separation between Eureka and Arcata channels; Bird, Sand, and Little Sand islands are all located just north of the separation between Mad River Slough and the old Arcata Wharf pilings (Skeesick 1963). Entrance Bay has one deep connecting channel (Samoa Channel) that joins the two major arms and also leads to the ocean, providing daily exchanges of seawater. The entrance to the bay is maintained by concrete and rock jetties, 2 km or more long.

Humboldt Bay is a "normal" or "positive" type of estuary according to the classification system of Emery and Stevenson (1957). These authors pointed out, however, that a large estuary opening to the sea near the middle is a complex environment and is not easily classified. Costa (1982) characterized Humboldt Bay as a multibasin, tide driven coastal lagoon with limited fresh water input. True estuarine conditions occur only where bay waters are measurably diluted by fresh water from major winter storms events.

Humboldt Bay is separated from the ocean by long sand spits. South Spit is narrow with low sand dunes and sparse vegetation. During extreme high tides and high seas, the ocean surf may pass over South Spit into the bay (Monroe 1973). The northern spit (Samoa Spit) is much higher and wider than South Spit and, although there is a dune community remaining, much of the spit has been developed for industrial and residential use.

Humboldt Bay's 578 km^2 drainage basin lies in the foothills of the Coast Range. The bay is immediately surrounded by lowlands, formerly marshy extensions of the bay, which were diked and drained for agricultural use, primarily grazing, beginning in the 1880's. The lowlands are intersected by low foothills of the Coast Range, which extend nearly to the bay shore at several locations (Monroe 1973). No large rivers enter the bay; major sources of fresh water are Jacoby Creek and Freshwater Creek in Arcata Bay, Elk River in Entrance Bay, and Salmon Creek in South Bay. In September 1971 portions of South Bay and Arcata Bay were set aside to form the Humboldt Bay National Wildlife Refuge, primarily to preserve and enhance migratory birds and their habitats.

Two cities, Eureka and Arcata, and five smaller communities are located on or near the bay, resulting in a total population of about 70,000 for the bay area. Much of the shoreline of Entrance Bay is occupied by port facilities for shipping, commercial fishing, and associated services. A number of other industrial sites are situated at various locations on Humboldt Bay. The remaining shoreline is used for agricultural purposes or remains undeveloped (Fig. 1.2).

During the recent geological past, before 2000–3000 years ago, the Mad River probably emptied into Humboldt Bay (Vick 1988; Vick and Carver 1988). The three embayments of Humboldt Bay occupy the seaward edge of a river valley drowned by increasing sea levels. This valley over time filled

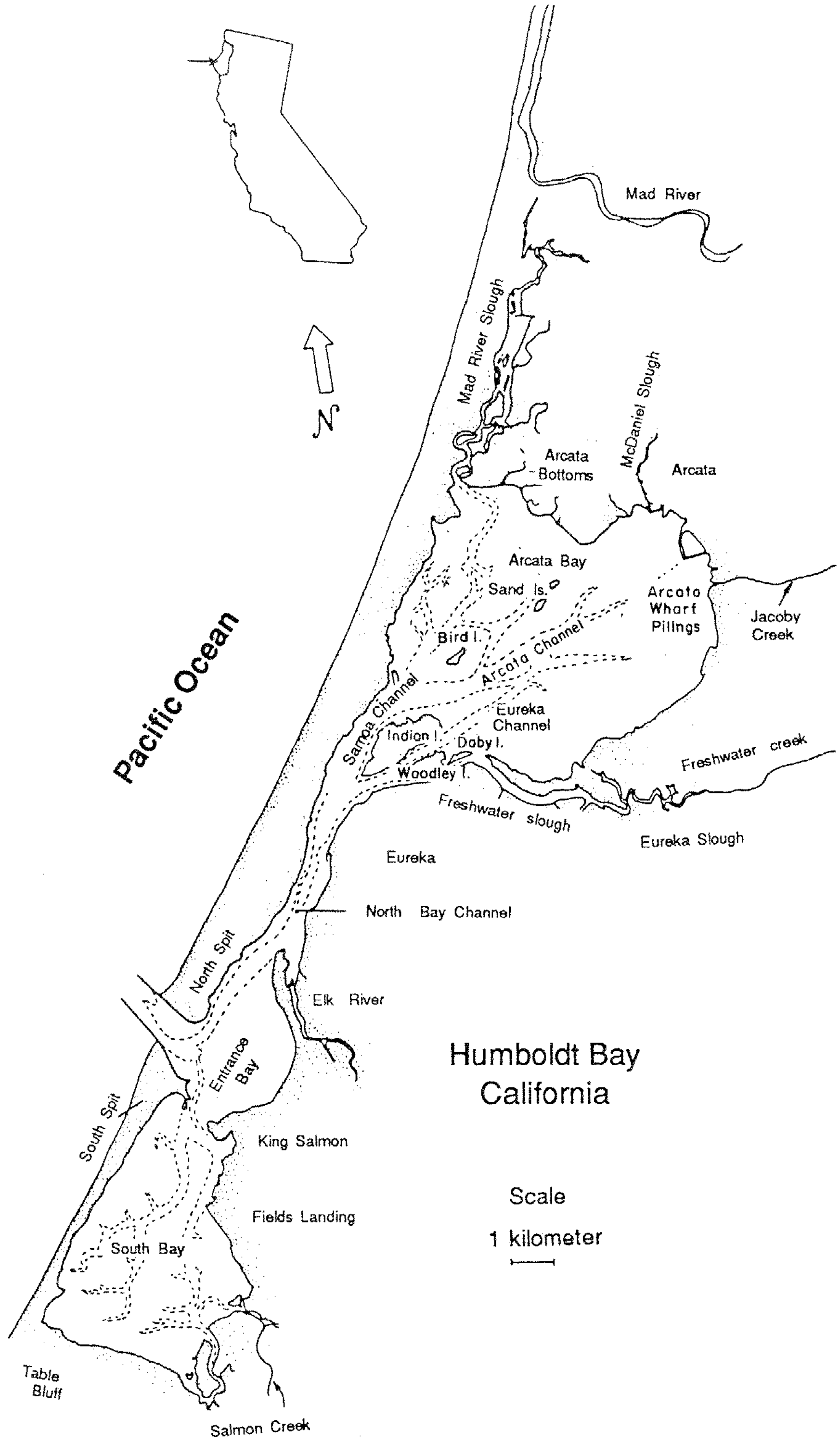

Fig. 1.1. Humboldt Bay, California, and environs (modified from Costa 1982).

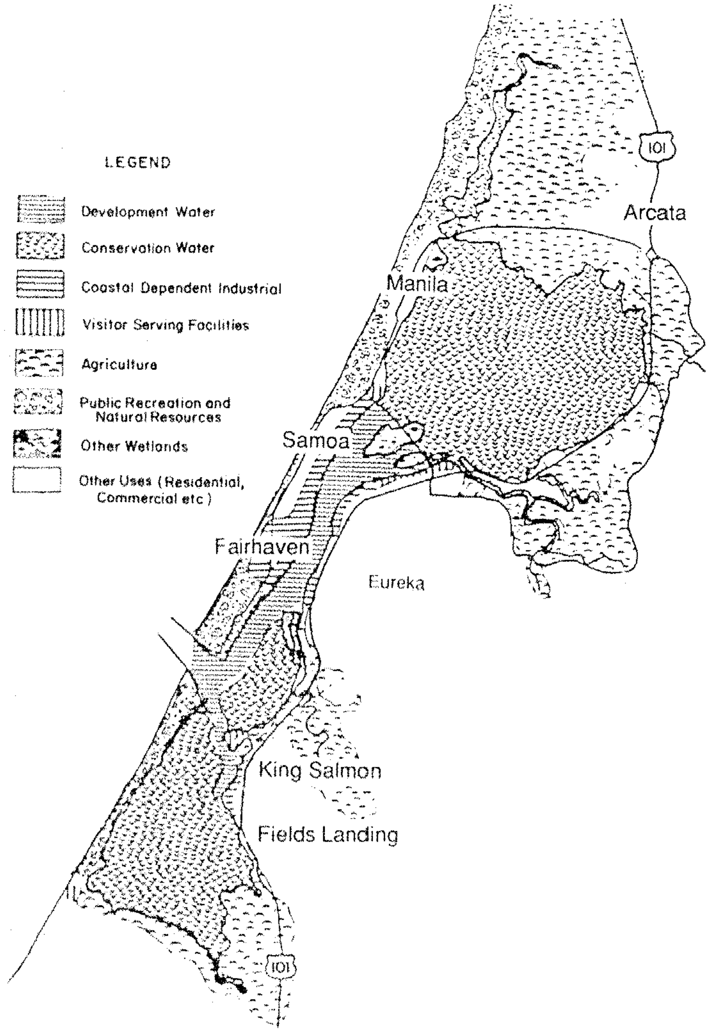

Fig. 1.2. Land-use patterns, Humboldt Bay environs (from Ray 1982).

with recent flood plain, tidal flat, and marsh deposits. Bay sediments contain buried salt-marsh deposits that represent episodic rapid subsidence of low-lying areas due to large magnitude subduction zone earthquakes during the Upper Holocene period resulting in the present configuration of Humboldt Bay (Vick 1988; Vick and Carver 1988).

The bay was discovered in 1806, but no settlement took place until the 1850's, when Humboldt Bay became a point of embarkation and supply for the gold mines of Trinity and Siskiyou Counties (Monroe 1973). Settling of early bay communities led to the immediate displacement of the resident Wiyot Indian population, which was estimated to be about 1,000 persons in 1850 (Glatzel 1982). The lumber industry soon developed and shipping facilities were built to export wood and agricultural products. Secondary harbors were developed in the bay by Finnish fishermen who settled in the Fairhaven area.

Land-use changes in the bay itself resulted primarily from the expansion of shipping. Docks were built in Eureka and Fields Landing and sailing vessels even reached upper Arcata Bay at a point near McDaniel Slough, where the city of Arcata maintained a dock. Ancillary shipping services, such as boat building and repair, were quite extensive in the bay from 1870 to 1946 (Glatzel 1982). In 1881, Congress authorized the U.S. Army Corps of Engineers (Corps) to dredge the navigation channel in front of Eureka to a depth of 3.3 m, and a channel at the Arcata wharf to a depth of 2.6 m. Currently the Corps maintains the entrance channel at 12.2 m deep; North Bay, Samoa, and lower Eureka

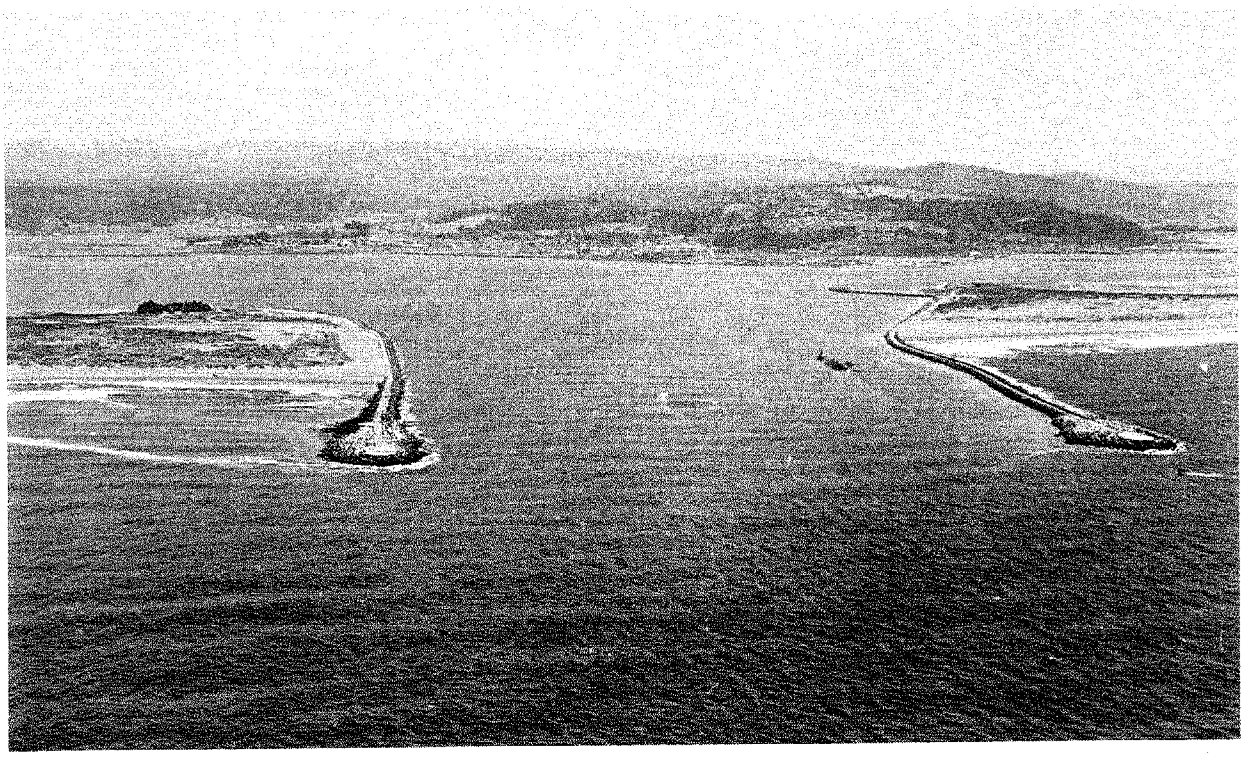

Fig. 1.3. Jetties define the entrance to Humboldt Bay.

channels at 10.7 m deep; and upper Eureka and Fields Landing channels at 7.9 m deep by periodic dredging. Maintenance of the Arcata channel has been discontinued due to nonuse. The entrance channel to Humboldt Bay was stabilized by the construction of jetties in 1889–99 (Fig. 1.3).

There was a period of rapid wetland change after the completion of the Northwestern Pacific Railroad along the eastern margins of Humboldt Bay in 1901. The railroad functioned as a dike in most locations, and tide gates were placed at almost all slough crossings. Many wetlands were converted to agricultural land, and seasonal wetlands were used for grazing. By 1927, with the construction of Highway 101 and the associated filling, most of the marshes east of Humboldt Bay had been diked and drained (Fig. 1.4; Ray 1982).

Development of Woodley Island first occurred with the placement of dredge spoils on a tidal marsh. Later, the island was used for building and repairing ships and for log storage. Commercial use of the island was abandoned between the 1950's and 1979; some minor residential use and goat grazing still occur. In 1971, the Humboldt Bay bridge was completed, connecting Eureka with the north spit. Part of the bridge construction involved filling mud flats, salt marsh and a small freshwater

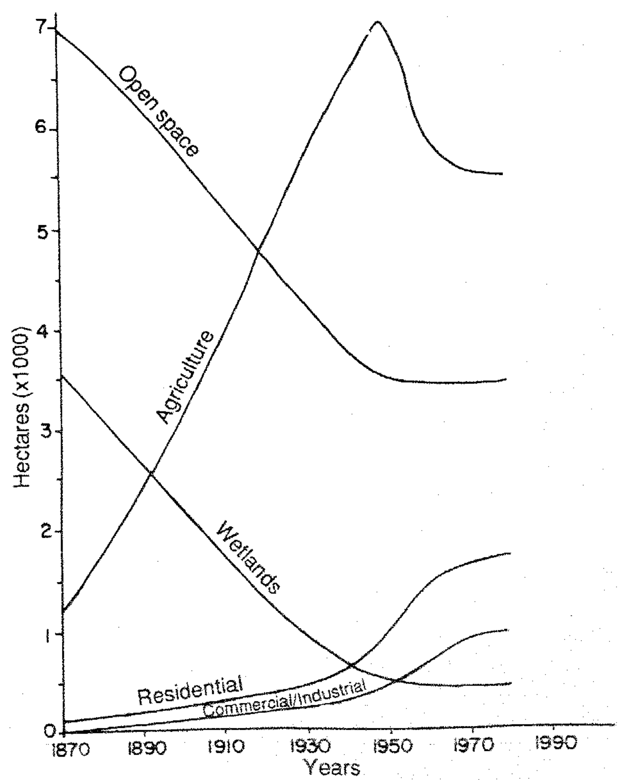

Fig. 1.4. Humboldt Bay land-use changes, 1870–1980 (modified from Shapiro and Associates, Inc. 1980).

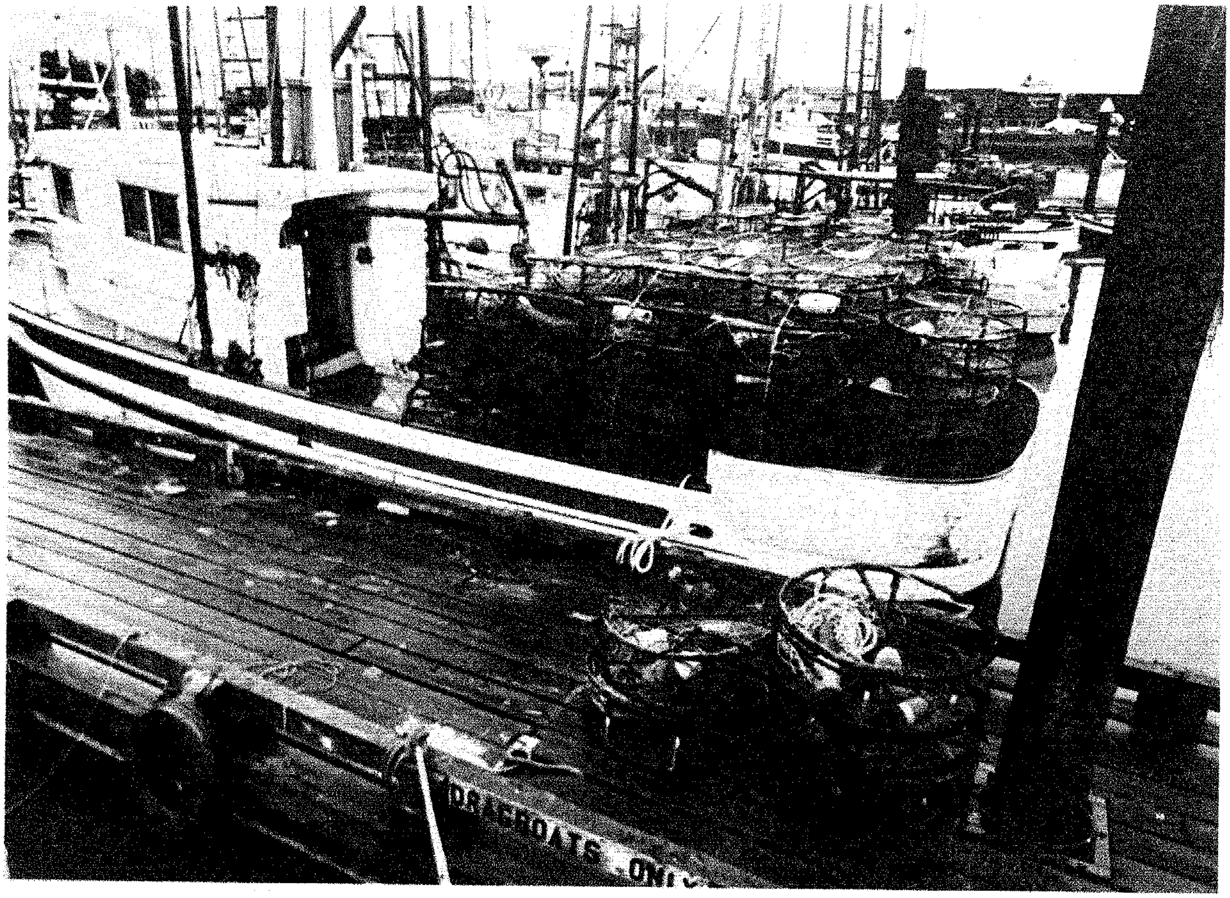

Fig. 1.5. Commercial crab boats at dock in Humboldt Bay.

pond on Woodley Island. Road access to Woodley Island allowed for planning and completion of the Woodley Island Marina in 1980. This project affected approximately 1,000 m of shoreline, where intertidal and subtidal mud flats were dredged and adjacent salt marsh and higher ground were filled to provide access, parking, and facility construction sites.

Originally, Humboldt Bay encompassed about 10,931 ha (Monroe 1973). Because of diking, drainage, filling, and other developments continuing to the present, the bay has been reduced to about 7,290 ha at mean high tide (calculated from Shapiro and Associates, Inc. 1980). Nevertheless, Humboldt Bay continues to be vital habitat for many fish and wildlife species. To date, 110 species of fishes have been recorded from the bay (Gotshall et al. 1980). Annual runs of chinook salmon (*Oncorhyncus kisutch*), coho salmon (*O. tshawytscha*), and rainbow trout (*O. mykiss*) still ascend major bay tributaries. The bay is an important nursery area for several commercial species including English sole (*Parophrys vetulus*), Pacific herring (*Clupea harengus pallasi*), lingcod (*Ophiodon elongatus*), some surfperches (Embiotocidae), and some rockfishes (Scorpaenidae). The bay is also an important nursery ground for at least three species of commercially or recreationally valuable crabs (Figs. 1.5 and 1.6): market or Dungeness crab (*Cancer magister*), rock crab (*C. antennarius*), and red crab (*C. productus*). At least 110 species of birds regularly frequent the various wetland habitats that occur in the Humboldt Bay area (Springer 1982). Springer extrapolated data by Hoff (1979) to estimate the average annual bird-days on agricultural lands in the entire Humboldt Bay area at 310,000 waterfowl, 2,700,000 shorebird, 650,000 other waterbird, 36,000 raptor, 17,000 upland gamebird, and 6,500,000 songbird bird-days. The bay is also important habitat for mammals; over 30 species have been found in and around Humboldt Bay (Shapiro and Associates, Inc. 1980). The bay also continues to be of considerable importance for shipping of forest products, commercial fishing, and seafood processing (Fig. 1.7).

Fig. 1.6. Processing the dungeness crab for market.

Fig. 1.7. Processing shrimp caught outside Humboldt Bay.

Chapter 2. Environmental Setting

Geological Aspects

Regional Geology

Humboldt Bay is situated approximately 50 km northeast of a Gorda–Pacific–North American triple junction. This triple junction represents the intersection of three crustal plates: the Pacific plate to the south, the Gorda plate to the northwest, and the North American plate to the east. The region is tectonically active, with the Gorda plate being subducted beneath the North American plate. The relative motion between these plates has produced a number of northwest–southeast trending faults in the vicinity of Humboldt Bay. River valleys cut through the various formations also trend northwest–southeast, along the fault lines. Rocks formed from marine sediments have been planed down by wave action and subsequently uplifted and folded to form marine terraces. This uplifting and folding, the differential motion at the various fault lines, and erosion have exposed a wide range of rock formations in a complex pattern around the Humboldt Bay area.

Geologic History

Four main geologic formations are exposed in the Humboldt Bay region. The oldest is the Franciscan Formation, Late Jurassic to Late Cretaceous in age (Ogle 1953). This mixture of graywacke, sandstone, shale, chert, altered basalt, and some limestone is overlain by the Yager Formation, consisting of interbedded shale, graywacke, and conglomerate. The Wildcat Group is younger (Late Cenozoic in age) and consists predominantly of weakly lithified mudstones, along with weakly consolidated siltstone, sandstone, conglomerate, and some interbedded limestone, tuff, and lignite. The Hookton Formation is younger still (Pleistocene in age) and is made up of continental and shallow marine deposits of variable lithology. These sediments are characteristically yellow- orange in color and consist of gravels, sands, silts, and clays. The most recent deposits are river channel and floodplain deposits, beach and dune sands, tidal flat deposits, and landslide debris. These deposits are 5–7 m thick and consist mainly of gravel, sand, and silt deposited by the Mad and Eel rivers.

Tectonics and Faulting

Cape Mendocino, where the San Andreas fault bends abruptly and follows the seismically active Mendocino fracture zone, lies 50 km south of Humboldt Bay. It is one of the most seismically active areas of California and has been the location of several earthquakes that caused damage to the Humboldt Bay area this century.

Major structural patterns are chiefly controlled at Cape Mendocino. Regional north-south compression has resulted in a radial pattern of right-lateral strike-slip faults trending in a west-northwesterly direction towards the Gorda Basin. The Mad River fault zone and the Russ Fault–False Cape shear zone, both active, bound the Tertiary sediments of the Eel River syncline.

Bay Morphology and Probable Formation

As mentioned previously, Humboldt Bay consists of three subbays, each situated at the seaward end of one or more stream valleys (Fig. 1.1). Arcata Bay (North Bay), the largest subbay, has Jacoby Creek flowing into the northeast corner and Freshwater Creek flowing into the southeast corner. Entrance Bay is found at the mouth of the Elk River valley; Salmon Creek flows into South Bay. The subbays are linked by relatively narrow channels constricted between the valley interfluves on the east (Eureka area and Humboldt Hill) and the barrier spit on the west. A very short channel connects South Bay and Entrance Bay, while the relatively long (approximately 9.7 km) and narrow North Bay Channel connects Entrance Bay and North Bay. The north end of North Bay Channel forks at Indian Island; the west fork is called Samoa Channel and the east fork Eureka Channel.

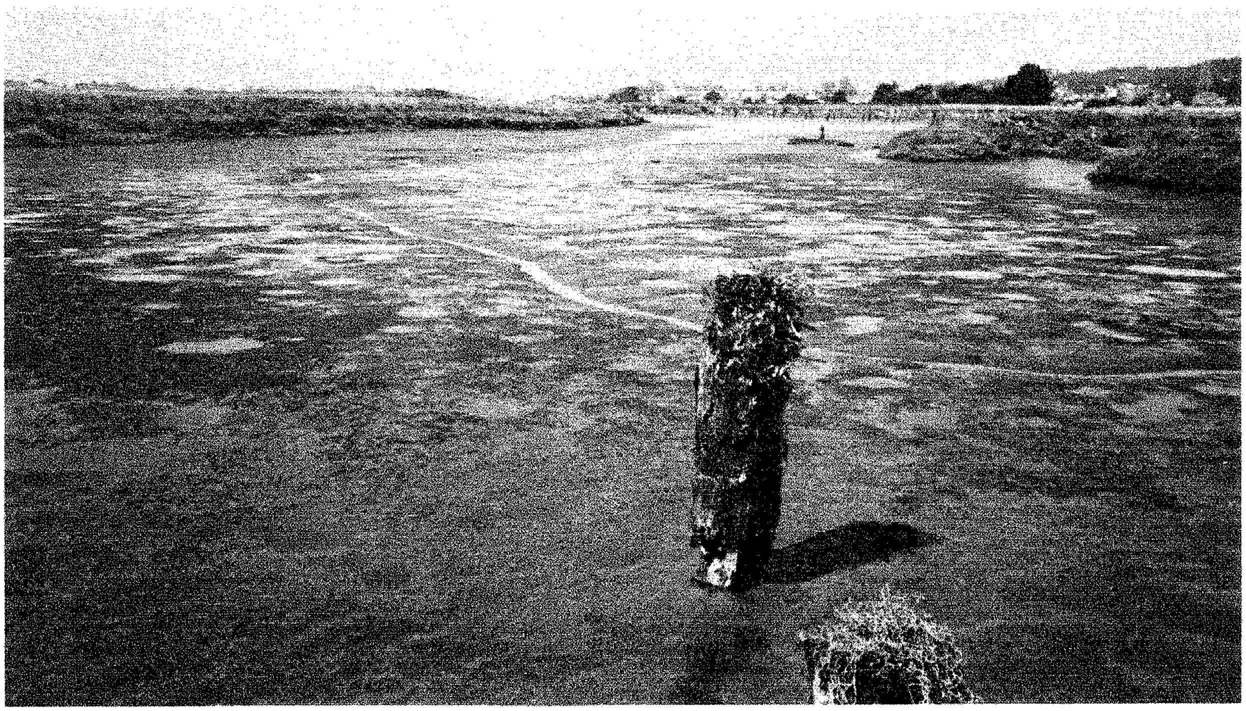

Fig. 2.1. Intertidal mudflats in Arcata Bay.

Arcata Bay and South Bay are characterized by three distinct morphologic subdivisions (Thompson 1971). The first subdivision, approximately 19% of the MHW area of Humboldt Bay, is tidal channel, which is the deepest part of the Bay, situated almost entirely below MLLW. The channels shoal in an up-bay direction from as deep as 9 m near the entrance to 2–3.5 m deep in the upper reaches of Arcata and South bays. There they form a complex tributary system and ultimately converge with the second morphologic subdivision, the intertidal mudflats, which occur as a more or less continuous apron around the flanks of Arcata and South bays. Mudflats are a dominant feature during periods of low tide (Fig. 2.1). The mudflats make up 77% of the MHW area of Arcata Bay, 81% of the MHW area of South Bay, and 65–70% of the total area of the bay. They extend from slightly below MLLW up to MHW, a relief of about 2 m. They are further subdivided morphologically into two fairly distinct parts: the high flats, which are steeper and run from MLLW to MHW; and the low flats, which are fairly flat and are found just below MLLW. About 61 km^2 of tidal mudflats are exposed at MLLW tidal levels or lower. The low flats are dissected by numerous small tidal gullies and are the regions of the most luxuriant growth of eelgrass, *Zostera marina*. Both low flats and eelgrass are most common in South Bay. The third morphologic subdivision is the salt marshes, which occur around the fringes of the tidal flats. Salt marshes currently cover approximately 4% of the Humboldt Bay area.

Unlike the other two subbays, Entrance Bay does not have broad expanses of tidal flats (less than 10%) and the surface area remains approximately constant over a tidal cycle. This is because Entrance Bay consists of a single deep channel with generally steep sides (Entrance Channel) that connects Humboldt Bay with the ocean. The channel is approximately 1,829 m long and 671 m wide at the seaward end and is flanked by twin jetties that extend 1,250 m offshore.

Humboldt Bay is apparently a bar-built estuary, formed from three distinct coastal plain estuaries that have been linked by the growth of the North and South spits. The present shape of Humboldt Bay probably developed during and since the last rapid rise of sea level, which occurred between 15,000 and 4,000 years B.P. (before present). One possible scenario is as follows: at the beginning of this period, sea level was 100–200 m below the present level. The Elk River and Jacoby, Freshwater, and Salmon creeks all likely flowed seaward of their present extent and occupied valleys located at the present site of the bay. From approximately 15,000 to 5,000 years B.P., sea level rose rapidly to within 5 to 10 m of its present position. As a result, the stream valleys became flooded, forming coastal plain estuaries over land that is now exposed (e.g., Sunnybrae and Arcata bottoms). The entire region extending from the McKinleyville Terrace in the north to Table Bluff in the south became a single open coastal embayment. As the rise in sea level slowed about 4,000–5,000 years B.P., the streams entering the arms of the embayment began pushing the shoreline seaward by first depositing estuarine and then deltaic sediment near their mouths. The Mad River, which may once have flowed into the embayment, is now separated from Humboldt Bay by the floodplain called Arcata Bottoms. Barrier islands extending across this coastal embayment were formed by wave activity concentrated along the shore seaward of its present position. With the subsequent rise in sea level, wave action moved the barrier island-spits and eroded the cliffs of the McKinleyville Terrace and Table Bluff to their present position. Eventually, a single bay entrance, approximately in the present location, was developed and maintained.

Bottom Sediments

Sediment Sources

The sediments in Humboldt Bay are derived from three main sources: runoff, oceanic input, and biological activity. Biological activity is the least important of the three. The creeks and small rivers carrying sediments into the bay may produce localized effects (i.e., at the mouth of Jacoby Creek), but since the watershed leading directly into Humboldt Bay is quite small (approximately 578 km^2), direct sediment input from runoff is also of limited importance. Much of the silt and clay in Humboldt Bay, and probably much of the sand as well, enters the mouth of the bay during flood tides. Thompson (1971) estimated a yearly oceanic sediment input of $5.4–6.7 \times 10^5$ m^3 as compared to only 9.0×10^4 m^3 of sediment per year from rivers and creeks. Most of this oceanic sediment is probably derived indirectly from river sources, however, particularly the Eel River, which discharges 15 km south of the mouth of Humboldt Bay. The Eel River has one of the highest sediment yields per unit area in the world and has the highest sediment yield per unit area of any major drainages in the United States (Judson and Ritter 1964; Brown and Ritter 1971; Jones and Stokes Associates, Inc. 1981). The nearshore currents tend to be towards the north (Davidson Current) during periods of high runoff, when the sediment load in the Eel River is extremely high. The Eel River plume is then carried into the bay during flood tides; Carlson (1973) has observed this from satellite imagery. Some of these sediments settle during the subsequent slack tide and remain in the bay. The Mad River, located to the north of Humboldt Bay, probably also contributes sediments in the same fashion during periods of southward-flowing nearshore currents. But it does so to a much lesser degree because the sediment load of the Mad is only about 9% of that of the Eel, and because the periods of southward flow do not tend to coincide with periods of high river runoff.

Distribution Patterns

Thompson (1971) produced the most complete description of the Humboldt Bay sediments (Figs. 2.2 and 2.3). Boyd et al. (1975) and Burdick (1976) provided additional information on sedimentation rates and the composition of the channel sediments. Thompson noted that the textural variations of the surface sediments are generally correlated with the morphologic subdivisions of the bay floor (tidal channels, mudflats, and salt marshes).

The sediment distribution pattern is produced mainly by tidal currents (Thompson 1971). The coarsest sediments are found in the channels near the mouth of the bay, where tidal currents scour the bottom and leave only coarse sands, gravels, and shell fragments. The sediments decrease in size as one moves up the channels and onto the mudflats because of reduced current activity and because fine sediments settle more slowly than coarse sediments. In addition, sediment from runoff may influence the grain size distribution in certain areas of the bay. This is most noticeable at the mouth of Jacoby Creek in the northeast corner of Arcata Bay, where the sediments are an even mixture of sand, silt, and clay (Thompson 1971; Figs. 2.2 and 2.3).

Once sediments are deposited, wind plays a role in redistributing them. Certain areas of the bay are protected from wind waves by the short fetch for north and northwest winds and therefore tend to have fine-grained (silty clay) sediments. Other areas, such as the south and east margins of Arcata Bay, tend to have slightly coarser-grained sediments (clayey silt) because the fetches leading into

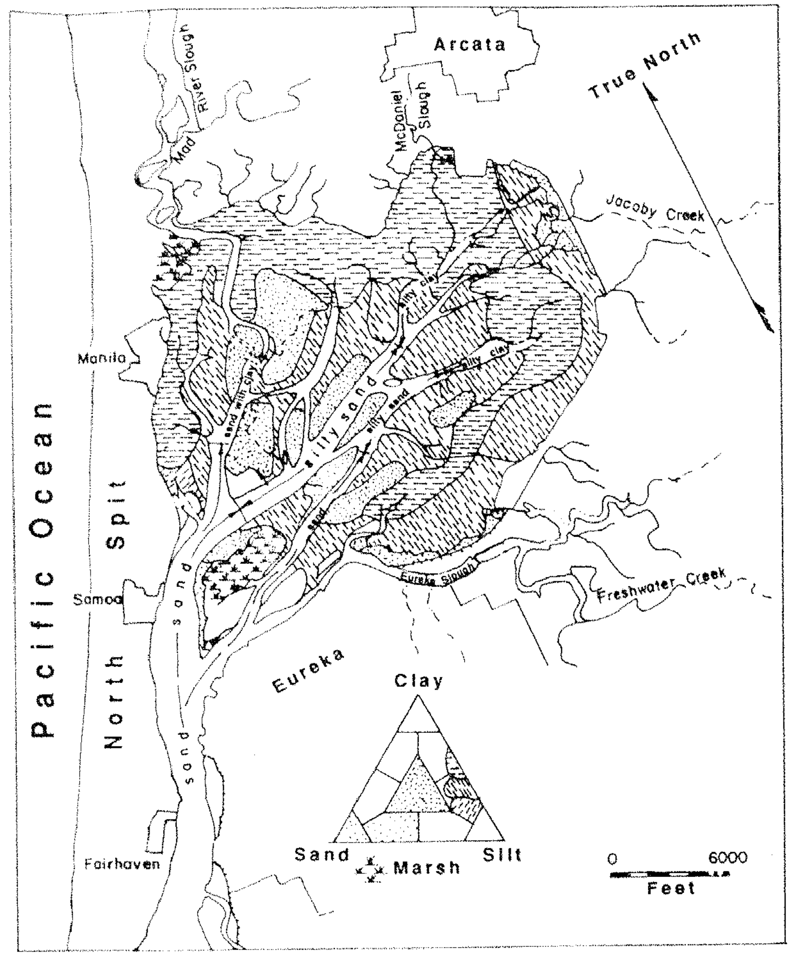

Fig. 2.2. Sediment distribution in Arcata Bay (from Thompson 1971).

them are sufficiently long to allow formation of wind waves capable of resuspending the finer sediments. The resuspended sediments are then transported away from these areas by tidal and wind-generated currents. The finest sediments (silty clays) are found around the wind- and wave-protected margins of the mudflats and in the salt marshes (Figs. 2.2 and 2.3). Thompson (1971) noted organic concentrations as high as 80% in marsh sediments. Material that is not immediately added to the bay is often buried and compressed, forming peat deposits.

Overall, the sediments in Arcata Bay tend to be finer than those in South Bay. There are a number of factors contributing to this difference. First, sediments in estuaries tend to become finer with distance from the mouth because of decreased flushing rates (less disturbance of the bottom) and the fact that fine particles have slower settling velocities than coarse particles. Arcata Bay, located at the end of a relatively long channel, is farther from the bay mouth and so receives less sediment but proportionately more clay than South Bay, which receives considerable amounts of silt and clay. Second, sediments in estuaries also tend to become finer with decreasing water depth, and Arcata Bay has relatively more high flats than South Bay.

The low flats of South Bay are covered with finer sediments than the low flats of Arcata Bay. Thompson (1971) attributed this mainly to oyster harvesting, which takes place in Arcata Bay but not in South Bay. The harvesting resuspends the substrate of the low flats, allowing fine sediments to be preferentially removed. In addition, coarse shell material is added to the low flats as part of the

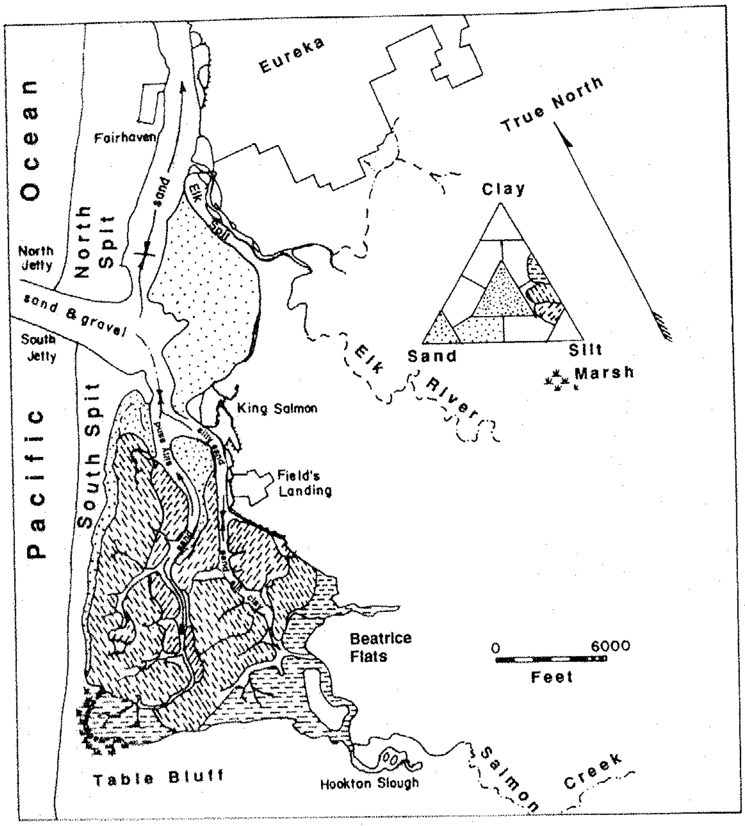

Fig. 2.3. Sediment distribution in South and Entrance bays (Thompson 1971).

oyster-culturing process. The dredging operations associated with oyster harvest have probably decreased the distribution and amount of eelgrass on the low flats in Arcata Bay (Waddell 1964; Keller and Harris 1966; Thompson 1971; Harding and Butler 1979); the low flats of South Bay have extensive eelgrass stands, which slow the current action and trap fine sediments.

Modification of Bay Morphology

The change in sediment distribution associated with oyster harvesting is but one example of how human activities in and around Humboldt Bay have changed the character of the bay during the last 100 years (Waddell 1964; Thompson 1971). The installation of jetties at the entrance of Humboldt Bay and the dredging of the channels to improve ship access and navigation have changed the circulation and sedimentation patterns in the bay (Noble 1971; Pequegnat 1988). Diking and filling in much of the salt marsh in both Arcata and South Bays have resulted in changes in circulation and nutrient cycling. In addition, deforestation in the watersheds of the bay and of the Mad and Eel rivers has dramatically increased the input of sediment into the bay by accelerating erosion of the surrounding fields, streambanks, and shores (Thompson 1971).

Jetties

The northern California coast is noted for its rugged features and rough seas. As the only deep-water harbor between San Francisco Bay and Coos Bay, Oregon, Humboldt Bay provides important shelter to marine vessels, especially during rough weather. Despite the construction of two jetties (Fig. 1.3), the entrance to Humboldt Bay remains quite dangerous to navigate (Bascom 1980).

The building of jetties at the mouth of Humboldt Bay was first proposed as part of the Rivers and Harbors Act in 1884, and the first jetties were completed in 1899 (Noble 1971). The south jetty deteriorated to the point where it had to be rebuilt between 1911 and 1915, and the north jetty had to be rebuilt shortly thereafter (Bascom 1980). The work was completed in 1927, but further repairs were needed by 1932 and again in the 1940's. After the heavy storms of the "El Nino" year of 1957–58, the jetties needed to be repaired again, and yet again after the winter storms of 1964–65. In 1971 there was a major rehabilitation of both jetties involving the placement of 246 reinforced concrete dolosses at the ends of the jetties (U.S. Army Corps of Engineers 1976). These 38-t dolosses have a shape designed to absorb wave energy and to resist movement, but they tend to promote water currents that cause scouring at the ends of the jetties and subsequent settling of the structure. The ends of the jetties were built up by placing additional dolosses on top of the others in 1987, but it is likely that settling of the dolosses will be a continuing problem.

Dredging

In 1881 Congress authorized the Corps to dredge a navigation channel in Humboldt Bay extending to Eureka and the Arcata wharf (University of Washington 1955; Reilly 1966). The work was performed in 1881 and 1882. All subsequent dredging has involved the deepening and widening of existing channels (Reilly 1966). Entrance Channel, North Bay Channel, Samoa Channel, and Eureka Channel are currently the principal commercial waterways of North Bay and are maintained by the Corps to depths of 7.9–10.7 m. Only one channel in South Bay, the Fields Landing Channel (Hookton Channel), is used commercially and maintained by the Corps. This channel was first dredged in 1883.

Prior to 1976, an average of 6.2×10^5 m^3 of sediment was removed from Humboldt Bay yearly because of ongoing widening and deepening of the channels (Thompson 1971; U.S. Army Corps of Engineers 1976). Between 1977 and 1982, between 4×10^5 and 8×10^5 m^3 of sediment were periodically removed from the bay and disposed of at the offshore disposal site (Borgeld and Pequegnat 1986). There has also been periodic dredging in the vicinity of Woodley Island Marina on the Eureka Inner Reach; the most recent was during the spring of 1988.

Diking and Filling

Extensive areas around Eureka and Arcata to the north and east of the bay are lowlands, consisting of creek and river floodplains and former tidal marshes that were drained and converted to agricultural uses. Due to diking, the salt marshes around Humboldt Bay were reduced from approximately 2,833 ha to about 393 ha (10–15% of the original area; Fig. 2.4), decreasing the tidal prism of the Bay and markedly changing fish and wildlife habitat (Shapiro and Associates, Inc. 1980).

Numerous parts of the bay have also been filled for various reasons. Bracut Lumber and Arcata Redwood created the most notable fills on the eastern perimeter of Arcata Bay by using fill dirt from a hill in the Bracut area. The site of Mid-City Motors and the Murray Field Airport, also on the eastern side of Arcata Bay, are other regions that have been created by filling parts of Humboldt Bay.

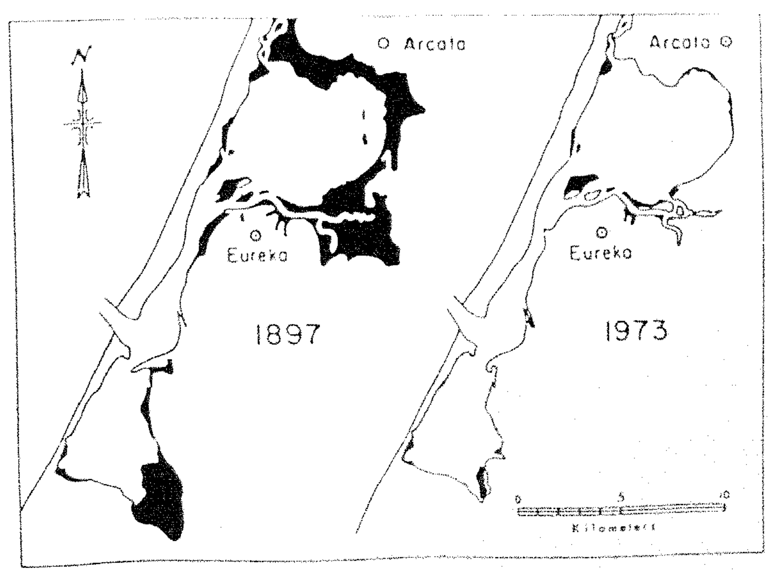

Fig. 2.4. Decrease in Humboldt Bay marshland distribution from 1897 to 1973 caused by diking (MacDonald 1977).

Other human activities have added sediments to Humboldt Bay as well. For example, wood fragments from various timber industry operations located on the shores of the bay are present in the bay water and are probably common in the sediments. Riprap, sand, and other construction materials used in levees, bulkheads, and other structures may also become estuarine sediments. There are presently 25 to 50 million oysters being raised in Arcata Bay and Mad River Slough. As previously mentioned, oyster harvesting operations are believed to have increased the grain size of the sediments on the low flats in Arcata Bay by adding shell fragments, reducing the amount of eelgrass, and resuspending the fine sediments. The harvesting process also disturbs the benthic communities.

Erosion and Deposition

Certain areas within Humboldt Bay are undergoing active erosion or accretion. Some of the erosion and deposition is naturally occurring, but some can be attributed directly to human modification of the natural system. For example, the building of jetties and dredging of Entrance Channel have significantly changed the morphology of Humboldt Bay, even in areas not directly modified by these projects. These projects have been correlated with high-energy waves in Entrance Bay and concentrated tidal currents that have almost completely eroded Red Bluff (next to the power plant in the King Salmon area) and Buhne Point (Tuttle 1982). To arrest this erosion, a project involving the placement of groins (small jetties) and the addition of sand between the groins was recently completed. Another example of the effect of jetties and the resultant wave patterns in Entrance Bay is the northward growth of the Elk River spit. The Elk River previously emptied into the center of Entrance Bay, but it now enters to the north in North Bay Channel (Fig. 1.1). This spit is still growing.

The salt marshes along the bay margins and on Indian Island are also undergoing active erosion. Thompson (1971) indicated that the marshes in the southeast corner of Arcata Bay adjacent to the Eureka Slough retreated at an average rate of 0.6–1.2 m/year from 1911 to 1966, primarily because of wave action. However, the marshes adjacent to McDaniel Slough and Jacoby Creek showed no erosion during the same time period. This is probably due to the protection from significant wave action in the McDaniel Slough area and the relatively high sediment input from Jacoby Creek, which is actively building an outwash fan on the high flats in this area. In South Bay, the northward migration of sand has resulted in sediment accumulation to form an east-trending recurved spit on the bayward side of South Jetty. This sediment may also contribute to the shoaling of Fields Landing Channel and the shoal lying across the north end of Southport Channel.

Climate

The Humboldt Bay region typically has two distinct seasons. The fall and winter season is mild but wet, characterized by a series of storms passing through the area; spring and summer is cool and dry, with fog in the summer. The monthly mean temperature varies by only 5.2° C through the year (Fig. 2.5), being lowest in January (8.5° C) and highest in August (13.7° C).

The Humboldt Bay region is noted for high precipitation; however, because most days during the winter receive little rainfall, the high precipitation is associated with occasional storms (Fig. 2.6). Eighty-five percent of the precipitation in the area usually occurs during a 7-month period from mid-October to mid-May (Elford and McDonough 1974). The annual precipitation in Eureka, located on Humboldt Bay, averages 97.8 cm, which is the lowest amount recorded for Humboldt County (Elford and McDonough 1974). Mean annual precipitation for the Humboldt Bay area is indicated in Fig. 2.7. This value more than doubles as one moves into the coastal and inland mountain valleys of the area; however, since the drainage basin leading into Humboldt Bay is quite small (578 km^2), runoff entering the bay is episodic and small (Jones and Stokes Associates 1981).

Fall and winter storms are spawned in the region of the Aleutian Low and travel through the Humboldt Bay area from west to east. These low-pressure storm systems, characterized by cyclonic (counterclockwise in the northern hemisphere) circulation, result in intense winds from the south and southwest as the storm passes through the area. Between the winter storms, the winds tend to be less intense and frequently come from the north and northwest (Pequegnat and Hodgson 1976).

During the spring and summer, the Aleutian Low disappears as the North Pacific High moves in to dominate the North Pacific. Since wind travel is anticyclonic (clockwise in the northern hemi-

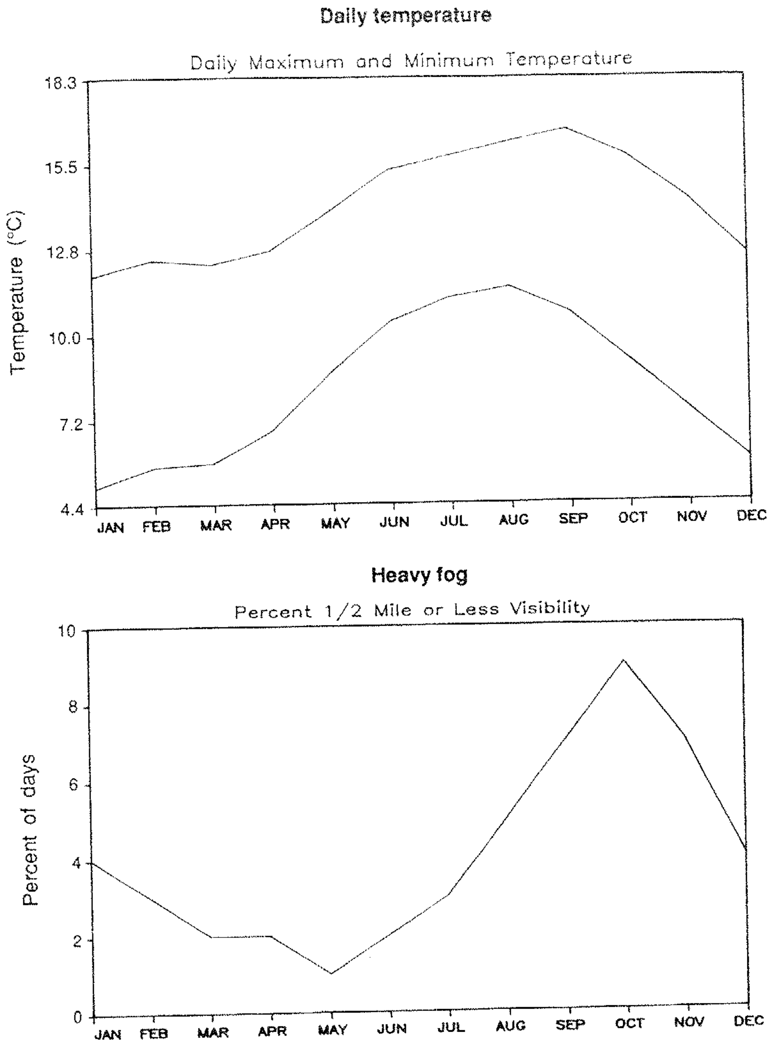

Fig. 2.5. Average daily maximum and minimum air temperatures, by month, and mean percent days of heavy fog (visibility 1/2 mile or less), by month, Eureka, California, 1941–70 (from USDC 1977).

sphere) around high pressure systems, the prevailing winds during the spring and summer tend to be from the north and northwest. These northwest winds, though persistent, tend to increase in velocity in the early afternoon and die in the late evening (Pequegnat 1975). They are caused by the interaction of two pressure systems: the North Pacific High and a thermal low in the central valley of California caused by local heating of the land during the day and a concomitant rise of the valley air. The winds have a diel nature because of the daily heating of the central valley. They persist through the night, although at lower intensity, because the North Pacific High is a semipermanent feature.

Coastal upwelling results from north and northwest winds in the Humboldt Bay region. Although it can occur during any time of the year, upwelling is most intense during the spring and tends to taper off during the summer as the responsible winds decrease in intensity. Since upwelling brings cold water from depth to the surface in the nearshore region, coastal fog is common during this period. Fog is more common during the summer and early fall than in spring since the winds are less intense, allowing the air to cool and water vapor to condense as the air mass moves over the area (Fig. 2.5). However, dense coastal fog can occur in the Humboldt Bay region during any time of the year.

Hydrology

Freshwater Input

The drainage basin affecting Humboldt Bay is quite small for a bay of this size, approximately

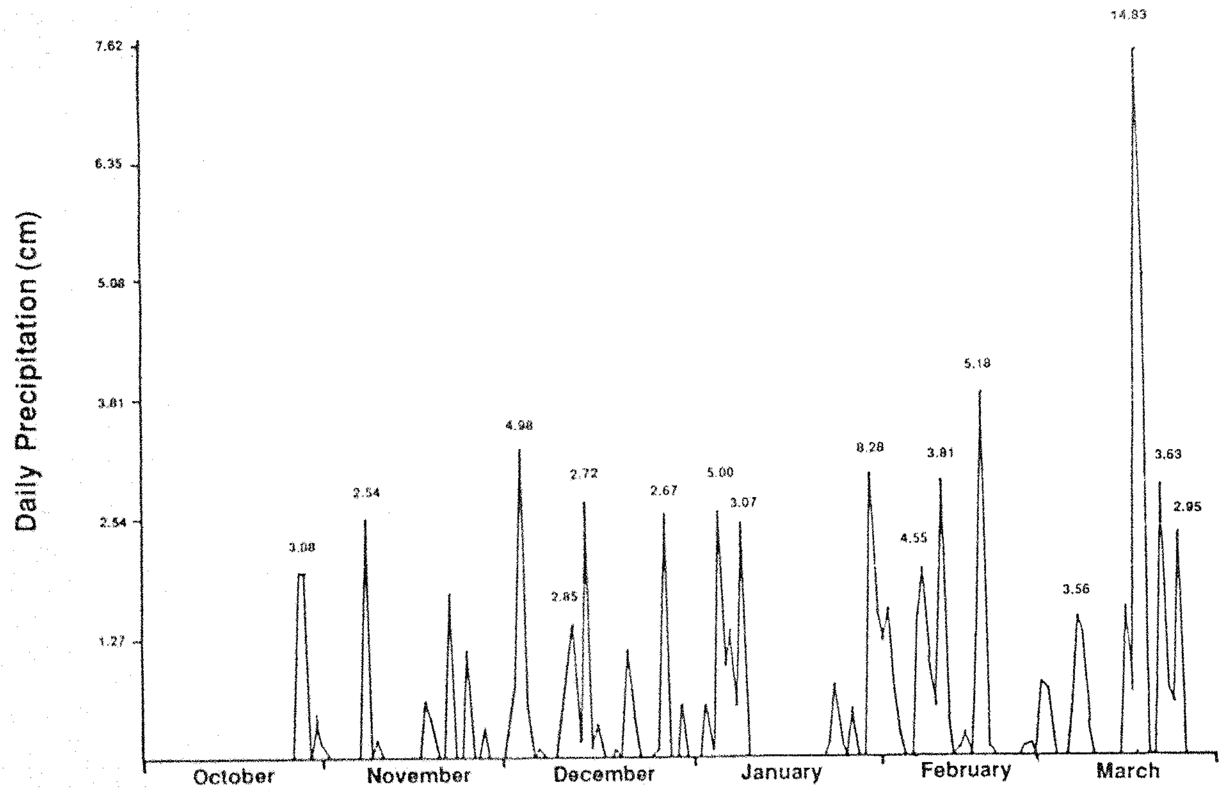

Fig. 2.6. Daily precipitation in Eureka, California, October 1974 to March 1975. Total precipitation in inches for each storm is noted (from Proctor et al. 1980).

578 km^2 (less than 1% of the Eel River watershed located south of Humboldt Bay), of which 62.4 km^2 is represented by the bay itself. Of the fresh water entering Humboldt Bay, 12% falls as precipitation directly on the bay, 85% is river drainage into Arcata Bay and North Bay Channel (Elk River); and the remainder is runoff into South Bay. The major rivers in the region do not drain into Humboldt Bay. Fresh water enters from point sources via Jacoby Creek, Elk River, Freshwater–Eureka Slough, McDaniel Slough, Mad River Slough (not associated with the Mad River), and other small sloughs and creeks (Costa 1984). The Mad River apparently has not flowed naturally into Humboldt Bay in historic times (although a canal to transport logs was built and maintained for a short period in the late 1800's) except during floods, when it spills over into Mad River Slough and thus into the bay.

The amount of runoff fluctuates widely and rapidly (as much as a 100-fold difference in 2 days), depending on precipitation. The volume of monthly runoff follows monthly precipitation quite closely: runoff is high from November to April and is lowest during the late summer. The only exception is at the beginning of the rainy season in fall, when the soil of the drainage basin retains a higher percentage of the precipitation following the summer drought.

Freshwater discharges into the bay are minor influences in terms of hydrology or hydraulics (Costa 1984). Thompson (1971) estimated the annual flow for Jacoby Creek at 1.31×10^7 m^3, Elk River at 7.31×16^7 m^3, and Freshwater and Salmon creeks at 9×10^4 m^3. The U.S. Army Corps of Engineers (1977) estimated the maximum flows for Jacoby Creek to be 21 m^3/sec and Elk River to be 43–97 m^3/sec. Musselman et al. (1978) estimated flow through the mouth of the Bay to be 3,450 m^3/sec (tide stage not indicated). Thus, runoff represents very little of the daily tidal exchange in the bay and can therefore have only a localized and transient effect on its hydrography.

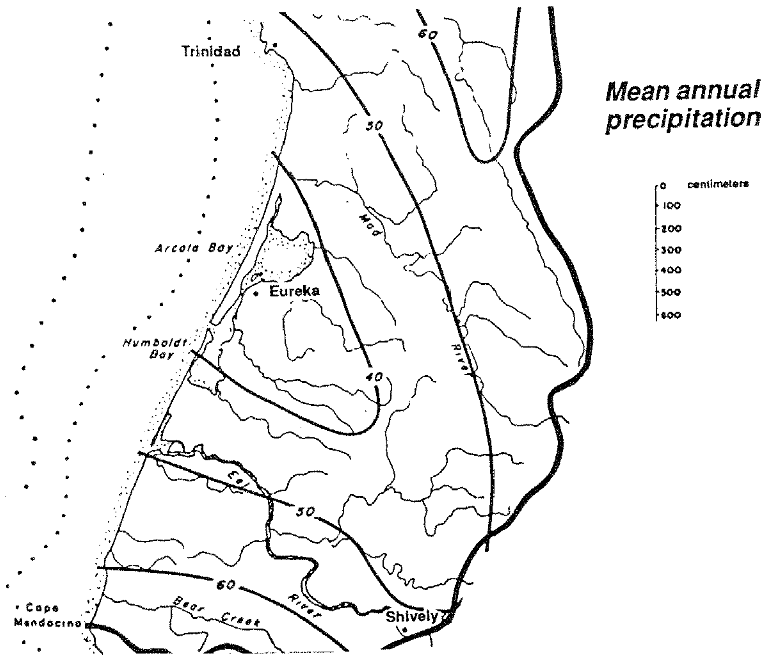

Fig. 2.7. Mean annual precipitation (inches), Humboldt Bay environs (from Proctor et al. 1980).

Tides and Flushing Characteristics

The tides in Humboldt Bay are characterized by a semidiurnal inequality; that is, successive high or low tides have different elevations (Fig. 2.8). On extreme tides this inequality may amount to as much as a 1.2 m difference in successive lows or a 0.8 m difference in successive highs (National Oceanographic and Atmospheric Administration 1988). Mean tide range and mean tide level increase with distance from the inlet into Arcata Bay, but not significantly in South Bay (Costa 1984). The tide moves more slowly into Arcata Bay than South Bay. In addition, low tide at Eureka lags significantly behind low tide at Samoa. Finally, the mean tidal range appears to have increased at several stations within the bay over the last 60 years. This increase may have resulted from the deepening of the channels, which could increase the volume of water flowing through them (Costa 1984). The general warming of the ocean and subsequent worldwide rise in sea level may cause tide-related flooding problems in the low-lying regions of the bay in the next few decades.

The three subbays differ significantly from each other in terms of hydrography; the differ-

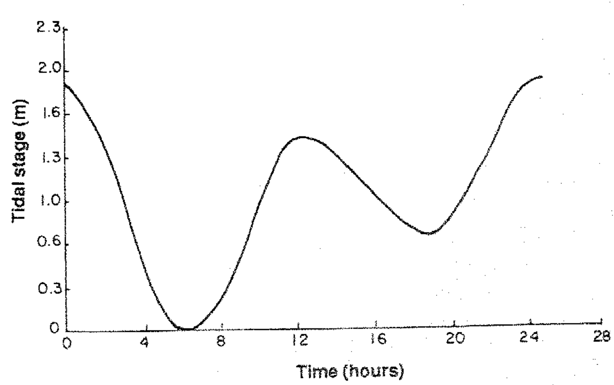

Fig. 2.8. Mean tide curve for South Jetty, Humboldt Bay (Costa 1982).

ences are mostly related to the degree of isolation from nearshore waters. Both South Bay and Arcata Bay have extensive mudflats with a complex pattern of channels (Figs. 2.2 and 2.3); consequently each of these subbays has a large tidal prism (Table 2.1). From MHW to MLLW, the volume of South Bay changes from 3.70×10^7 to 1.24×10^7 m^3 (while the area increases from 1.83×10^7 to 7.1×10^6 m^2). This yields an average tidal prism of 60% of the MHW volume. Arcata Bay changes in volume from 8.51×10^7 to 4.80×10^7 m^3 and in area from 3.45×10^7 to 1.19×10^7 m^3, resulting in an average tidal prism of 44%. Gast and Skeesick (1964) estimated that 44% of the Arcata Bay waters are replaced each lunar day (41% for the entire bay) and that 99% replacement takes approximately 7 lunar days or 14 tidal cycles. Gast and Skeesick (1964) estimated 15 tidal cycles (7.5 lunar days) for complete replacement, but noted that flushing time varies considerably with tidal prism and freshwater input. These estimates, based on a simple model that assumes considerable mixing within the bay, suggest that the flushing rate is rapid compared with other bays. However, the flushing rate appears to vary with distance from the mouth and the volume of the joining channels. Costa (1981), using a model based on tide height distributions, estimated the flushing time of the relatively isolated Mad River Slough to be nearly 85 tidal cycles, while Casebier and Toimel (1973) estimated the flushing time for the major channels in Arcata Bay to be 2.1 tidal cycles; their estimate was based on the movements of drogues within the channels.

The waters of Arcata Bay and South Bay do not rapidly assume the character of the nearshore waters, as would be expected with complete mixing and large tidal prisms; rather, the bay waters are sufficiently isolated from the nearshore and the flushing time is such that the bay waters take on chemical and biological characteristics of their own, including separate zones within the bay itself (Beittel 1975; Pequegnat and Butler 1982). For example, zooplankton communities in the subbays differ from each other and from those in the nearshore waters (Pequegnat and Butler 1982; J. E. Pequegnat and N. Haubenstock, Department of Oceanography, Humboldt State University, Arcata, Calif., unpublished data). Also, the gradients of several chemical and physical parameters within the bay, including temperature and salinity, show that the waters nearest the bay mouth at low tide most closely assume the characteristics of the nearshore (J. Brandes and J. E. Pequegnat, Department of Oceanography, Humboldt State University, Arcata, California, unpublished data), and confirm that some of the peripheral areas within the bay do not flush as rapidly as the main channels. This effect is especially pronounced in Arcata Bay because it is isolated from the nearshore by a long, deep channel (North Bay Channel) with a volume similar to the tidal prism, which inhibits the flushing process. South Bay, having a much less extensive channel system and being connected

Table 2.1. *General characteristics of Humboldt Bay (Shapiro and Associates, Inc. 1980).*

Characteristic	South Bay	Entrance Bay	Arcata Bay	Humboldt Bay
Area, 10^7m^2, MLLW[a]	0.71	0.73	1.19	2.63
Area, 10^7m^2, MHW[b]	1.83	0.79	3.45	6.07
Volume, 10^7m^3, MLLW	1.24	3.21	4.80	9.25
Volume, 10^7m^3, MHW	3.70	4.44	8.51	16.65
Tidal prism, 10^7m^3	2.46	1.23	3.71	7.40
Tidal prism/vol., MLLW	1.98	0.38	0.77	0.87
Tidal prism/vol., MHW	0.66	0.28	0.44	0.44
Average depth, m	1.70	6.10	4.00	3.50
Annual river discharge, 10^7m^3	3.20	0	26.40	31.60
River discharge/vol., MLLW	2.60	0	5.90	3.40
River discharge/tidal prism	1.30	0	7.12	4.27

[a] Mean lower low water (0 feet).
[b] Mean high water (5.7 feet).

to the nearshore waters by a much shorter channel, has a shorter flushing time and more closely assumes the characteristics of the nearshore environment (Pequegnat and Butler 1982).

Even within Arcata Bay and South Bay, mixing appears to be limited; the waters of these subbays are found in two well developed compartments (Beittel 1975; Pequegnat and Butler 1982). Bay compartment water is found over the mudflats at high tide and moves into the channels at low tide. Nearshore compartment water consists of nearshore water advected into the channels during flood tide; it is found in the channels at high tide and is advected offshore during ebb tide. Because conditions in the nearshore fluctuate dramatically between upwelling and nonupwelling periods (in a matter of days), the waters of these subbays are continually approaching, but seldom reaching, some sort of equilibrium (J. Brandes and J. E. Pequegnat, unpublished data).

In contrast to the waters of the other subbays, the water in Entrance Bay is quite transient and well mixed. It appears that Entrance Channel and Entrance Bay function as mixing areas, receiving water through the bay mouth and from North Bay Channel (Arcata Bay) and South Bay (Beittel 1975; Costa 1982). This region is an extremely energetic area; water entering Entrance Bay is probably vigorously mixed before being transported north, south, or west. Turbulence causes mixing in this location as nearshore water enters the bay during flood tide and impinges on the shallow area on the east side of Entrance Bay, sending a divergence to the north and south along the eastern shore. Much, if not all, of the vertical stratification of the nearshore water column is disrupted by turbulent water rushing into Entrance Channel and Entrance Bay. Because the subsurface nearshore water is usually colder than the surface water, this mixing results in water temperatures within the bay which are 0.2–0.3° C lower than the nearshore surface temperatures.

Currents and Circulation

The circulation of Humboldt Bay is almost completely tidally driven (Costa 1982, 1984). The large change in volume with tide results in a very energetic system with high-velocity tidal currents and considerable vertical mixing in the channels. Fresh water, normally an important driving force in estuaries, has little influence because freshwater input to Humboldt Bay is episodic and small relative to the tidal prism of each subbay (Table 2.1). The total annual freshwater input to Humboldt Bay is approximately equal to the exchange during only four tidal cycles (approximately 2 days).

The basic circulation pattern in Humboldt Bay is fairly straightforward and has been described by Gast and Skeesick (1964; Fig. 2.9). The currents follow the major channels, are strongest in the channels, and decrease with increased distance from the bay mouth. Gast and Skeesick (1964) noted little change in velocity with depth in the water column, with the exception that surface waters moved slightly faster than the deep waters. R. L. Beittel and J. E. Pequegnat (Department of Oceanography, Humboldt State University, Arcata, California, unpublished data) and Pequegnat and Butler (1982) found that the nearshore water moved up the axis of North Bay Channel and intruded into the channels of Arcata Bay when the tidal change was greater than 1.8 m. They found that the water moved in the major channels approximately 1.6 km per 0.3 m of tidal change.

There is relatively little current velocity data. J. E. Pequegnat and M. C. Landsteiner (Department of Oceanography, Humboldt State University, Arcata, California, unpublished data) found peak current velocities to be approximately 1.3 m/sec in North Bay Channel, 1 m/sec at the entrance to South Bay, and slightly faster than 1.7 m/sec in Entrance Channel. Beech (1977) studied the currents in Eureka Slough and in North Bay Channel leading to Arcata Bay. He found peak velocities of 0.5 m/sec in the channel between Eureka and Woodley Island adjacent to the marina (Eureka Inner Reach); the channels between Woodley Island and Indian Island had peak velocities of 0.75 m/sec. Beech (1977) found that 75% of the water entering and exiting Arcata Bay passed through Samoa Channel. The velocity pattern and volume transport for the various channels is not well understood (Costa 1982).

The most dangerous currents undoubtedly occur in the Entrance Channel, particularly during outgoing tides, when the water leaving the Bay interacts with the incident ocean waves. The Pacific Northwest experiences the most severe wave conditions in the continental United States (Costa 1984). It is not uncommon for waves to break across the entire bay mouth during such times, especially during spring tides when the tidal range is large. The hazard is further increased by the fact that the waves offshore are often so large that they break over the jetties.

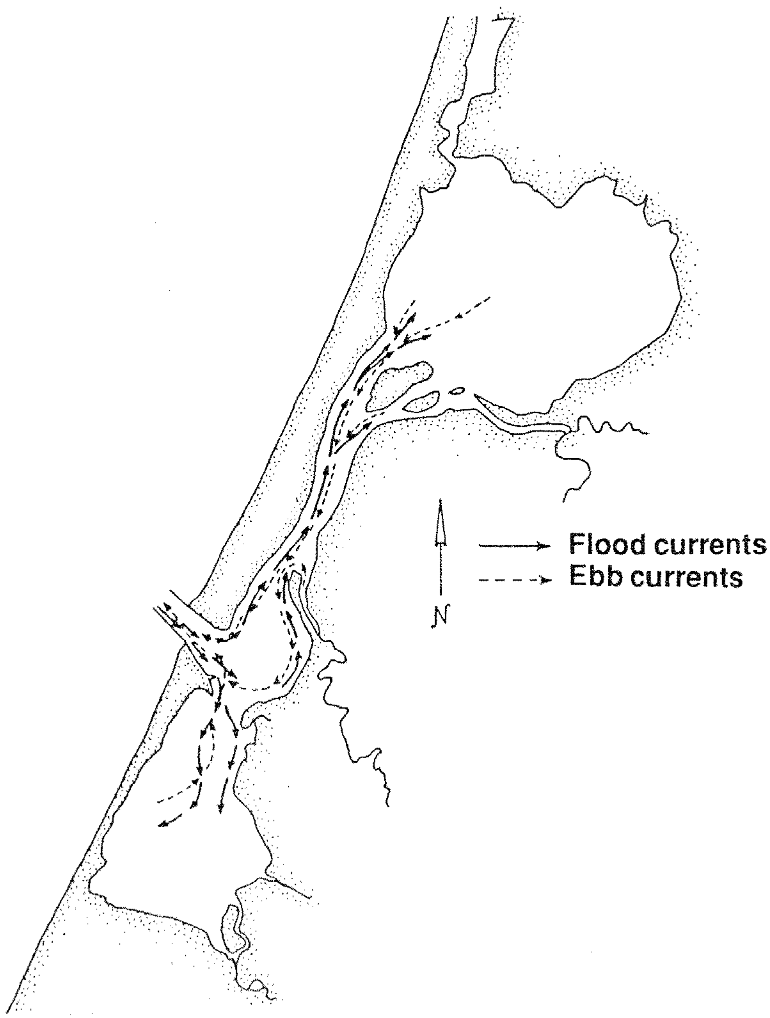

Fig. 2.9. Ebb and flood tidal current patterns for the major channels in Humboldt Bay (from Costa 1982).

Physicochemical Aspects

Because of the presence of both nearshore compartment waters and bay compartment waters in each subbay, the water characteristics in Humboldt Bay at a given point change dramatically with tidal stage and are determined by a combination of processes occurring in the nearshore (e.g., upwelling), in the bay itself (e.g., evaporation), and episodically on the land surrounding the bay (e.g., runoff from the small watershed). The extensive movement of water in the channels with the ebb and flood of the tides results in turbulent mixing, which rapidly breaks down any vertical stratification in the channels of the bay; however, horizontal gradients up the channel axes separate the nearshore compartment waters from the bay compartment waters (note movement of the 11° C isotherm in Figs. 2.10 and 2.11). These gradients are seen in temperature, salinity, and nutrient and chlorophyll concentrations, with the water near the bay mouth at low tide being most similar to, but still distinct from, the conditions in the nearshore (Beittel 1975; Pequegnat and Butler 1982; J. Brandes and J. E. Pequegnat, unpublished data).

Seasonal Changes in the Nearshore Water

The coast of northern California is noted for upwelling, but there are actually three basic oceanographic conditions, with associated water types, possible in the nearshore environment. These conditions are dictated by the winds, and the vagaries of the winds are such that any of these conditions can occur at any time of the year.

Upwelling periods. These periods, common during spring and early summer, are characterized by strong winds from the north and northwest and a southerly current set. High nutrient concentrations, low oxygen concentrations, low water temperatures, and moderately high salinities are found in the nearshore waters during upwelling periods.

Low wind periods. Such periods, with light winds from no predominant direction, are common in late summer and early fall. During these periods, the California Current, normally offshore with a slow southerly set, moves closer to shore and brings low nutrient concentrations, high temperatures, and moderate salinities to the nearshore environment.

Stormy periods. These are common in late fall and winter and are characterized by strong south and southwest winds and a northerly current set (the Davidson Current). During these periods the nearshore water is characterized by low salinities, high sediment loads, moderate nutrient concentrations, and oxygen saturation.

Pirie and Steller (1977) have given names to three hydrographic seasons as follows: the upwelling period from March to August, the oceanic period from August to November, and the Davidson Current period from November to March. Although these periods are characterized by the hydrographic conditions given for upwelling, stormy, and low wind periods, their divisions are statistically derived and the conditions can change rapidly any time of the year. In the spring and summer, for example, the characteristics of the nearshore water have been observed to rapidly oscillate from those associated with upwelling periods to those associated with nonupwelling periods and back within a few weeks (Pequegnat 1975; Pequegnat and Butler 1982; J. Brandes and J. E. Pequegnat, unpublished data). In late January of most years, there is a calm period when conditions more typical of the oceanic period are observed. During a drift-card study of the nearshore cur-

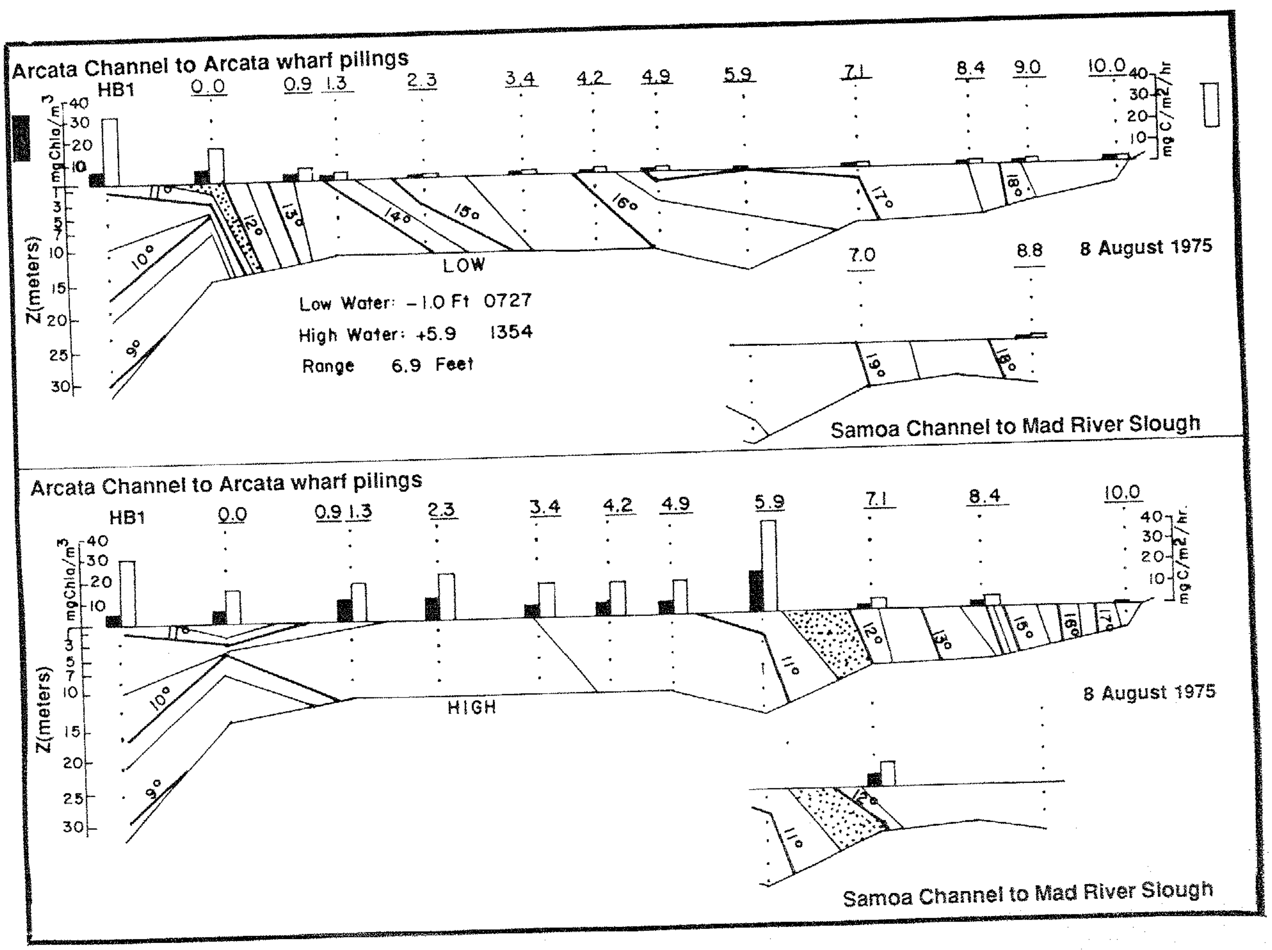

Fig. 2.10. Temperature, chlorophyll (*black bar*), and productivity distribution (*white bar*) at low and high tides in channels from Humboldt Bay entrance into Arcata Bay, 8 August 1975. Station HB1 is marker buoy 1 nmi off shore; station 0.0 is at mouth of Humboldt Bay; and all other stations are indicated by distance in nautical miles up bay from mouth (Pequegnat and Butler 1982).

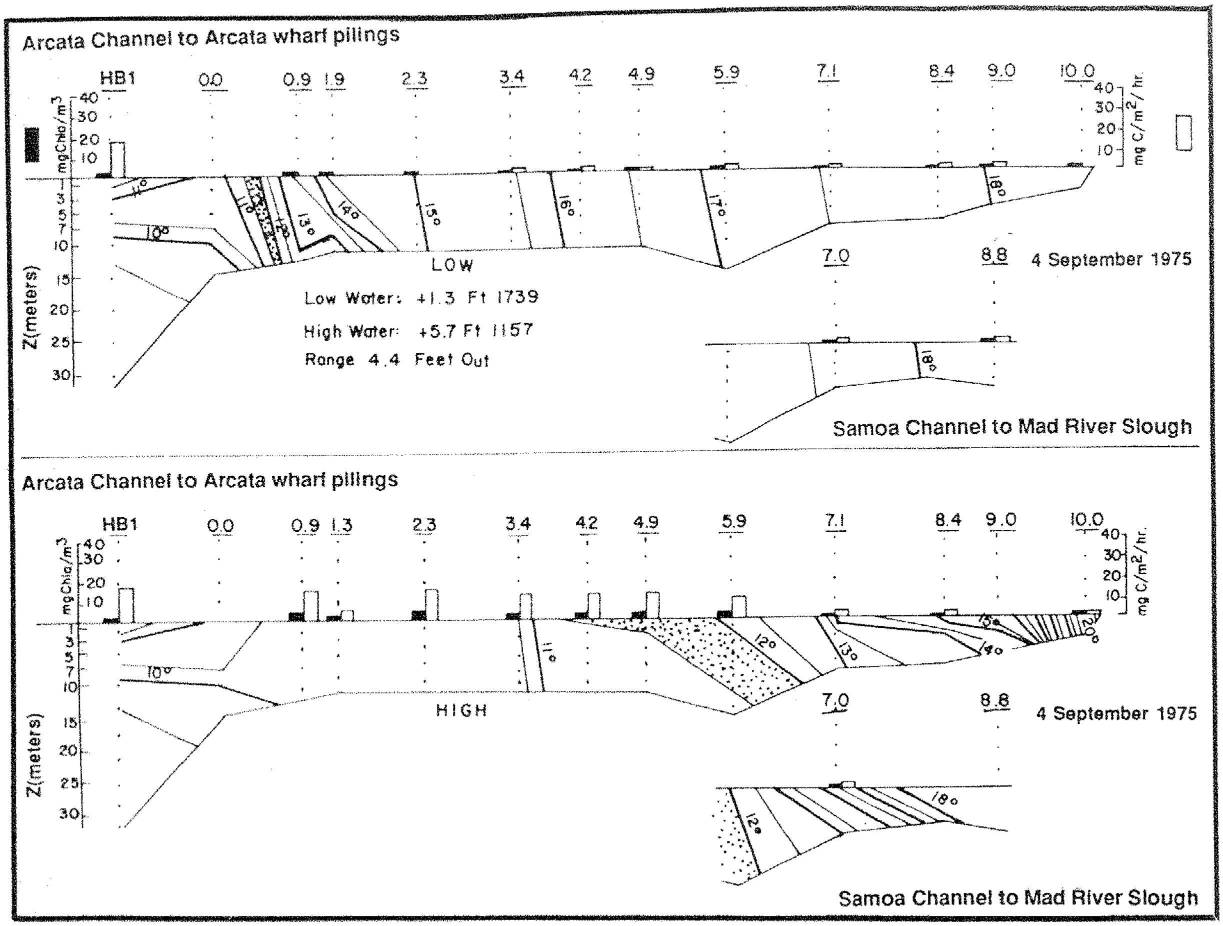

Fig. 2.11. Temperature, chlorophyll (*black bar*), and productivity distribution (*white bar*) at low and high tides in channels from Humboldt Bay entrance into Arcata Bay, 4 September 1975. Station HB1 is marker buoy 1 nmi off shore; station 0.0 is at mouth of Humboldt Bay; and all other stations are indicated by distance in nautical miles up bay from mouth (Pequegnat and Butler 1982).

rents conducted in 1975, all three oceanographic conditions were observed in the nearshore within a 6-week period (Pequegnat and Hodgson 1976).

Temperature and Salinity Patterns

The temperature of the nearshore waters of northern California has a normal range of 9–14° C, with occasional episodes of up to 2° C outside this range. The range of temperatures in Humboldt Bay is considerably wider, from 9° C to more than 20° C (Pequegnat and Butler 1982; J. Brandes and J. E. Pequegnat, unpublished data). Nearshore and bay salinities range from less than 25 parts per thousand (ppt) during periods of high runoff to greater than 34 ppt when deeper water is advected to the surface during periods of intense upwelling. In both cases the lower salinities are associated with periods of moderate runoff, but higher salinities are associated with periods of high evaporation rather than upwelling. Of course, the distribution of properties within the bay depends greatly on the stage of the tide, and the patterns of temperature and salinity in the nearshore waters and in Humboldt Bay can vary rapidly with changing wind regimes. Nevertheless, sampling at various locations in the bay (Fig. 2.12; Tables 2.2 and 2.3) has indicated patterns associated with nearshore hydrographic conditions (upwelling and low wind [nonupwelling]).

Upwelling periods. During upwelling periods, the nearshore water temperature drops to below 11° C and the salinity rises to over 33 ppt. During intense upwelling periods the sea surface temperature may drop to less than 8° C, with salinities greater than 34.1 ppt. Since upwelling is associated with north and northwest winds and clear skies, runoff is low, and evaporation within the Bay tends to be high. During these periods there is a marked increase in temperature with distance up the main channels of Humboldt Bay (Figs. 2.10 and 2.11;

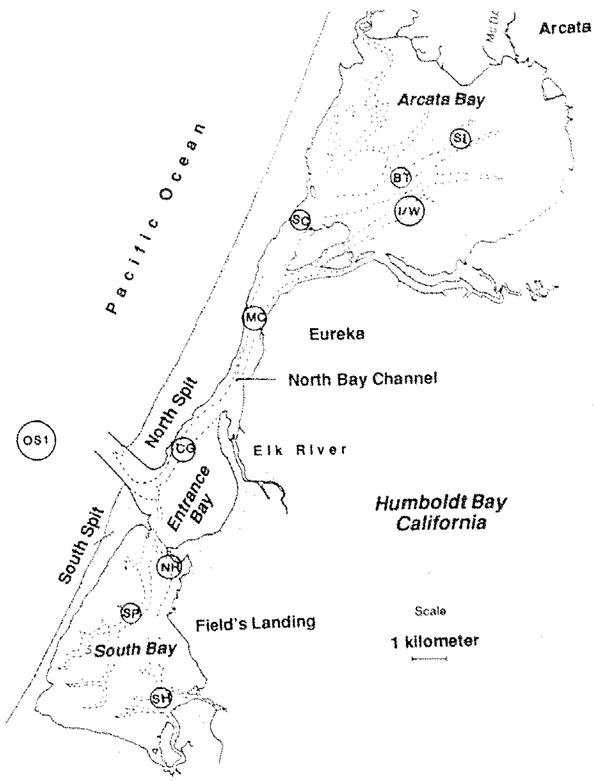

Fig. 2.12. Location and designation of Humboldt Bay physicochemical sample stations. Data are presented in Tables 2.2 and 2.3 and Fig. 2.15 (Pequegnat and Butler 1981).

Tables 2.2 and 2.3) and the salinity tends to be high throughout the Bay (i.e., more than 33.6 ppt).

Low wind periods. During periods of calm wind, the warm surface water offshore tends to move onshore. Concurrently, the sea surface temperature typically rises higher than 13° C and the salinity is usually less than 33.5 ppt. The waters may be vertically stratified with respect to both temperature and salinity. During periods of low wind in the late summer and fall, both the temperature and salinity tend to increase up the channel axes of each subbay; conversely, when the winds subside in winter, both temperature and salinity decrease up the channel axes.

Stormy periods. Because the northerly flowing Davidson Current is associated with winter storms, the nearshore surface waters tend to be cool (less than 11° C) with low salinity (less than 32 ppt) because of high runoff. The nearshore waters also tend to be highly stratified, primarily because of vertical salinity gradient. Since this stratification tends to be destroyed by turbulent mixing in the channels of the bay, the salinity of the bay waters tends to be higher (greater than 33 ppt) than the nearshore surface waters. Runoff can cause stratification within the bay compartment waters, but because of the relatively small amount of runoff entering the bay and turbulent mixing, the bay compartment waters are strati-

Table 2.2. *Temperature, salinity, Secchi depth, dissolved oxygen, pH, and chlorophyll-*a *measurements during upwelling and nonupwelling conditions in Humboldt Bay, June and September 1980 (Pequegnat and Butler 1981).*

Station[a]	Distance from bay mouth (km)	Temperature (° C)	Salinity (ppt)	Secchi depth (m)	Dissolved oxygen (ml/L)	Dissolved oxygen Saturation (%)	pH	Chlorophyll-*a* (mg/L)
				26 June 1980 (nonupwelling)				
NH	5.6	15.5	33.48	1.10	4.35	76	8.37	6.04
SP	5.6	15.2	33.53	1.10	4.29	75	8.42	5.59
OS	-1.6[b]	12.4	33.34	4.00	4.17	69	8.33	13.27
MC	7.4	15.7	33.47	1.00	3.24	57	8.13	11.38
SC	11.1	17.3	33.29	0.90	2.93	53	8.01	6.38
I/W	12.6	—	33.54	0.80	2.60	—	8.03	5.90
				24 September 1980 (upwelling)				
NH	5.6	14.2	33.48	1.00	2.04	35	7.97	2.31
SP	5.6	13.3	—	1.44	1.96	—	7.95	—
OS	-1.6[b]	10.9	33.46	2.20	1.75	28	7.92	3.40
MC	7.4	15.3	33.66	1.40	2.00	35	7.94	3.54
SC	11.1	16.4	33.68	1.00	1.61	29	7.98	3.16
I/W	12.6	16.9	33.80	1.30	2.17	39	7.96	2.90

[a] See Fig. 2.12 for station locations.
[b] Nearshore station approximately 1.6 km offshore.

Table 2.3. *Temperature, salinity, Secchi depth, dissolved oxygen, pH, and chlorophyll-a measurements during upwelling and nonupwelling conditions in Humboldt Bay, July 1986 (J. Brandesand J. E. Pequegnat, Department of Oceanography, Humboldt State University, Arcata, California, unpublished data).*

Station[a]	Distance from bay mouth (km)	Temperature (° C)	Salinity (ppt)	Secchi depth (m)	Dissolved oxygen (ml/L)	Dissolved oxygen Saturation (%)	pH	Chlorophyll-a (mg/L)
				10 July 1986 (upwelling)				
SH	7.1	17.2	33.76	0.90	4.93	90	8.09	3.50
NH	5.6	16.2	33.76	1.00	5.10	91	8.10	3.41
SP	5.6	14.7	33.70	1.15	5.48	95	8.09	3.50
CG	3.3	15.2	33.71	1.30	2.41	42	7.91	4.48
MC	7.4	16.8	33.76	1.10	4.58	83	7.95	3.31
SC	11.1	17.6	33.85	1.00	4.77	88	7.95	3.50
BT	13.0	17.3	33.87	0.90	4.75	87	7.93	3.71
SI	15.0	18.0	33.95	0.75	4.36	81	7.83	4.16
I/W	12.6	18.3	34.06	0.90	4.73	88	8.06	3.49
TB	0.0[b]	9.8	33.52	3.10	5.12	80	7.83	2.59
				24 July 1986 (nonupwelling)				
SH	7.1	14.6	33.84	0.80	5.19	90	7.92	1.55
NH	5.6	13.7	33.83	0.90	5.03	85	7.96	1.54
SP	5.6	13.0	33.80	1.15	5.53	93	7.96	1.23
CG	3.3	14.9	33.93	1.15	5.32	93	7.97	2.45
MC	7.4	16.3	34.07	1.00	5.12	92	7.98	1.06
SC	11.1	17.1	34.13	1.25	5.05	92	7.80	0.88
BT	13.0	17.2	34.19	0.90	4.96	91	7.99	0.88
SI	15.4	17.3	34.14	0.70	3.81	70	7.81	0.65
I/W	12.6	17.4	34.35	1.10	4.93	91	8.02	0.50
TB	0.0[b]	12.6	33.67	1.75	7.40	123	8.30	5.37

[a] See Fig. 2.12 for station locations.
[b] Trinidad Bay, 22 km north of Humboldt Bay, was used for nearshore control.

fied only episodically, immediately following periods of high runoff (Beittel 1975).

Oxygen and pH

The oxygen concentration in the nearshore water is inversely correlated with the intensity of upwelling; during intense upwelling, the oxygen concentration may be less than 50% of the saturation concentration. As a result, the concentration of dissolved oxygen in the channels of Humboldt Bay at high tide is often quite low. On the other hand, because the bay compartment waters are spread out over the mudflats in a thin layer at high tide, and because the exchange velocity of oxygen between water and air is fairly high (Broecker and Peng 1982), the concentration of oxygen in the bay compartment waters is always near saturation. This is in agreement with Gast and Skeesick (1964), who recorded their highest and lowest oxygen concentration at the bay entrance (11.97 mg/L during nonupwelling periods and 4.26 mg/L during upwelling periods) and found the most stable oxygen concentrations in the northeast quadrant of Arcata Bay (8–9.6 mg/L). Pequegnat and Butler (1982) and J. Brandes and J. E. Pequegnat (unpublished data) found dissolved oxygen concentrations in Arcata Bay close to the expected saturation values based on temperature and salinity (Tables 2.2 and 2.3).

The pH values found in Humboldt Bay waters have not shown any unusual patterns (Tables 2.2 and 2.3); recorded values range from 7.7 to 8.1, with the lower values being associated with similar pH values in the nearshore waters during periods of upwelling (J. Brandes and J. E. Pequegnat, unpublished data).

Nutrients

Pequegnat (1988) suggested that the three major sources of nutrients to the Bay are runoff, the nearshore waters, and municipal wastewater. Pequegnat and Butler (1981) estimated that in 1979 the wastewater from Eureka contributed 20–50% of the fixed nitrogen found in the bay compartment waters of Arcata Bay during the 150-day period of low runoff in summer and early fall. Since then, the amount of nutrients entering the Bay from wastewater sources has been decreased by measures enacted between 1982 and 1986 by the municipalities surrounding the bay. In June of 1984, Eureka began diverting its partially treated wastewater into a freshwater marsh for further treatment, then pumping the marsh water into North Bay Channel on outgoing tides. Since July of 1986, Arcata has diverted its wastewater into an innovative freshwater marsh system before it is released into Arcata Bay.

Before these changes, both the nearshore waters and wastewater were important sources of nitrate and other nutrients to the bay. This is illustrated by nutrient concentration data collected at locations in the nearshore and the North Bay Channel, and at two locations in Arcata Bay before (1980) and after (1986) cessation of wastewater input (Fig. 2.13; Pequegnat 1988). In 1980 the concentration of nitrate was high in the nearshore during upwelling periods and decreased with distance up the channel into Arcata Bay, while during nonupwelling periods the concentration of nitrate was low in the nearshore waters, lower in the channels, but not much different in Arcata Bay. It is interesting to note that the same general patterns were found in 1986, after the wastewater nutrients were diverted from the bay, but that the actual nitrate concentrations were lower than previously (Fig. 2.13; Tables 2.4 and 2.5; Pequegnat 1988; J. Brandes and J. E. Pequegnat, unpublished data).

The diversion of wastewater leaves runoff and the nearshore waters as the primary sources of nutrients to Humboldt Bay. Runoff tends to be episodic, occurring mainly during the late fall and winter. Therefore, nutrient contributions to the bay from runoff may be significant during the winter, when runoff is high, but not during the summer. The amount of nutrients available to the bay from the nearshore varies with the hydrographic regime in effect. As previously noted, there are three basic water types found in the nearshore, depending on wind conditions, each with characteristic nutrient concentrations. The highest nutrient concentrations in the nearshore are associated with upwelling periods, while the

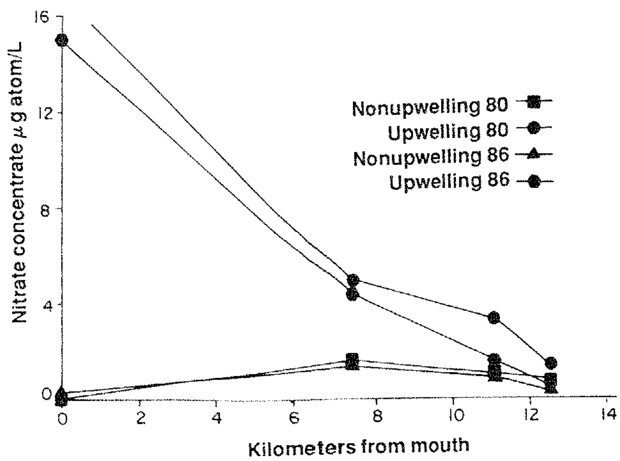

Fig. 2.13. Nitrate concentrations in Humboldt Bay waters during periods of upwelling and nonupwelling (Pequegnat 1988).

stormy periods are associated with moderate nutrient concentrations and the low wind periods with low nutrient concentrations. Since the hydrographic regime depends on the local wind, which can change rapidly at any time of the year, the nearshore may at times act as either a source of nutrients or a sink for nutrients. Because upwelling can be quickly triggered by a short period of high wind following a period of storms, offshore conditions may be in a state of flux unless a long period of stable weather occurs. This constantly changing nearshore environment is reflected in the nitrate concentrations found in the nearshore and in North Bay Channel which leads to Arcata Bay (see stations CG, MC, and SC in Tables 2.4 and 2.5). A time lag between the nearshore and channel water characteristics indicates that the channel waters reflect not what is occurring at the moment in the nearshore waters, but what was present a few days earlier (in effect, two sinusoidal curves, with one being driven by the other).

That the nearshore waters may be a sink for certain nutrients in the bay as well as a source for others is implied by the phosphate, nitrate, and ammonium gradients between the bay and the nearshore waters.

Phosphate

Pequegnat and Butler (1981) and J. Brandes and J. E. Pequenat (unpublished data) measured phosphate concentrations in the bay at low and high tides and found the concentrations at low tide to be

Table 2.4. *Nutrient concentrations and total nitrogen-to-phosphorus ratios during upwelling and nonupwelling conditions in Humboldt Bay, June and September 1980 (Pequegnat and Butler 1981).*

Station[a]	Distance from bay mouth (km)	NO_2 (µg·atoms/L)	NO_3 (µg·atoms/L)	NH_3 (µg·atoms/L)	PO_4 (µg·atoms/L)	Si (µg·atoms/L)	N:P
			26 June 1980 (nonupwelling)				
NH	5.6	0.03	0.49	0.17	0.79	8.9	0.9
SP	5.6	0.05	0.00	0.46	0.73	7.7	0.7
OS	-1.0[b]	0.03	0.23	0.00	0.03	2.1	8.7
MC	7.4	0.07	0.48	0.81	1.27	13.5	1.1
SC	11.1	0.13	0.55	1.14	2.04	22.9	0.9
I/W	12.6	0.16	0.93	1.27	1.87	22.9	1.3
			24 September 1980 (upwelling)				
NH	5.6	0.19	4.01	2.97	1.56	21.5	4.6
SP	5.6	0.22	5.23	2.98	1.56	21.1	5.4
OS	-1.0[b]	0.36	16.90	2.41	1.70	26.0	12.0
MC	7.4	0.25	4.96	4.22	2.10	22.2	4.5
SC	11.1	0.20	3.30	3.56	2.28	21.8	3.1
I/W	12.6	0.14	1.39	2.78	2.38	21.4	1.8

[a] See Fig. 2.12 for station locations.
[b] Nearshore station approximately 1.6 km offshore.

Table 2.5. *Nutrient concentrations and total nitrogen-to-phosphorus ratios during upwelling and nonupwelling conditions in Humboldt Bay, July 1986 (J. Brandes and J. E. Pequegnat, Department of Oceanography, Humboldt State University, Arcata, California, unpublished data).*

Station[a]	Distance from bay mouth (km)	NO_2 (µg·atoms/L)	NO_3 (µg·atoms/L)	NH_3 (µg·atoms/L)	PO_4 (µg·atoms/L)	Si (µg·atoms/L)	N:P
			10 July 1986 (upwelling)				
SH	7.1	0.21	0.79	1.9	1.6	18.4	1.8
NH	5.6	0.29	2.21	2.0	1.5	19.3	3.0
SP	5.6	0.23	2.67	1.3	1.2	19.9	3.5
CG	3.3	0.44	9.90	1.9	1.6	30.4	7.7
MC	7.4	0.37	4.80	2.4	1.7	29.3	4.5
SC	11.1	0.28	3.22	2.3	1.6	31.9	3.6
BT	13.0	0.38	2.70	2.3	1.9	38.7	2.8
SI	15.4	0.37	1.00	3.8	2.5	36.8	2.1
I/W	12.6	0.23	0.40	1.8	1.8	30.6	1.4
TB	0.0[b]	0.68	21.50	1.6	1.5	41.8	16.0
			24 July 1986 (nonupwelling)				
SH	7.1	0.38	1.77	2.98	2.02	13.0	2.5
NH	5.6	0.27	2.65	2.75	1.59	13.6	3.6
SP	5.6	0.22	2.40	1.96	1.37	13.8	3.3
CG	3.3	0.35	4.03	2.98	1.73	13.7	4.3
MC	7.4	0.24	4.39	2.63	1.56	14.6	4.7
SC	11.1	0.17	1.57	2.96	1.80	14.5	2.6
BT	13.0	0.18	1.22	1.72	1.90	14.3	1.6
SI	15.4	0.34	0.34	2.71	2.75	20.1	1.2
I/W	12.6	0.14	0.50	1.65	1.81	14.2	1.3
TB	0.0[b]	0.00	0.04	0.41	0.30	1.7	1.5

[a] See Fig. 2.12 for station locations.
[b] Trinidad Bay water was used for the nearshore control.

greater than at high tide and greater than the high tide concentrations that Gast and Skeesick (1964) found. The phosphate gradient runs from low to moderate in the nearshore waters to relatively high in the upper bay waters. Wastewater is a likely source of phosphate within the bay, as are the bay sediments, because, according to Burton and Liss (1976), estuarine sediments can act as phosphate buffers, maintaining high phosphate concentrations in an estuary by sediment leaching for some time after discontinuation of wastewater input. The excess phosphate in the bay can then act as a source of phosphate to the adjacent nearshore waters.

Nitrate

The nitrate gradient is the reverse of the phosphate gradient, ranging from high to moderate concentrations in the nearshore waters to very low concentrations in the upper bay waters. Therefore, the bay acts as a sink for nitrate, most likely through plant production and denitrification. Loss of nitrogen compounds through denitrification is suggested by the ratio of nitrogen to phosphate in the bay, which is relatively low compared to the 16:1 ratio suggested by Redfield (1956).

Ammonium

Although the nearshore waters are the main source of nitrate-nitrogen during summer, they tend to be low in ammonium and may act as a sink, along with plant production inside the bay. Nitrogen in the form of ammonium has several potential sources within the bay; wastewater and recycling of plant nitrogen by animals, especially oysters, are the two most important ammonium sources.

Chlorophyll

The chlorophyll concentrations, which reflect productivity, are generally low in both Humboldt Bay and the nearshore waters during the winter (Fig. 2.14), although the concentrations within the bay are considerably higher than in the nearshore (Pequegnat and Butler 1982). This is probably because at high tide, the phytoplankton in the bay are held over the mudflats in a shallow water column, allowing them to remain in the sunlit layer where they receive sufficient light to grow and reproduce. The phytoplankton in the nearshore, in contrast, are mixed to considerable depth, out of the sunlit layer. During the early spring, chlorophyll concentrations in both the bay and the nearshore waters increase as the nearshore waters stratify (thus reducing the depth of mixing), and neither light nor nutrients are limiting. The chlorophyll concentration in the nearshore generally remains high during the spring and summer because of the upwelling of nutrients, but chlorophyll concentration in the bay typically decreases during the summer months (Fig. 2.14).

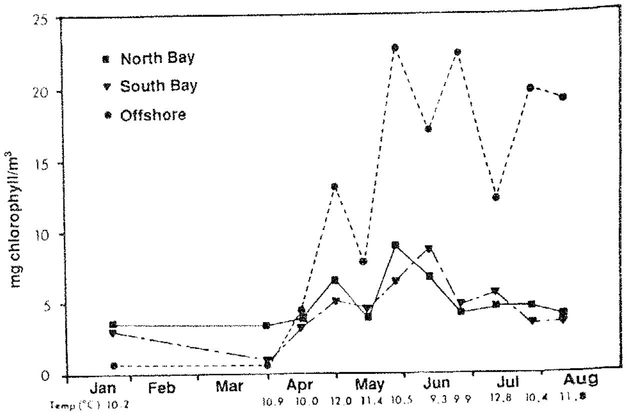

Fig. 2.14. Chlorophyll concentrations and water temperatures for offshore, North Bay (Arcata Bay), and South Bay during an 8-month period in 1979 (Pequegnat and Butler 1982).

Pequegnat and Butler (1981) suggested that wastewater nutrients were important to the bay's sustained productivity and that the removal of this source could decrease the productivity of the bay; recent chlorophyll data confirm this possibility (Fig. 2.15). Chlorophyll concentrations measured at two stations in the channels of Arcata Bay during the summer of 1980, when wastewater was being discharged into the bay, were consistently higher than those measured in the same locations during the summer of 1986, after cessation of wastewater input (J. Brandes and J. E. Pequegnat, unpublished data). Although the chlorophyll concentrations were lower in the bay compartment waters in June and early July of 1986 than in 1980, there was a dramatic drop in late July and early September of 1986. This drop coincided with the mid-July diversion of Arcata's wastewater flow from the bay to the freshwater marsh project and indicated a lowering in primary productivity in the bay associated with this diversion (J. Brandes and J. E. Pequegnat, unpublished data). It is likely that the wastewater nutrients were playing a part in the bay's nutrient budget and may have been important to its sustained productivity. The loss of these nutrients eventually may result in reduced zooplankton and ben-

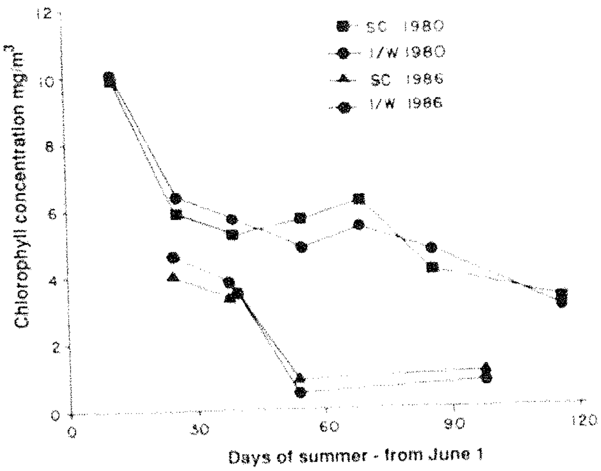

Fig. 2.15. Chlorophyll concentrations before (1980) and after (1986) cessation of wastewater discharge into Arcata Bay (Pequegnat 1988).

thic productivity, especially filter feeders such as the commercially raised oysters.

Turbidity

The waters of Humboldt Bay are quite turbid. Assuming that *k*, the extinction coefficient, is related to D, the depth of disappearance of a Secchi disk, by the equation $k = 1.6/D$ (Idso and Gilbert 1974), the water depth to which 1% of the surface illumination reaches varies from less than 2 m to about 5 m, with the norm being near 3 m (Tables 2.2 and 2.3). The turbidity of the bay water is due mainly to suspended sediments (both from runoff and those resuspended from the mudflats by wind-waves) and from phytoplankton found in the water column during periods of high productivity.

Water Quality

With increased shipping and fishing, Humboldt Bay has been exposed to typical pollutants such as petroleum, antifouling bottom paints, and untreated human and fish-processing wastes. Most of these problems are being addressed (i.e., by wastewater treatment and removal). Until recently there were sanitary waste disposal landfills at each end of the bay, and although they are now closed and the Arcata landfill is covered by impervious muds, there is still a potential for these two regions to introduce a suite of toxins to the bay in their leachates.

Since there is relatively little heavy industry in the region surrounding the bay (the largest being two pulp mills that discharge to the ocean rather than the bay), there are few sources of toxic metals other than natural mining in the small watershed. The State Mussel Watch program found Humboldt Bay to be one of the least polluted bays in the state (M. Martin and M. D. Stephenson, Marine Resource Laboratory, California Department of Fish and Game, Monterey, unpublished data). In oysters tested from all enclosed bays in California as part of the Mussel Watch program, the overall concentration of anthropogenic indicator trace metals (silver, zinc, and lead) was lowest in Humboldt Bay. Concentrations were similar in Humboldt Bay oysters and in those from Drakes Estero, the open coast control station (Table 2.6). However, the concentrations in oysters of trace metals indicative of terrestrial influence were generally higher in Humboldt Bay than in Drakes Estero samples (Table 2.6).

Table 2.6. *Metal concentrations (mean ppm ± 95% C.I.) in oysters from Drakes Estero (an open coast control station) and Humboldt Bay (M. Martin and M.O. Stephenson, Marine Resources Laboratory, California Department of Fish and Game, Monterey, unpublished data).*

Metal	Drakes Estero	Arcata sewer outfall	Central Arcata Bay	South Humboldt Bay
Silver	0.15±0.06	0.68±0.42	0.52±0.40	0.33±0.32
Zinc	316±37	347±159	390±300	430±521
Aluminum	52±17	106±37	196±179	144±77
Iron	25±0	407±172	450±131	450±131

Chapter 3. Biological Habitats and Communities

The wide variety and complexity of habitat in and around Humboldt Bay provide the necessary living space and life requirements for many species of plants, invertebrates, fishes, birds, and mammals. Monroe (1973) presented a generalized view of Humboldt Bay habitats (Fig. 3.1).

Marshes, Fringing Wetlands, and Grass Beds

Wetland habitats were classified according to the criteria presented by Cowardin et al. (1979). Humboldt Bay is the only area of appreciable acreage of salt marsh between San Francisco Bay and Coos Bay, and it links the two floristically. Although MacDonald (1977) distinguished three groups of California salt marshes—northern, San Francisco Bay, and southern, Holland (1986) recognized only a northern and a southern group. While Humboldt Bay contains plant species common to both southern and northern salt marshes, its flora is distinct from the central and southern California marshes.

In the Humboldt Bay area, nearly 90% of the original salt marsh areas have been either diked or filled. Only 393 ha of the original estimated 2,833 ha of salt marsh remain (Monroe 1973; Shapiro and Associates, Inc. 1980). Other remaining wetland habitats around Humboldt Bay include 101 ha of brackish marsh, 111 ha of freshwater marsh (not including grazed seasonal wetlands, which total 2,697 ha), and 69 ha of woody freshwater swamp (according to a draft Humboldt Bay wetlands mitigation needs and restoration goals study, conducted in 1984 by Humboldt County, Eureka, Calif.).

Three main factors influence the vegetation of all wetlands: duration of inundation, water chemistry, and site history. Currently, the salt marshes exist largely as remnants in a narrow perimeter around the bay. Notable exceptions include the large areas of salt marsh on low islands in the middle of Entrance Bay and islands included in Mad River Slough. Brackish and freshwater wetlands most often occur contiguously with the salt marshes and with the exception of the extensive areas of grazed seasonal wetlands, are usually narrow remnants along sloughs and near riparian woodlands.

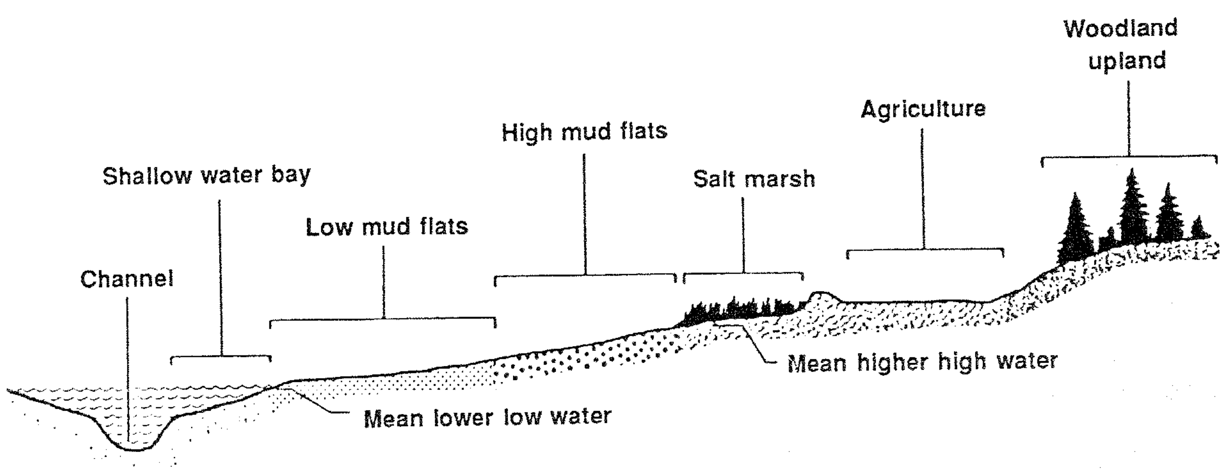

Fig. 3.1. Profile of Humboldt Bay habitats (modified from Monroe 1973).

Fig. 3.2. Humboldt Bay tidal marsh border with unique mixture of cordgrass and pickleweed. Note pickleweed at lower elevation than cordgrass.

Salt Marshes

Dominant Species

Humboldt Bay salt marshes are dominated by three vascular plant species: pickleweed (*Salicornia virginica*), Humboldt cordgrass (*Spartina densiflora*), and saltgrass (*Distichlis spicata*; see Appendix A). Autecological information on pickleweed and saltgrass can be found in Mahall and Park (1976), MacDonald (1977), Newby (1980), Rogers (1981), Zedler (1982), and Josselyn (1983). Similar data on *Spartina densiflora* can be found in Newby (1980), Rogers (1981), and Spicher and Josselyn (1985). While central and southern California salt marshes are also dominated by pickleweed and salt grass, the large areas dominated by *Spartina densiflora* are unique to Humboldt Bay.

Until 1984, *Spartina densiflora* was referred to as a local ecotype of *Spartina foliosa*, which attains its northernmost extension in Bodega Bay and is common from San Francisco Bay south to Baja California (Spicher and Josselyn 1985). *Spartina densiflora* occurs at a higher intertidal position than *S. foliosa* and exhibits a tufted or clumped habit (tussocks), as opposed to the solitary, evenly spaced culms of *S. foliosa* stands. Researchers noted the difference in growth form and intertidal distribution (MacDonald 1977; Rogers 1981; Josselyn 1983), but this taxon was not recognized as a different species until 1984. Ecological and taxonomic evidence compiled by Spicher and Josselyn (1985) documented that the Humboldt Bay cordgrass is an exotic species introduced from South America. Lumber was exported to Chile from the north coast during the mid-1800's and it is speculated that *S. densiflora* found its way to Humboldt Bay as ballast (Spicher and Josselyn 1985). *Spartina densiflora* occurs in only one other location in North America, in Marin County, California, where it was initially introduced as part of a revegetation experiment in 1976. In Marin County, it has spread and currently grows at Creekside Park Marsh, Corte Madera Creek, Muzzi Marsh, and Greenwood Cove.

Humboldt Bay cordgrass maintains its higher intertidal position in the Marin marshes where it occurs with *S. foliosa*, demonstrating that its elevational range is an autecological response rather than a unique situation of Humboldt Bay. The intertidal position of *S. densiflora* results in the bimodal distribution of pickleweed that has been noted by many researchers, including MacDonald (1977), Rogers (1981), Claycomb (1983), and Eicher (1987). In salt marshes that form a gradual interface with the bay waters, pickleweed dominates the lower intertidal and upper intertidal elevations, while cordgrass attains dominance in between (Fig. 3.2). Cordgrass becomes less important in higher elevation marshes, where it may be limited by phosphorus (Newby 1980).

Environmental factors that affect salt marsh species distribution include time and duration of tidal inundation, soil and water salinity, soil aeration, soil type and development, air and water temperature, drainage patterns, nutrient availability, water table height, precipitation, and light (Chapman 1938; Morgan 1961; Adams 1963; Waits 1967; Phleger 1971; Keefe 1972; Squiers 1973; Valiela et al. 1975; Nestler 1977; Parrondo et al. 1978; Gallagher et al. 1980; Newby 1980; Smart and Barko 1980; Rogers 1981). The salt marsh species grow along intermixed environmental gradients. The most obvious gradient, and the one that is most often measured in salt marshes, is elevation (Chapman 1938; Adams 1963; Eilers 1975; Claycomb 1983; Eicher 1987; Fig. 3.3). The elevational gradient, however, more often than not is an indication of other factors, such as inundation, soil salinity, and soil texture (Zedler 1977). Therefore, the term "tide elevation complex," as defined by Clarke and Hannon (1969), best describes the various ecological factors that interact to produce the elevational gradient within a marsh.

Quantitative measurements of the intertidal distribution of the most common species found in salt marshes around Humboldt Bay have been few. Eicher (1987) gathered data on the intertidal position of salt marsh species at five different bay locations predominantly in North Bay; Claycomb (1983) and Newton (1989) measured elevational data associated with mitigation projects on Eureka Slough.

Plant Associations

Three to four plant associations have been recognized in the Humboldt Bay salt marshes (Claycomb 1983; Koplin et al. 1984; Newton 1987, 1989; Eicher 1987). At the lowest elevations, the *Salicornia* type occurs and is composed of pure stands of pickleweed. Above this zone, monotypic stands of *Spartina densiflora* make up the *Spartina* type. Both of these associations contain few to no other vascular plant species but are commonly entangled with algae such as *Enteromorpha* and *Ulva* (Fig. 3.4). A variety of small gastropods, crustaceans, and polychaete worms feed on algal mats.

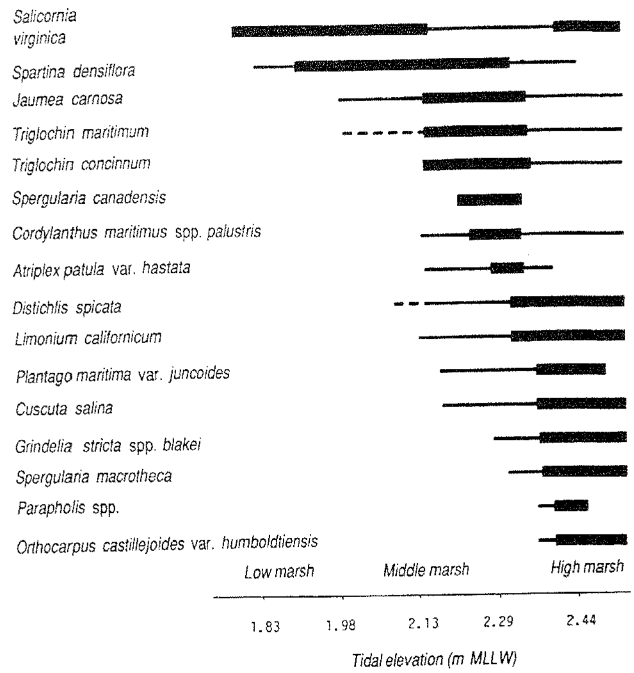

Fig. 3.3. Distribution of major salt marsh plant species across the tidal elevation gradient in North Humboldt Bay, California. Wider bands indicate the range in which each species had its peak cover, as assessed within 7.6 cm elevation classes. Broken bands indicate sporadic occurrence (Eicher 1987).

The marshes above the *Spartina* stands have been lumped (Eicher 1987) or separated into two associations (Claycomb 1983; Koplin et al. 1984; Newton 1987, 1989). Koplin et al. (1984) recognized a *Salicornia–Jaumea* type and a *Salicornia–Distichlis* type. The *Salicornia–Jaumea* type is floristically diverse and in this respect is similar to San Francisco high marshes (*Salicornia–Jaumea–Distichlis* in MacDonald 1977). With the exception of cordgrass, the salt marsh species listed in Appendix A attain their highest abundances in this vegetation type. The *Salicornia–Distichlis* type is depauperate, containing few if any other species, and is often found at the highest elevations or in hypersaline conditions caused by restricted tidal flows and impounding (Newton 1989).

Rare Species

In addition to the different plant associations represented in Humboldt Bay salt marshes, there are three rare salt marsh plant species: Humboldt Bay owl's clover (*Orthocarpus castillejoides* var. *humboldtiensis*), Point Reyes bird's beak (*Cordylanthus maritimus* ssp. *palustris*), and Humboldt

Fig. 3.4. Midlevel tidal salt marsh showing dense growth of pickleweed surrounding cordgrass culms. Note algal mat in foreground.

Bay gumplant (*Grindelia stricta* ssp. *blakei*). The owl's clover and the gumplant are endemic to Humboldt Bay, while the bird's beak is found from Morro Bay, San Luis Obispo County, California, to Coos Bay, Oregon. All three species are on the California Native Plant List 1b, a list containing species which qualify for State listing as rare and endangered throughout their range (California Native Plant Society 1984).

Humboldt Bay owl's clover is an annual member of the family Scrophulariaceae and likely employs haustorial connections as do other owl's clovers. It is distinguished by its two-celled anthers, purple bracts, and bright pink flowers on a large showy spike. Point Reyes bird's beak is also an annual species of the Scrophulariaceae and is known to employ haustorial connections. It is distinguished by the oblong shape of its leaves and bracts and by its purple flower. The Humboldt Bay gumplant is a perennial member of the family Asteraceae. It is distinguished by recurved phyllaries and reddish, erect stems.

The taxonomy of Point Reyes bird's beak is in question. Chuang and Heckard (1973) separated it from the southern California subspecies *C. m. maritimus* based on geography. An outlying population of a *Grindelia* that closely resembles Humboldt Bay gumplant also raises taxonomic questions. This population is located at approximately 457 m elevation on what is locally known as the Mattole Road; currently this population is not being treated as the rare subspecies.

Populations of the three rare species of Humboldt Bay are most common in the high elevation salt marshes, where the *Salicornia jaumea* and the *S. distichlis* associations are frequently disturbed or have been largely destroyed. The gumplant has wider habitat requirements and can be found along berms and dikes adjacent to as well as in salt marshes. Populations of the two annual species have been found to fluctuate widely from year to year (Koplin et al. 1984; Newton 1987). The role that disturbance plays in the distribution of all three species is not clear. Open habitat within a salt marsh tends to favor germination and growth. Therefore, disturbance, such as light trampling that decreases the cover of pickleweed without destroying the marsh, will encourage the growth of the rare species (Newton 1987, 1989).

Transitional Habitats

Brackish and Freshwater Marshes

The delineation between freshwater and brackish marshes is often not as well defined as the distinction between salt and brackish marshes. There is much overlap, with species common to brackish marshes occurring well into the freshwater marshes and riparian woodlands.

Brackish marshes form at the interface between the salt marshes and the freshwater marshes, and species composition slowly changes along the environmental gradients between them. Qualitative and quantitative descriptions of brackish and freshwater marsh vegetation can be found in Monroe (1973), Shapiro and Associates, Inc. (1980), Koplin et al. (1984), and Newton (1989).

Three plant species common throughout the various brackish marshes are salt rush (*Juncus lesueurii* var. *lesueurii*), pacific silverweed (*Potentilla egedii* ssp. *grandis*), and water parsley (*Oenanthe sarmentosa*). Most of the brackish marsh species appear to separate into monotypic patches probably because of vegetative expansion. The following brackish marsh assemblages are delineated by species composition and structure and defined by the dominant species.

The ecotone between the salt marsh and brackish marsh contains components of both, often including salt marsh species such as saltgrass and tufted hairgrass (*Deschampsia caespitosa*), either of which can dominate large areas, and brass buttons (*Cotula coronopifolia*), which occurs in disturbed locations. In areas that are inundated well into the growing season, three-corner (*Scirpus americanus*) or slough sedge (*Carex obnupta*) dominate. Saltmarsh bulrush (*Scirpus maritimus*) and large populations of the disputed Lyngby's sedge (*Carex lyngbyei*) are most often found in remnant sloughs and adjacent depressions that receive both tidal and freshwater input.

Josselyn (1983) reported that San Francisco brackish marshes are dominated by cattails (*Typha latifolia*) and *Scirpus acutus*. Many Humboldt Bay marshes contain *T. latifolia* at the brackish-freshwater interface, with large stands being quite common. However, while *Scirpus acutus* is found in Humboldt Bay marshes, it does not dominate large areas, except in the artificial ponds created as part of the Arcata marsh project.

Freshwater marshes often contain species similar to brackish marshes. One evident change is in the dominant rush species, which changes from salt rush to common rush (*Juncus effusus* var. *brunneus*; Koplin et al. 1984; Newton 1989). Species that occur in freshwater marshes but not brackish marshes include reed canary grass (*Phalaris arundinacea*), willowherb (*Epilobium watsonii* var. *franciscanum*), speedwell (*Veronica scutellata*), bedstraw (*Galium trifidum*), and monkey flower (*Mimulus guttatus* ssp. *litoralis*).

Small seeded bulrush (*Scirpus microcarpus*) can dominate large areas of freshwater marsh, as can cattails. Both of these species can also be found near brackish marshes. They may form monotypic stands or may grow in open stands with various incidental species occurring underneath.

Water parsley, marsh pennywort (*Hydrocotyle ranunculoides*), floating fern (*Azolla filiculoides*), duckweed (*Lemna* spp.), pondweed (*Potamogeton* spp.), mare's tail (*Hippurus vulgaris*), and water foxtail (*Alopecurus geniculatus*) grow in small ponds and relict freshwater sloughs.

Diked Seasonal and Grazed Wetlands

By far the largest contributor to the loss of tidal wetlands in Humboldt Bay is the diking associated with agricultural development (see Fig. 2.4). While these grazed seasonal wetlands afford winter habitat to waterfowl, their plant associations are largely dominated by introduced grass species, with few species unique to brackish and freshwater wetland systems. Most of the area currently converted to agricultural land was reclaimed between 1880 and 1910. The salt marsh habitat is permanently altered by these activities, resulting in dramatically different species composition. Salt marsh species remain only along relict sloughs, tidally influenced drainages, and isolated hypersaline ponds. Quantitative vegetation analysis of the grazed seasonal wetlands can be found in Koplin et al. (1984) and Newton (1989).

The agricultural areas are dominated by introduced grass species such as velvet grass (*Holcus lanatus*), annual bluegrass (*Poa annua*), perennial and annual ryegrass (*Lolium perenne* and *L. multiflorum*), vernal grass (*Anthoxanthum odoratum*), bentgrass (*Agrostis tenuis* and *A. stolonifera*), orchard grass (*Dactylis glomerata*), meadow fescue (*Festuca arundinacea*), red brome (*Bromus rubens*), and blando brome (*Bromus mollis*). Other herbaceous species commonly associated with these areas include cat's ear (*Hypochoeris radicata*), dandelion (*Taraxacum officinale*), perennial trefoil (*Lotus corniculatus*), and curly dock (*Rumex crispus*). Common clovers are creeping white clover (*Trifolium repens*) and cow's clover (*T. wormskioldii*). Areas within the pastures often support dense stands of common rush. In the shallow freshwater drainage ditches or depressions, rush (*Juncus* spp.), spikerush (*Eleocharis macrostachya*, and occasionally *E. bella* and *E. acicularis*), water foxtail, and pacific silverweed dominate.

Willow Swamps and Riparian Woodlands

Two major types of riparian habitats, willow swamps and riparian woodlands, are present around Humboldt Bay. They are distinguishable from each other by species composition and structure, but they often intermix, with the willow swamps forming the edge of a riparian woodland. More specific information on these vegetation types can be found in Monroe (1973), Shapiro and Associates, Inc. (1980), Koplin et al. (1984), and Newton (1989).

Riparian woodlands occur in areas that receive perennial to annual fresh water; therefore, the species composition is more closely linked to freshwater marshes than to brackish marshes. Remnants of these woodlands occur at the base of conifer forests, or of what was historically forest, around the perimeter of the bay. The dominant tree species are red alder (*Alnus oregona*) and willow (*Salix lasiandra*), which can attain heights of 20 m. The understory can be open, usually from grazing pressure, but more often is closed.

The shrub layer is usually composed of willow species similar to those of the swamps, and the herbaceous layer contains species similar to those of freshwater marshes. In addition, the shrub layer usually contains salmon berry (*Rubus spectabilis*), cascara sagrada (*Rhamnus purshiana*), and elderberry (*Sambucus callicarpa*). The herbaceous layer, which is often over 2 m in height, includes skunk cabbage (*Lysichiton americanum*), slough sedge, water parsley, watercress (*Nasturtium officinale*), chain fern (*Woodwardia fimbriata*), lady fern (*Athyrium filix-femina*), small-seeded sedge, and mannagrass (*Glyceria declinata*).

Willow swamps are located around the edges of freshwater and brackish water marshes and in dune hollows. The most common species are dune willow (*Salix piperi*) and Hooker's willow (*Salix hookerana*), with an occasional wax myrtle (*Myrica californica*) reaching about 7 m in height. The understory is most often related to the adjacent herbaceous marsh. Commonly associated are blackberry and himalaya berry (*Rubus vitifolius* and *R. procerus*), slough sedge, salt rush, common rush, and cattail.

Eelgrass Beds

The eelgrass bed is an important marine habitat type in Humboldt Bay. Arcata Bay and South Bay combined have 1,221 ha of eelgrass beds, with 435 ha in Arcata Bay and 786 ha in South Bay (Harding and Butler 1979). In total, eelgrass beds account for about 20% of the intertidal habitat of the bay. Eelgrass beds in Arcata Bay are not as dense as those of South Bay, a fact apparently related to the dredging for oysters on commercial beds in Arcata Bay (Waddell 1964). Eelgrass is characteristically found near the level of mean low water in Humboldt Bay, and it exerts an important influence on the sedimentary regime, distribution of infaunal organisms, and occurrence of fish and birds.

Phillips (1984) included Humboldt Bay eelgrass flats in his comprehensive discussion of eelgrass meadows of the Pacific Northwest of the United States. He recognized Humboldt Bay as having one of the three largest stands of eelgrass in the region (the other two were Padilla Bay in northern Washington and the Willapa Bay–Grays Harbor area in southwestern Washington). The features of the eelgrass beds at Humboldt Bay are unique.

Eelgrass at Humboldt Bay grows in muddy to silty sediments and has a significant influence on the sedimentary regime in parts of the bay where growth is luxuriant. The sediments in the beds are very fine (Thompson 1971), particularly in South Bay, making it difficult to sample infaunal and epifaunal organisms except from boats.

Marsh Restoration

Marsh restoration as mitigation for wetland destruction is becoming increasingly common in California and on Humboldt Bay. Of the monitored wetland restoration projects on Humboldt Bay (Koplin et al. 1974; Miner and Moore 1980–87; Stopher et al. 1981; Base 1982; Claycomb 1983; Gearheart 1983; Jacobson 1984; Newton 1989), most have been left to revegetate naturally. The common trend is for the area to experience a dramatic die-off of the previously dominant species, followed by increased importance of opportunistic exotic halophytes, such as fat hen (*Atriplex patula* ssp. *hastata*), sicklegrass (*Parapholis incurva* and *P. strigosa*), brass buttons, and rabbitfoot grass (*Polypogon monspeliensis*). Over time, the appro-

Table 3.1. *Marsh restoration projects on Humboldt Bay.*

Project name	Date	Size (acre)	Preconstruction conditions	Present status	Monitoring reports
Park Street	1979	9.5	Old log pond with some marsh vegetation	Saltwater marsh	Claycomb 1983 Chamberlain 1988
Elk River	1980	20	Wetland with restricted tidal flow and high areas	Increasing dominance by *Salicornia*	Stopher et al. 1981 Miner and Moore 1980–87 Base 1982
Arcata Marsh project	1981	175	Largely intertidal mudflat	Freshwater ponds	Gearheart 1983
Elk River Wildlife Area	1982	124	Grazed seasonal wetlands, brackish marsh, uplands, and riparian	Seasonal freshwater wetlands, tidal marsh riparian, and uplands	Koplin et al. 1984 Chrisney 1988 Newton 1989
Bracut Marsh	1981	6	Filled tidal wetland	Open area and salt marsh	None formal
Second Slough	1986	1	Salt marsh and upland berm	Salt marsh	Newton 1989

priate salt marsh species become dominant on the site. However, the presence of vegetation alone should not be construed as a decisive measure of success. Other ecological factors need to be considered, including vegetational structure and composition, soil conditions, invertebrate populations, and bird and mammal usage. Table 3.1 summarizes the data from the Humboldt Bay restoration and mitigation projects.

Invertebrates

Invertebrates of Marshes

Both the diversity and biomass of benthic invertebrates in the marshes of Humboldt Bay are relatively low (Appendix B). The abundant plant cover present in the marsh is in a state relatively inedible by benthic invertebrates, which are deposit feeders and grazers of microalgae on the surface of the marsh. MacDonald (1967, 1969a, 1969b) sampled invertebrates in a number of salt marshes along the Pacific coast of North America, excluding insects. Cameron (1972) and Lane (1969) used different methods to sample insects in marshes at San Francisco Bay, but insects of Humboldt Bay salt marshes have been sampled only in a preliminary manner (Boyd 1982). Insects probably use more marsh plant production than benthic invertebrates do, but even so, only a small part of the plant production is directly consumed (Teal 1962; Cameron 1972).

Benthic invertebrate populations in marshes are dominated by gastropods, crustaceans, and polychaetes. Species are present year-round and fluctuate little in abundance seasonally (Boyd 1982). The gastropods *Assiminea californica* and *Ovatella myosotis* are commonly encountered within the marsh, and *Alderia modesta* is found on the fringes of marshes at Humboldt Bay. Considerably less abundant at Humboldt Bay is the gastropod *Littorina newcombiana*, a species reportedly more common in salt marshes of Oregon (MacDonald 1977). Four infaunal polychaete species are found in the topmost sediments of the low marsh and at midrange elevations—*Eteone californica*, *Streblospio benedicti*, *Polydora ligni*, and *Pseudopolydora kempi*—and all probably deposit microflora feeders or grazers on the immediate surface of marsh sediments. Crustaceans in the marshes are a mixture of those with greater affinities to the adjacent uplands and species that are more typically found on the upper mudflats of the bay. *Armadilloniscus coronocapitalis*, *Porcellio* sp., and *Littorophiloscia richardsonae* are three isopod species from the uplands that have been found in the marshes. *Gnorimosphaeroma oregonensis*, *Anisogammarus confervicolus*, and *Corophium spinicorne* are crustacean species more characteristic of high intertidal mudflats adjacent to the marshes. Only the amphipod *Orchestia traskiana* reaches its greatest abundance in marshes, rather than in adjacent habitats. In other coastal marshes in California, the green shore crab *Hemigrapsus oregonensis* frequently burrows into the banks of marsh channels, but only occasionally lives in Humboldt Bay marshes. The pattern of species occurrences among the benthic invertebrates supports the concept of the marsh as a transitional environment between the uplands around the bay, and the tidally emergent mudflats that form much of Humboldt Bay.

The importance of the marshes in the trophic economy of the bay is not well understood. A variety of birds find refuge in the marshes at high tides (Springer 1982), but many species feed on intertidal flats during low tides as well. Fish are known to move onto the flooded marshes at high tide, but the importance of feeding activities there has been difficult to assess (Chamberlain 1988). The major contribution of the marshes to the trophic economy of the bay is the export of detrital plant material. Unfortunately, the significance of this detrital export is difficult to estimate. The plant material is first subjected to microbial decomposition and becomes available to potential consumers in the form of dissolved organic carbon (DOC), and smaller particles of plant material that are colonized by bacteria. Sediments of the adjacent mudflats are rich in organic material, some of it originating in the marshes. This organic matter is certainly significant in providing food to the deposit- and suspension-feeding animals on and in the mudflat sediments.

Invertebrates of Intertidal Sand and Mud Flats

The physical environment of the bay exerts a profound impact on the plants and animals that occupy the intertidal habitats. The bay covers a large enough area (62.4 km^2; Proctor et al. 1980) to present a diversity of habitat types, from those that are wholly marine in salinity conditions to others that are typically estuarine for a significant period of time each year. The sedimentary environment is similarly diverse, with a general pattern of coarse sands and shell fragments in the entrance area of the bay, grading both north and south into finer sands and then muds (with various percentages of sand), and finally silts in the upper reaches of both South Bay and Arcata Bay (Thompson 1971). The salinity regime also exerts a profound effect on the settlement, survival, and growth of benthic invertebrates. The complex pattern of species distribution within Humboldt Bay is thus the result of many factors, the most significant of which are relative intertidal height (usually expressed in relation to MLLW, the 0.0 tidal datum), sedimentary structure of the substrate that animals live on or in, and seasonal salinity regime. Two major intertidal habitat types exposed on a daily basis are high intertidal flats from approximately 2.15 m to 1.16 m above MLLW, and low intertidal flats from 45 cm to 116 cm below MLLW.

High Intertidal Flats

Primary producers on the surface of the high flats are a variety of microscopic and macroscopic algae (see Appendix A). Relatively little is known about the microscopic algae, but they do include phytoplankton species that settle from the water column during high tides and remain on the surface of the flats, benthic diatoms, and some blue-green algae (Cyanobacteria). Surface sediments that are examined microscopically are always rich in these microscopic forms, but relative abundances of the particular species involved have not been determined. The two major species of macrosopic algae present are *Enteromorpha intestinalis* and *Ulva* sp., with *Fucus distichus* growing on debris, emergent rocks, and even larger pebbles.

The abundance of macroalgae on the high flats fluctuates greatly on a seasonal basis. The largest standing stocks are observed during the summer and early fall, usually declining rapidly with the onset of winter storms in late fall or early winter. The predominantly northwesterly winds accompanying these storms produce wave turbulence in surface waters that dislodge the algae and transport plant material to other bay locations or to nearshore habitats outside the bay. In these various sites, the macroalgae become part of the detritus foodweb of the bay and nearshore waters.

Polychaetes, crustaceans, and mollusks are the significant invertebrates of the high intertidal flats. A large number of fish and birds feed on these invertebrates, moving onto the flats according to the tidal regime. The abundant populations of invertebrates support impressive populations of vertebrate predators, suggesting that the secondary (animal) production of the flats is relatively high. Just below the line of salt marsh vegetation, the burrows of both small and larger invertebrates are apparent in examining the surface of the mudflat. Complex, deep burrows of ghost shrimp (*Callianassa gigas*, with only an occasional *C. californiensis*) are found on the high flats at many locations in both Arcata Bay and South Bay. These animals are relatively long-lived and, once the adults have dug their deep burrows, probably secure from predation. Much more abundant smaller crustaceans are found on the surface of the flats associated with macroalgae, finding refuge under debris, and in shallow, impermanent burrows at the surface of the flats. Fish feed on these crustaceans during high tides (Toole 1978) and shorebirds probably consume them at low tide (Carrin 1973).

The most abundant organisms of the high flats are a variety of polychaetes that tend to be distributed widely in the bay. Some differences in polychaete abundance are determined by seasonal salinity regimes near creeks that enter the bay. Smaller polychaetes reproduce annually, seldom reach lengths of more than a few centimeters, and are probably fairly short-lived (Dales 1967). Capitellids, spionids, and syllids are the most abundant species encountered (Appendix B). Under conditions of varying salinity, oligochaetes can also be somewhat abundant. Toole (1978) found that juvenile English sole fed on capitellid polychaetes as an increasing percentage of their diets during the first year of growth in Humboldt Bay. Shorebirds are also undoubtedly significant predators of these high intertidal polychaete species (Carrin 1973), but quantitative or experimental data to demonstrate the relative importance of these worms in shorebird diets are lacking.

The small bivalve *Transennella tantilla* is abundant on the high mudflats. This species is found just below the surface of the flat and is probably important in the diets of both fish and shorebirds (Carrin 1973; Collins 1978). *Macoma nasuta* is occasionally found on the high flats but is typically more abundant on lower intertidal flats. The small grazing gastropod *Alderia modesta* feeds on the macroalgae or microalgae on the surface of the flats, particularly near marsh vegetation. In areas where creeks enter both Arcata Bay and South Bay, and when estuarine conditions prevail at least seasonally, *Mya arenaria* can be abundant on the higher flats. Recruitment to these populations has been sporadic when studied elsewhere (Warwick and Price 1975) and seems to follow a similar sporadic recruitment pattern at locations in Humboldt Bay (Simel 1980). In the estuarine areas of the bay, the small bivalve *Macoma balthica* occurs and can be locally abundant.

Barnacles (*Balanus glandula, Chthamalus dalli*), algae (*Fucus distichus, Enteromorpha intestinalis*), and the native oyster *Ostrea lurida* colonize emergent rocks, logs, and small bits of debris on the high flats. The overall importance of these small patches of solid substrate to the overall economy of the bay is probably minor.

Low Intertidal Flats

The character of the fauna and flora of the mud and sandflats in the bay changes at about 91 cm to 61 cm above MLLW. There is considerably less exposure during low tides at these elevations, and the abundance of infaunal organisms increases considerably. Many species that occur to -61 cm in the lower intertidal and subtidal sediments of the bay first occur on low intertidal flats. Many plant and invertebrate species occur on these flats (see Appendix B).

The sedimentary environment in different parts of the bay affects the distribution of low intertidal plants and animals on the mudflats. Typically sands and gravels predominate in the central part of the bay, grade gradually into fine sands, and eventually into muds and silts away from the central part of the bay into South Bay and Arcata Bay. There are also small areas of silt deposition near the mouths of creeks and rivers that enter the bay, often accompanied by an estuarine salinity regime. Midintertidal silts and sands do not allow the free movement of water into the sediments, resulting in an anoxic condition (with the characteristic accumulation of H_2S) that develops just below the sediment surface. The animals living in sediments must possess appropriate behavioral or physiological adaptations to withstand these anoxic conditions. These adaptations can involve burrows that open to the surface (e.g., *Upogebia pugettensis, Pista pacifica, Urechis caupo*), feeding structures that have a dual function in respiration (phoronids, pectinarid polychaetes), or specialized respiratory pigments (several mollusks and polychaete worms).

Sandy substrates at low intertidal levels in the central portion of the bay contain a rich fauna dominated by mollusks and polychaetes. During any low tides of zero or lower, these areas of the bay are visited by many people in search of edible clams; they most commonly take gaper clams (*Tresus capax*, occasionally *T. nuttallii*), Washington clams (*Saxidomus nuttalli, S. giganteus*), littleneck clams (*Protothaca staminea*), and cockles (*Clinocardium nuttallii*). *Tresus* spp. are more common in sandy substrates, and *Saxidomus* spp. in muddier sands, but there is no clear demarcation line between the two. A wide variety of smaller bivalves (including several tellinids) also occurs at low intertidal levels. The siphons of these smaller bivalves can form a significant component in the diets of bottom feeding fish (Collins 1978; Toole 1978).

The polychaete worms of these substrates are abundant and important in the diets of fish and shorebirds. Both sandy and muddy substrates contain large nereids that many who fish on the bay use as bait. Other polychaetes—capitellids, cirratulids, spionids, terebellids, and oweniids—are smaller in size but often number up to several thousands per square meter, depending on the part of the bay where samples are taken (Boyd et al. 1975; Bott and Diebel 1982).

Invertebrates of Eelgrass Beds

Phillips (1984) indicated a lack of definitive information about distinctive assemblages of infaunal species in sediments of eelgrass beds. Unpublished investigations of infaunal organisms in eelgrass beds at Humboldt Bay and a survey of the literature suggest that eelgrass sediments do not usually contain unique assemblages of infaunal organisms. The sediments do contain a rich fauna of mollusks and polychaetes that flourish in this biotope. The polychaetes are mostly deposit feeders, suggesting that they feed on decaying vegetation and sediments rich in organic matter. The mollusks probably also benefit from the dissolved organic carbon released from eelgrass blades, roots, and algal epiphytes (Phillips 1984).

The animals and plants found on eelgrass blades represent a distinctive assemblage of organisms. Dykhouse (1976) found that five species of invertebrates were dominant occupiers of blade space on eelgrass in South Bay: the hydrozoans *Obelia longissima* and *Tubularia marina*, the bryozoan *Hippothoa hyalina*, and the colonial ascidians *Diplosoma macdonaldi* and *Botrylloides* sp. None of these species is restricted to eelgrass blades in Humboldt Bay, but populations flourish seasonally on the blades. The aplysid gastropod *Phyllaplysia taylori* is highly adapted in coloration and morphology for growth and survival on eelgrass blades. The larvae undergo direct development (Bridges 1975) and begin browsing on the surfaces of eelgrass blades as juveniles. This is perhaps the only species in the bay that can be said to depend exclusively on eelgrass blades as a habitat, although even in this species individual animals are sometimes found on other substrates. The relationship between eelgrass and its epiphytes is facultative in Humboldt Bay, but populations growing on the blades are certainly much increased by seasonally flourishing there.

A wide variety of motile invertebrates and fish frequent eelgrass meadows of the Pacific Northwest (see Phillips 1984). In Humboldt Bay, three species of commercially important crabs, Dungeness crab (*Cancer magister*) and rock crabs (*C. antennarius* and *C. productus*) are relatively common in dense eelgrass beds of South Bay. The rock crabs have recently been the basis for a small commercial fishery, while Dungeness crab is the basis of a large fishery in coastal nearshore waters. Dungeness crabs are taken regularly in the bay by sport fishing. Other crab species, various shrimps, amphipods, nudibranchs, brittle stars, nemerteans, flatworms, sea cucumbers, snails, and flatfishes are also commonly found in eelgrass beds of the bay.

Invertebrates of Subtidal Marine Habitats

The subtidal channels in the central part of Humboldt Bay were sampled in 1974 before a major dredging operation (Boyd et al. 1975) and again in 1980 (Bott and Diebel 1982) to determine the nature of recolonization of sediments after dredging. Little is known about the fauna of shallow, irregularly dredged channels in South Bay and Arcata Bay. Thompson (1971) described the sediments in shallow channels as containing progressively more silt in their upper reaches, and the different sediment composition can be expected to exert some influence on the composition of infaunal assemblages.

Boyd et al. (1975) enumerated 141 species of invertebrates taken at 65 stations in Entrance Bay, North Bay Channel, Samoa Channel, and Eureka Channel. With the exception of the Entrance Bay stations, Bott and Diebel (1982) revisited 58 stations in the same area and enumerated 188 species of benthic invertebrates. In both surveys, polychaetes dominated the fauna, followed by mollusks and crustaceans. These three groups accounted for approximately 90% of the species present in 1974 and 1980. Polychaetes were the most numerous, accounting for 49% of all species collected in 1974 and 54% of all species taken in 1980. Mollusks accounted for 19% of the species in 1974 and 21% of the species in 1980. About 22% of the species taken in 1974 were crustaceans, but this group declined slightly to 16% of the species in 1980. Benthic organisms were classified as "characteristic" of the sampled area if they occurred at 50% or more of the sampled stations. There were nine polychaete species, six mollusk species, two nemertean species, and a phoronid that fit this criterion in both the 1974 and 1980 sampling periods (Table 3.2). The presence and abundance of these and several other species collected in both surveys indicates that the faunal composition of benthic subtidal assemblages

Table 3.2. *Characteristic species (taken at >50% of stations sampled) in benthic subtidal habitats of the central portion of Humboldt Bay in 1974 and 1980 (Boyd et al. 1975; Bott and Diebel 1982).*

Family	1974	1980
Polychaetes	*Glycinde polygnatha*[a]	*Amaeana occidentalis*
	Haploscoloplos elongatus[a]	*Eumidia bifoliata*
	Lumbrineris tetraura	*Exogone lourei*
	Lysilla labiata[a]	*Glycinde polygnatha*[a]
	Mediomastus californiensis[a]	*Haploscoloplos elongatus*[a]
	Owenia collaris[a]	*Lysilla labiata*[a]
	Phloe tuberculata[a]	*Mediomastus californiensis*[a]
	Platynereis bicanaliculata[a]	*Nephtys caecoides*
	Polydora socialis[a]	*Ophelia assimilis*
	Spiophanes bombyx[a]	*Owenia collaris*[a]
	Spiophanes berkeleyorum	*Phloe tuberculata*[a]
		Platynereis bicanaliculata[a]
		Polydora socialis[a]
		Sphaerosyllis californiensis
		Spiophanes bombyx[a]
		Tharyx monilaris
		Tharyx multifilis
Crustaceans	*Crangon nigricauda*	None
	Diastylis sp.	
	Lamprops sp.	
	Photis brevipes	
	Protomedia nr. *articulata*	
	Tritella pilimana	
Mollusks	*Adula diegensis*[a]	*Adula diegensis*[a]
	Clinocardium nuttallii[a]	*Alvinia compacta*
	Lyonsia californica	*Clinocardium nuttallii*[a]
	Macoma inquinata	*Mysella tumida*[a]
	Mysella tumida[a]	*Protothaca staminea*[a]
	Protothaca staminea[a]	*Transennella tantilla*[a]
	Saxidomus sp.	*Tresus capax*[a]
	Transennella tantilla[a]	
	Tresus capax[a]	
Nemerteans	*Paranemertes californica*[a]	*Cerebratulus californiensis*
	Tubulanus pellucidus[a]	*Paranemertes californica*[a]
		Tubulanus pellucidus[a]
Phoronids	*Phoronopsis viridis*[a]	*Phoronopsis viridis*[a]

[a] Species found in >50% of samples in both 1974 and 1980.

in the bay is relatively constant, even following significant disturbances. There were some surprising findings in the 1980 survey, however. In that year, no crustacean species were found at 50% or more of the sampled stations, whereas six relatively motile crustacean species had been characteristic of the sampled stations in 1974. Although these motile species appear to be able to move freely over subtidal substrates and quickly recolonize exposed sediment surfaces, this apparently had not occurred throughout the area sampled. The six crustacean species characteristic of all samples in 1974 were collected again in 1980 but were more sporadic in occurrence. This could reflect sampling error (possible), insufficient time for crustacean species to fully reoccupy dredged areas (unlikely), or greater habitat heterogeneity than had been present prior to dredging (probable). The five mollusk species that occurred at more than 50% of the stations in 1974 and 1980 may represent remnant populations. These animals, deeply burrowed into the sediments, would remain in areas where dredging had taken place. Their presence appears to indicate little change, but actually the absence of motile and selective crustaceans indicates that a major change had occurred. The crustacean and polychaete distribution patterns indicate the existence of more restricted and heterogeneous sediment types.

A significant change in the faunal composition of the dredged channels was the increased abundance of the polychaete *Owenia collaris*. This species was present throughout the study area in 1974, but accounted for over half the number of individual animals collected at all stations in 1980. Apparently, *Owenia* was able to recolonize the newly dredged areas of the channels with a high degree of success, becoming the numerically dominant species throughout the area.

In both 1974 and 1980, the distribution of benthic animals was related to the sediment composition in the central part of the bay. In general, "clean sands" with little or no silt present contained a species-poor assemblage with the polychaete *Glycera oxycephala*, the bivalve *Tellina nuculoides*, and the sand dollar *Dendraster excentricus* in both sampling periods. In 1974, two other polychaete species, *Ophelia assimilis* and *Spiophanes bombyx*, were also present in the assemblage. It seems unlikely that the character of the sediment itself determines the fauna contained, but rather, that the sediment composition and the fauna are both responding to some other determining factor, probably the speed of water movement over the bottom. Water currents of relatively high speed transport smaller sediment particles away from heavier sand particles, and also require that sessile animals possess adaptations that allow them to remain in place. Sand dollars possess adaptations that allow individuals to remain stably positioned in fairly dynamic benthic habitats (Chia 1973), and *Tellina nuculoides* occupies shallow inshore habitat not subject to direct forces of bottom currents. The polychaete *Glycera oxycephala* is more difficult to characterize in relation to bottom currents and the sedimentary regime. Morphologically, the proboscidial organ would suggest a predatory life style, with small crustaceans and other small polychaetes as prey. Alternatively, the species could be a deposit feeder, but the lack of much organic matter in the sands would argue against that conclusion.

The species-poor assemblage was found in 1974 and 1980 off the southwestern tip of Indian Island at the confluence of the Samoa and Eureka channels. Another species-poor area lies between the North Spit and the Elk River Spit, where North Bay Channel is narrowly confined as it joins Entrance Bay (Fig. 1.1). In both areas identified as species poor in 1974, dredging activities in 1977–78 appear to have resulted in the expansion of the assemblage (Fig. 1.1). The species-poor area between North Spit and Elk River Spit was significantly larger in 1980 than it had been in 1974, and the area to the southwest of Indian Island had also increased in size following dredging.

Other areas in the central part of the bay have been characterized as species-rich or of mixed faunal composition. These areas had more silt present in sediments, or are mixed sediments with various amounts of silt, gravel, and biogenous material. The species-rich assemblage contains more species and a greater abundance of organisms at each station. Polychaetes and mollusks (Table 3.2) are characteristic of species-rich areas. The feeding types of the polychaetes in particular indicate that suspension feeding and surface-deposit feeding are the successful trophic strategies in areas occupied by this assemblage. These strategies suggest moderate to slow-moving currents over bottom areas where the assemblage is encountered, with resultant deposition of finer particles of sediment and organic matter during periods of low tidal water movement.

It would be of considerable interest to extend investigations of benthic assemblages into the less frequently disturbed shallow channels of Arcata Bay and South Bay. It is known that commercially important fish species move into these channels (Misitano 1970) and probably feed there (Toole 1978). It is not known if the faunal assemblages of the shallow channels are similar to those found in the deeper channels of the central bay. Maintaining the conditions necessary to support abundant populations of benthic invertebrates is directly related to the continuation of commercial fisheries for English sole and speckled sanddabs.

Mariculture and Introduced Species

A number of attempts have been made over the past century to introduce potentially valuable invertebrates into Humboldt Bay. The most notable success has been the introduction of Pacific oysters (*Crassostrea gigas*), grown most extensively on beds in Arcata Bay. A number of other introduced species failed to flourish on a commercial basis (e.g., the Atlantic oyster *Crassostrea virginica* and the Atlantic quahog, *Mercenaria mercenaria*). With the introduced species have come a variety of incidental species that have sometimes flourished, although the species with which they originally were introduced have had to be maintained by continual introduction. Introduced estuarine species are not nearly as common in Humboldt Bay as they are in other Pacific coastal bays, probably because true estuarine conditions prevail in only a part of the bay during above-normal runoff periods. San Francisco Bay in particular has come to support a veritable potpourri of introduced estuarine species from around the world as a result of the more extensive estuarine conditions, the commercial shipping entering the bay from all over the world, and numerous attempts at culturing exotic species. The invertebrate fauna there is now dominated by non-native species (Carlton 1979). In contrast, relatively few exotic species have become successfully established in Humboldt Bay.

Oyster culture in Arcata Bay is carried out primarily on raised beds that are harvested by dredging. There is also a small tray culture and suspended lantern net operation in Mad River Slough, but that fishery is of minor economic significance compared to oysters taken from Arcata Bay. Oyster harvesting is the largest commercial fishery in the bay, with a yearly production of 397,000 kg and a market value of $1.7 million (Shapiro and Associates, Inc. 1980). Oyster culturing has apparently caused major changes in the biological communities of Arcata Bay, the most evident of which has been the reduction of eelgrass beds. The growth of eelgrass in Arcata Bay is sparse compared to growth in South Bay, apparently a result of oyster culture on the raised beds, with consequent reduction in bottom area on which eelgrass can grow. There has also been speculation that finer sediments are continually resuspended by harvesting oysters with dredges, with resulting increases in water turbidity and decrease in growth of eelgrass (Waddell 1964). Native bivalve species (notably littleneck clams, *Protothaca staminea*) also flourish in the oyster beds, but the biological character of Arcata Bay has obviously been modified by oyster-culturing activities.

The softshell clam (*Mya arenaria*) has been notably successful in estuarine areas of Arcata Bay and in a small area of South Bay near Whites Slough. It is not known whether this species was intentionally introduced or accompanied the introduction of some other species. It was often the practice in the late nineteenth and early twentieth centuries to pack seed cultch bearing young oysters in algae from the source area, and this apparently accounted for the introduction of many incidental species, softshell clams possibly among them. Softshells are relatively abundant in Mad River Slough and along the northern intertidal areas of Arcata Bay. The species is able to reproduce in the bay (Simel 1980) and supports a small sport fishery.

A number of other less conspicuous species are apparently of foreign origin, although essentially nothing is known of their influences on the bay ecosystem. The snail *Ovatella myosotis*, found in salt marshes, is of Atlantic coastal origin. Pilings in the bay are eventually riddled by gribbles, the Atlantic boring isopods *Limnoria tripunctata* and *L. quadripunctata*. The polychaetes *Pseudopolydora kempi* and *Streblospio benedicti* were probably introduced to the bay. Although the Humboldt Bay fauna has not been greatly modified by these introductions, there is no doubt that many introductions have occurred as a result of commercial shipping activities and oyster culture. It would be difficult to assess now what impact these introductions have had on the bay ecosystem.

Fishes

Humboldt Bay has a diverse fish fauna composed of estuarine and marine forms. Appendix C, modified from Gotshall et al. (1980), and Shapiro and Associates, Inc. (1980), lists 110 species recorded for the bay.

Sharks and Rays

The most common sharks in the bay are the brown smoothhound (*Mustelus henlei*), the leopard shark (*Triakis semifasciata*), and the sevengill shark (*Notorynchus maculatus*). These sharks inhabit the deep tidal channels at low tide, but swim into small channels and over the mudflats to feed at high tide. Sharks are most numerous in the bay during the summer months. The bay supports a minor commercial fishery for the sevengill and leopard sharks, which are caught by hook and line and in drift gill nets. These sharks are quite palatable and some sport anglers specialize in bay shark fishing. The Eureka office of the California Marine Advisory Extension Service distributes a brochure on shark angling in Humboldt Bay. Sharks are high-level carnivores, but most species are omnivorous (Shapiro and Associates, Inc. 1980). Smaller inshore species (i.e., the brown smoothhound and leopard shark) feed largely on crustaceans and mollusks.

Bat rays (*Myliobatis californica*) are common in Humboldt Bay channels and over the mudflats at high tides. In bays and sloughs, bat rays feed heavily on clams, oysters, shrimp, and crabs (Baxter 1960). Commercial oyster beds in Arcata Bay are commonly fenced or "staked" to protect them from bat rays, which can severely damage an oyster bed in a short time. Humboldt Bay oyster companies are periodically given special reduction permits to seine channels adjacent to oyster beds to remove rays. Bat rays are often caught by sport anglers. The meat filleted from the pectoral fins or wings is edible, but most anglers catch and release rays because they are unaware of their palatability.

Herrings and Anchovies

Humboldt Bay is an important spawning and nursery area for the Pacific herring. Adult herring enter the bay and spawn from December to March. In winters 1974–75 and 1975–76, 80% of all spawning in the bay took place in eelgrass beds in Arcata Bay (Fig. 3.5; Rabin and Barnhart 1986); spawning herring biomass was estimated at 337 t in 1974–75 and 210 t in 1975–76. Herring larvae, collected from January through May, were second in abundance in a 1969 larval survey of Humboldt Bay (Eldridge and Bryan 1972). Herring juveniles have been collected in the bay by trawl and seine during the spring, summer, and fall (Samuelson 1973; Sopher 1974; Waldvogel 1977).

There is commercial gill-net fishing each winter in Humboldt Bay for adult herring, primarily to obtain roe for export to Japan (Barnhart 1986a). The quota since 1983 has been 54 t and each year the catch approaches the quota. The fishery is located primarily in Arcata Bay.

Herring eggs deposited on eelgrass are consumed by birds, primarily gulls, *Larus* spp. (Spratt 1981; Barnhart 1986a), although bird predation in Humboldt Bay is probably not significant (Rabin and Barnhart 1986). Subadult and adult herring in schools appear to be one of the major forage fishes of the sea, providing food for salmon, sharks, lingcod, waterfowl, sea lions, and whales (Hart 1973).

Schools of subadult and adult northern anchovy (*Engraulis mordax*) migrate into Humboldt Bay in spring and summer, primarily to feed (Peters 1970; DeGeorges 1972; Sopher 1974; Waldvogel 1977). Estimates of summer (July–August) biomass of anchovies in Humboldt Bay for the years 1976, 1979, 1980, 1983, 1984, and 1986 averaged 82 t (Barnhart 1986b). These fish are important as food for other fish and birds; in some years anchovy schools apparently attract salmon into the bay, providing a salmon sport fishery (Monroe 1973; Warner 1982).

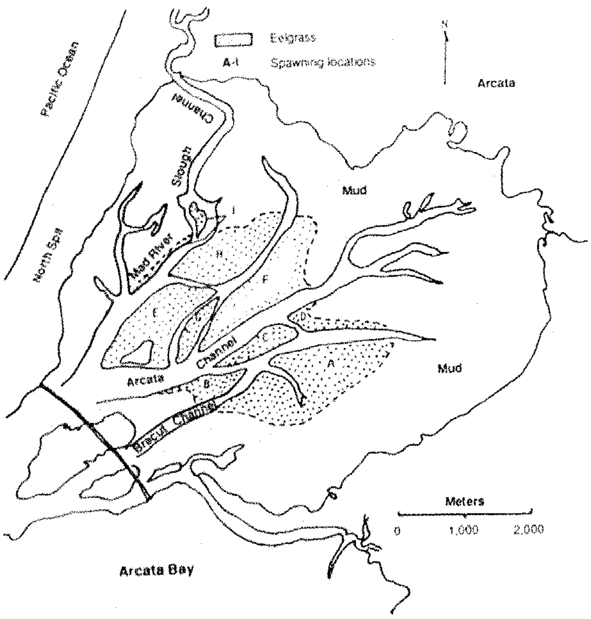

Fig. 3.5. Eelgrass and Pacific herring spawning distributions in Arcata Bay during the winters of 1974–75 and 1975–76 (from Rabin and Barnhart 1986).

There is a live-bait fishery for northern anchovy by albacore (*Thunnus alalunga*) fishermen in Humboldt Bay, with a quota of 13.6 t and a season of September 1–December 1. The number of albacore-bait boats that fish the bay varies considerably from year to year.

Misitano and Peters (1969) examined the stomach contents of herring and anchovy from Humboldt Bay. Anchovy fed largely on benthic copepods, other benthic crustaceans, and diatoms (69% of the total diet), whereas herring fed predominantly on pelagic copepods (69% of the total diet).

Salmons and Trouts

Chinook salmon (*Oncorhyncus tshawytscha*), coho salmon (*O. kisutch*), rainbow trout (*O. mykiss*), and cutthroat trout (*O. clarki*) are anadromous species that enter Humboldt Bay tributaries as adults to spawn. The most important tributary streams are Jacoby Creek and Freshwater Creek in Arcata Bay, Elk River in Entrance Bay, and Salmon Creek in South Bay. Several bay tributaries support remnant resident populations of cutthroat trout. Bay tributaries historically supported larger populations of anadromous fish that contributed significantly to a bay fishery, but stream-habitat degradation has severely limited these populations (Monroe 1973). Young salmonids, after spending varying lengths of time in fresh water, migrate into saltwater to grow further and mature. Humboldt Bay provides a nursery area for juvenile salmonids (Monroe 1973).

Since 1964 the Humboldt Fish Action Council, a citizens' action group, has worked with the California Department of Fish and Game, Humboldt County, the California Conservation Corps, and the Pacific Lumber Company on a number of salmon and steelhead rearing and stocking programs to restore fish populations in the Humboldt Bay area (Miller 1982). The Council currently has a fish trap and fish-rearing facilities on Freshwater Creek. Since 1963, the Arcata Wastewater Aquaculture facility has operated on Arcata Bay. Several ponds adjacent to a city of Arcata's large wastewater oxidation pond are used to rear salmonids for release into Humboldt Bay. Some fish are released directly into the bay and others into nearby Jolly Giant Creek. A projected system will use an existing 6.9 ha recreational lake to produce a totally self-sustaining run of salmonids to be released into a small, artificially created drainage on Arcata Bay.

At present, the recreational fishery for salmonids on Humboldt Bay consists largely of salmon fishing during the summer in Entrance Bay, particularly from the jetties or by boat between the jetties. However, large numbers of salmon anglers leave from the bay to fish nearshore waters outside. Smith (1966) estimated that 10,000–15,000 anglers operating from about 5,000 boats fish out of Humboldt Bay annually. The Pacific Fishery Management Council (1986) reported that in 1971–75, recreational salmon anglers fished an average of 40,000 angler-days annually out of Humboldt Bay and averaged about 10,000 chinook salmon caught. Salmon anglers took 26,000 chinook in 1985, fishing from ports on Humboldt Bay. Three licensed party boats operate from

Fig. 3.6. Salmon caught by party boat anglers fishing outside Humboldt Bay.

Humboldt Bay; the majority of their clients fish for salmon (Fig. 3.6). One party boat operator estimated that he charters 1,000–1,500 anglers each season (Walters 1982).

Commercial fishing has historically been a major industry for the Humboldt Bay area and salmon fishing has always sustained a large portion of the commercial fishery. From 1971 through 1975, fishermen averaged 276,000 salmon annually landed at Eureka docks (Pacific Fishery Management Council 1986). In recent years, however, landings have been greatly reduced due to declines in salmon populations and coincident restrictions on commercial seasons.

Smelts

Smelts are important forage fishes in Humboldt Bay. Longfin smelt (*Spirinchus thaleichthys*) larvae were third in abundance in a larval fish survey of Humboldt Bay (Eldridge and Bryan 1972) and longfin smelt juveniles and adults were fourth in abundance in a trawl survey of Arcata Bay (Sopher 1974). The most abundant incidentally caught fish while fishing for anchovies with a lampara seine were three species of smelts: longfin, night (*S. starksi*), and surf smelt (*Hypomesus pretiosus*; Waldvogel 1977). The longfin smelt, classified as weakly anadromous by Fry (1973), probably enter Humboldt Bay tributaries to spawn. Smelt in marine waters feed on small crustaceans, but will eat a variety of polychaete worms, larval fish, jellyfish, and other suitable food organisms (Shapiro and Associates, Inc. 1980). They, in turn, are taken by predatory fishes, seabirds, and marine mammals.

Surfperches

Seven species of surfperches are abundant or common in Humboldt Bay (Appendix C). In Sopher's 1974 trawl survey of Arcata Bay, these species accounted for 45% of the total catch and the shiner perch (*Cymatogaster aggregata*), the smallest species, ranked first numerically. A South Bay trawl survey gave similar results; the same seven surfperch species made up almost 50% of the total catch and the shiner perch accounted for 31% of the total (Samuelson 1973).

Surfperch species are important recreationally in Humboldt Bay and are caught from shore, piers, jetties, and skiffs all year. A sport-fish survey of Humboldt Bay (1957–60) revealed that surfperch made up almost 53% of the catch (Gotshall 1966). From March to June most of the redtail surfperch (*Amphistichus koelzi*) catch in Humboldt Bay is females whereas from July to October the sex ratio is 1:1 (Ngoile 1978). Female redtails enter estuaries in the spring to give birth to young (Miller and Gotshall 1965; Bennett and Wydowski 1977; Ngoile 1978).

There is also a minor commercial fishery for surfperches in Humboldt Bay, primarily for the redtail surfperch. These fish are captured by beach seine and hook and line. Surfperch landings for Humboldt Bay from 1981 to 1985 averaged 9,230 kg annually (California Department of Fish and Game, Eureka, unpublished data). The diet of redtail surfperch in Humboldt Bay consisted of decapods, amphipods, mollusks, polychaetes, isopods, cirripeds, bryozoans, and fish, with decapods first in importance (Ngoile 1978). The diet of surfperches in general consists of small crustaceans and other small invertebrates (Baxter 1960). In turn, surfperch serve as forage for carnivorous fish species, seabirds, and marine mammals.

Scorpionfishes (Rockfishes)

As indicated by trawl surveys (Samuelson 1973; Sopher 1974) and sport-fish surveys (Gotshall 1966) the black rockfish (*Sebastes melanops*) is probably the most abundant rockfish in Humboldt Bay. Rockfish are commonly caught by anglers fishing from jetties. Gotshall (1966) stated that juvenile rockfish are common in Humboldt Bay channels; the trawl surveys verified this and indicated that the bay serves as a rockfish nursery area. Prince (1972) reported that rockfish inhabiting an artificial reef in South Bay fed primarily on arthropods associated with the reef: Dungeness crab, gammarid amphipods, and bay shrimp. Fish is important in the diet of rockfish.Rockfish are caught by commercial anglers outside Humboldt Bay and from 1981 to 1985 made up 25–31% of the commercial landings at Humboldt Bay (California Department of Fish and Game, Eureka, unpublished data).

Greenlings

Humboldt Bay provides spawning and nursery areas, particularly the areas around the entrance, seawalls, and jetties, for four species of greenlings. Jetty anglers fish for the kelp greenling (*Hexagrammos decagrammus*) and most highly prize the lingcod because it attains large size and is very palatable. Greenling feed on a variety of crustaceans, polychaete worms, and small fish. Lingcod feed chiefly on other fishes, including herring, flounders, and rockfish, and perhaps incidentally on squid and various crustaceans (Shapiro and Associates, Inc. 1980).

Flatfishes

The two most common bottom-feeding fish species in Humboldt Bay are English sole (*Parophrys vetulus*) and speckled sanddab (*Citharichthys stigmaeus*). The English sole, a commercially important flatfish, uses Humboldt Bay extensively as a nursery area. In trawl surveys of South Bay and Arcata Bay (Samuelson 1973; Sopher 1974), English sole were second in abundance, making up 24% and 26% of the catches, respectively. This species spawns offshore and the pelagic larvae are carried into the bay by tidal currents. Upon metamorphosis to the benthic form, the larvae settle or migrate to shallow, sandy areas in the bay. Most juvenile sole leave the bay and emigrate to deeper waters during the fall of their first year, although some remain in the bay through their first winter (Misitano 1970; Samuelson 1973; Sopher 1974).

On the basis of comparisons between available prey items and composition of prey organisms in stomach contents, juvenile English sole in estuarine channels are considered nonselective feeders (Collins 1978). Recently metamorphosed English sole inhabit intertidal and shallow subtidal sand, sand–eelgrass, and mud–eelgrass habitats, where they feed primarily on small epibenthic crustaceans such as calanoid and harpacticoid copepods and cumaceans (Toole 1980). Older juvenile English sole feed primarily on polychaetes, bivalves, amphipods, and other infaunal organisms.

Speckled sanddabs are abundant in Humboldt Bay; they accounted for 8% of the total trawl catch in Arcata Bay (Sopher 1974) and 9% of the trawl catch in South Bay (Samuelson 1973). Sopher's (1974) length-to-frequency data suggested three age classes present in the bay. Speckled sanddabs are somewhat selective bottom feeders, with small crustaceans accounting for the majority of prey items taken, in both number and volume (Collins 1978). There is some degree of overlap between the diets of English sole and speckled sanddabs, although not enough to cause significant competition for prey (Fig. 3.7).

The starry flounder (*Platichthys stellatus*) is also common in Humboldt Bay and is sometimes caught by bay anglers. It is a euryhaline species known for its tolerance of low salinities and has been known to move far upstream into fresh water.

Dover and English soles are commercially important outside Humboldt Bay (Fig. 3.8). Flatfishes averaged 31–42% of the total landings for Humboldt Bay from 1981 to 1985 (California Department of Fish and Game, Eureka, unpublished data).

Amphibians and Reptiles

Shapiro and Associates, Inc. (1980) compiled a list of amphibians and reptiles thought to occur in the Humboldt Bay area and their occurrence by

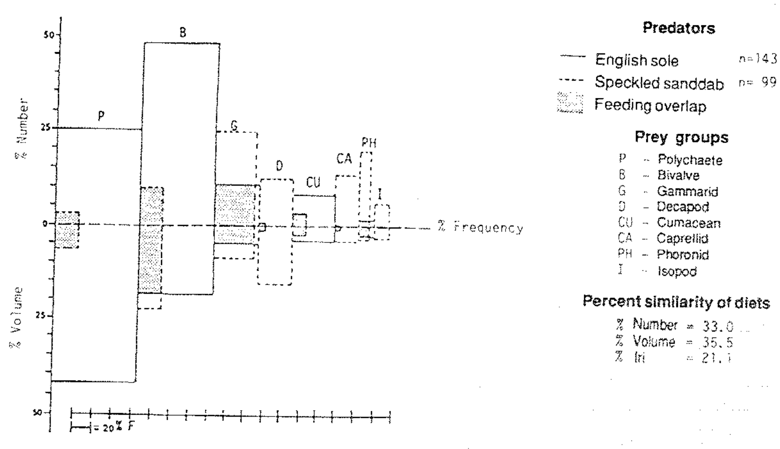

Fig. 3.7. Percentage composition of prey groups in the diets of English sole and speckled sanddab collected from all sections of Humboldt Bay in October 1974 (from Collins 1978).

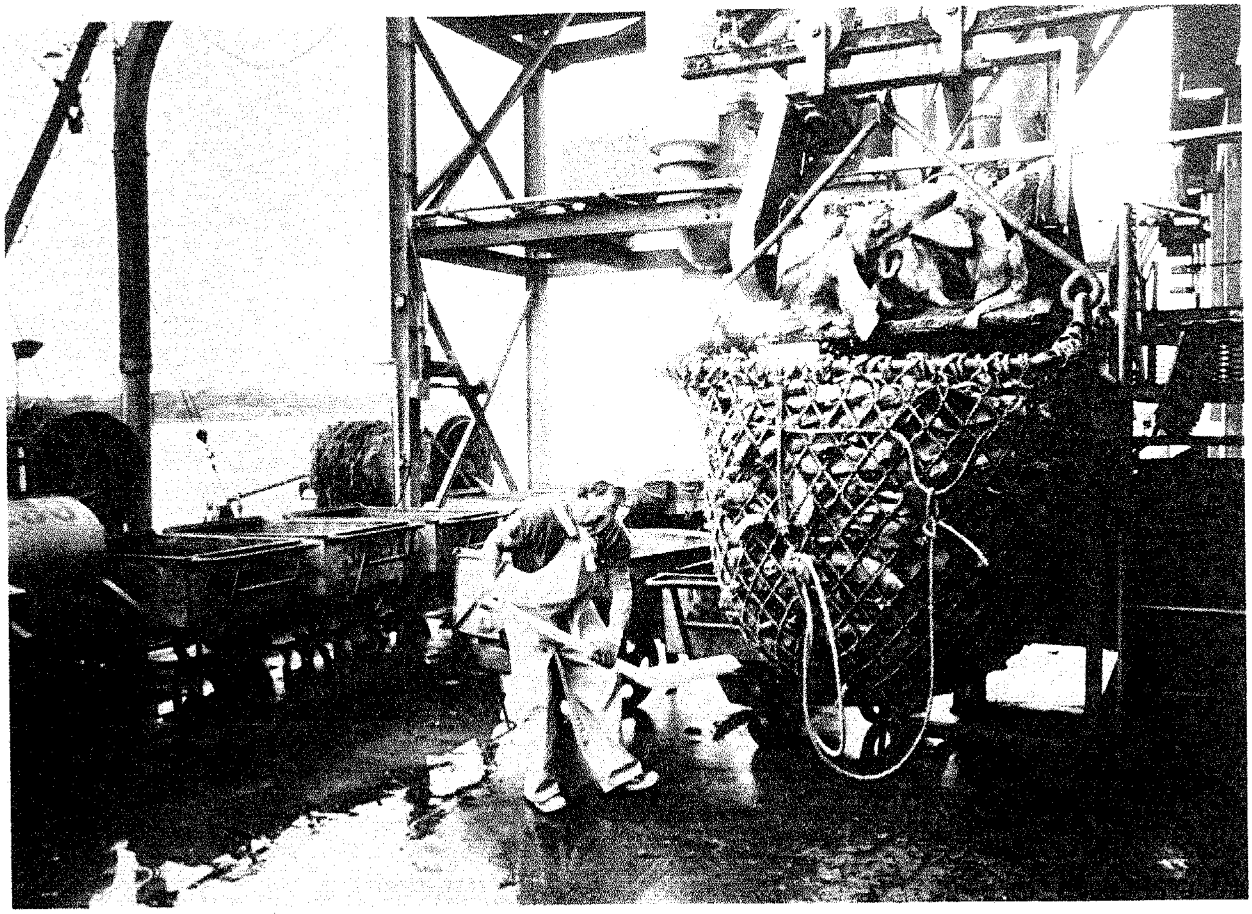

Fig. 3.8. A catch of sole being processed at a Humboldt Bay seafood processing plant.

habitat types. Published literature on herptiles of the bay region is scarce. Salt marsh and brackish marsh habitats are reportedly inaccessible to herptile species because of the difficulty they encounter in maintaining internal water balance. The Oregon garter snake, *Thamnophis couchii hydrophila*, is reported to occur in brackish areas occasionally (Stebbins 1966). No threatened or endangered species of amphibians or reptiles occur in the Humboldt Bay region.

Birds

The most visible and at times spectacular wildlife of Humboldt Bay are the birds. Most of the millions of fall and winter birds migrating southward along the Pacific coast pause to rest and feed on, or in areas adjacent to, the bay for varying periods of time (Monroe 1973). Humboldt Bay is a major wintering area for over 100 species of migrating water birds (Harris 1966). The bay also supports a variety of resident birds. A total of 251 species of birds have been noted for Humboldt Bay (Appendix D).

Waterfowl

Humboldt Bay, as an ecological unit, is most important to the waterfowl (Monroe 1973). Counts of 124,000 ducks have been recorded for Humboldt Bay (Proctor et al. 1980), but midwinter counts generally range from 20,000 to 60,000 (Springer 1982). The American widgeon (*Anas americana*) is consistently the most abundant duck during the hunting season (October–December) with the greater scaup (*Aythye marila*), white-winged scoter (*Melanitta fusca*), northern pintail (*Anas acuta*), redhead (*Aythya americana*), mallard (*Anas platyrhynchos*), and green-winged teal (*A. crecca*) present in high numbers during this period (Shapiro and Associates, Inc. 1980). Waterfowl hunting is estimated to provide over 25,000 hunter–days of recreation annually (Monroe 1973).

Ducks mostly use open-water areas of the bay and water-covered mudflat and eelgrass areas. Diet studies by Yocum and Keller (1961) showed plant foods to be more important to puddle ducks (widgeons, pintails, mallards, and green-winged teal), with clams and gastropods the principal animal foods. With the exception of the ruddy duck (*Oxyura jamaicensis*), the diving ducks—canvasback (*Aythya valisineria*), lesser scaup (*A. affinis*), greater scaup, bufflehead (*Bucephala albeola*), and scoter—were more dependent on animal foods. Diets varied somewhat by species, location, and food availability.

Mallards and gadwalls are not abundant but are present all year and nest locally. Cinnamon teal (*Anas cyanoptera*) also nest on Humboldt Bay and are generally observed during the spring and summer. Approximately 19,770 ha of suitable nesting area are available within the bay area (Monroe 1973). Mallards seem to prefer tall stands of hairgrass to shorter cover for nesting (Wheeler and Harris 1970); cinnamon teal nest more frequently in short vegetation. No diving ducks nest locally. Arcata Bay supports over 70% of the duck use in Humboldt Bay (Monroe 1973).

Although all three species of mergansers or fish ducks are found in Humboldt Bay, only the common merganser (*Mergus merganser*) nests locally. Foreman (1975) reported that flocks of the common merganser averaged 2.7 individuals during the spring mating season and 8.2 during the brooding season, and occasionally were quite large during the winter. Mergansers feed almost entirely on animal matter, with small fish making up the bulk of their diet along with mollusks, crustaceans, and insects (Monroe 1973).

A bird dependent on Humboldt Bay is the black brant (*Branta bernicla nigricans*), a small marine goose. Pacific Flyway brant nest in the Arctic and winter in estuaries of southern California and Mexico. Humboldt Bay is located approximately halfway between suitable brant habitat in Washington and Mexico, and indications are that the bay is an important rest and feeding stop. An estimate that 25% of the total brant population, or about 35,000 birds, pause in Humboldt Bay during northward spring migration may be low because constant ingress and egress of migrants make an accurate estimate difficult (Henry 1980). Brant numbers and brant-use days have declined greatly for the bay (Springer 1982). Henry (1980) concluded that human disturbance and hunting have been the principal cause of the decreases. One objective for the formation of the Humboldt Bay National Wildlife Refuge was to provide a sanctuary for brant and to restore a wintering population of brant on the bay. At one time, as many as 10,000 brant wintered there (Moffitt 1934), but the number has now declined to less than 100 birds (Springer 1982). Recently, the peak migrant brant numbers for Humboldt Bay have been only 900 in fall and 11,000 in spring, and brant-use days were about 350,000 in 1981–82 (Springer 1982). Brant prefer to eat eelgrass (>80% of diet), and brant feeding habitat roughly aligns with eelgrass beds in the bay. For short periods when eelgrass is limited, brant will subsist on grasses from agricultural lands adjacent to the bay. South Bay is by far the most important brant area, with more than 90% of the brant use recorded there (Monroe 1973).

A breeding colony of double-crested cormorants located on the abandoned remains of the old Arcata wharves in Arcata Bay is thought to be the largest in California and the second largest on the Pacific coast (Ayers 1975). Cormorants fish mostly in the deep channels of the bay.

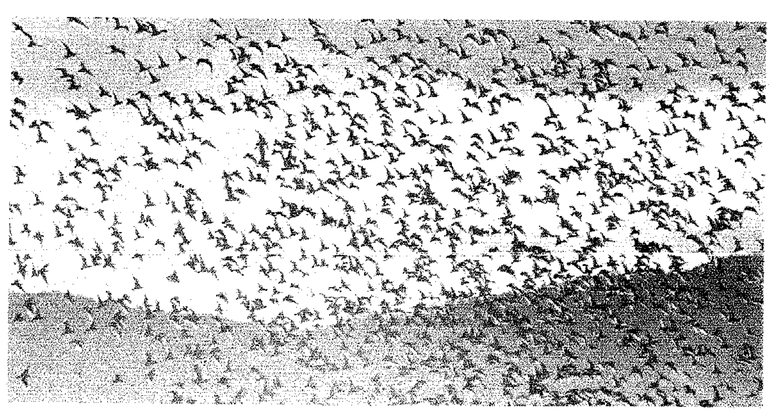

Fig. 3.9. Shorebirds over Humboldt Bay (*photograph by Eureka* Times Standard).

Shorebirds

Humboldt Bay has been known historically as one of the most important shorebird concentration areas in California (Fig. 3.9), hosting plovers, avocets, phalaropes, and shorebirds. Feeding areas are primarily intertidal mudflats, pastures, beaches, sandflats, shoreline eelgrass wracks, and marshes. They feed extensively on invertebrates, usually extracting them from the soft mud or sandy substrate by various ways of probing or pecking. Holmberg (1975) examined food in the digestive tracts of seven species of shorebirds collected from Arcata Bay mudflats and pastures.

During the summer, small numbers of nonbreeding shorebirds are present in Humboldt Bay. Southward migrating birds begin arriving in late July and peak from September through April when the daily average shorebird count exceeds 26,000. Counts are consistently higher for Arcata Bay than for South Bay.

The common snipe (*Gallinago gallinago*) is a shorebird game species. White and Harris (1966) found that salt marshes were most important to the snipe, with upland pasture, plowed land, and lowland pasture less important. Snipe eat both plant and animal material; plant fibers, insects, and seeds appeared most frequently in stomach samples (White and Harris 1966).

Wading Birds

Herons, egrets, and bitterns are regularly seen on Humboldt Bay, and a 1.6 ha grove of trees on Indian Island is a rookery for the great egret (*Casmerodius albus*), great blue heron (*Ardea herodias*), black-crowned night-heron (*Nycticorax nycticorax*), snowy egret (*Egretta thula*), and cattle egret (*Bubulcus ibis*; Fig. 3.10). As many as 256 pairs of great egrets (the most northerly nesting group along the Pacific coast), 87 pairs of great blue herons, 23 pairs of snowy egrets, and 3 pairs of cattle egrets (first reported nesting in the rookery in 1978) have been counted (Springer 1982). A rookery used only by black-crowned night-herons is located on the Samoa Spit.

Great egrets forage in groups in mudflats and salt marshes and singly along tide channels and highway margins (Schlorff 1978). Wading birds feed primarily on small fish, crustaceans, amphibians, and other water-associated organisms; herons and egrets will also take small mammals and reptiles (Monroe 1973). Schlorff (1978) found that although small mammals made up only 1% of the overall diet of great egrets, they contributed 15% of the biomass and 16% of the energy they consumed annually.

Raptors

The most common raptors observed for Humboldt Bay are the osprey (*Pandion haliaetus*), red-tailed hawk (*Buteo jamaicensis*), and American kestrel (*Falco sparverius*). The peregrine falcon (*Falco peregrinus*), an endangered species, is thought to breed in the vicinity of Humboldt Bay but there are no recent nesting records. The osprey's principal fishing ground is South Bay, where several species of fish are taken; surfperches are probably the most important (Ueoka 1974). The red-tailed hawk hunts over bay marshes and adjacent agricultural land, taking primarily rodents and other small mammals. The kestrel is more common in spring, fall, and winter (S.W. Harris, Department of Wildlife, Humboldt State University, Arcata, California, unpublished data). Kestrels hunt in pastures, marshes, and shrubby riparian areas of the bay, catching a variety of invertebrates and small vertebrates. These birds are commonly observed hunting from the tops or wires of utility poles.

Miscellaneous Birds

Humboldt Bay is important habitat to a number of gulls and terns; 24 species of the family Laridae have been observed on the bay (S.W. Harris, Department of Wildlife, Humboldt State University, Arcata, California, unpublished data). Over 100 pairs of Caspian terns (*Sterna caspia*) formerly nested on Sand Island (Yocum and Harris 1975), but no nesting terns have been reported in recent years.

Other studies on bird use of the Humboldt Bay environs were reported by Burton (1972) for Gunther Island, Hill (1977) and Sorensen and Springer (1977a) for dune habitat, Hoff (1979) for Arcata bay pasture land, Spitler (1985) for newly created wetlands, Sorensen and Springer (1977b) for diked coastal salt marsh, and Nelson (1989) for south Humboldt Bay.

Mammals

Over 37 species of mammals are commonly found in the Humboldt Bay area, and at least 32 other species can be found at times (Appendix E). Shapiro and Associates, Inc. (1980) divided Humboldt Bay mammals into five categories: big game,

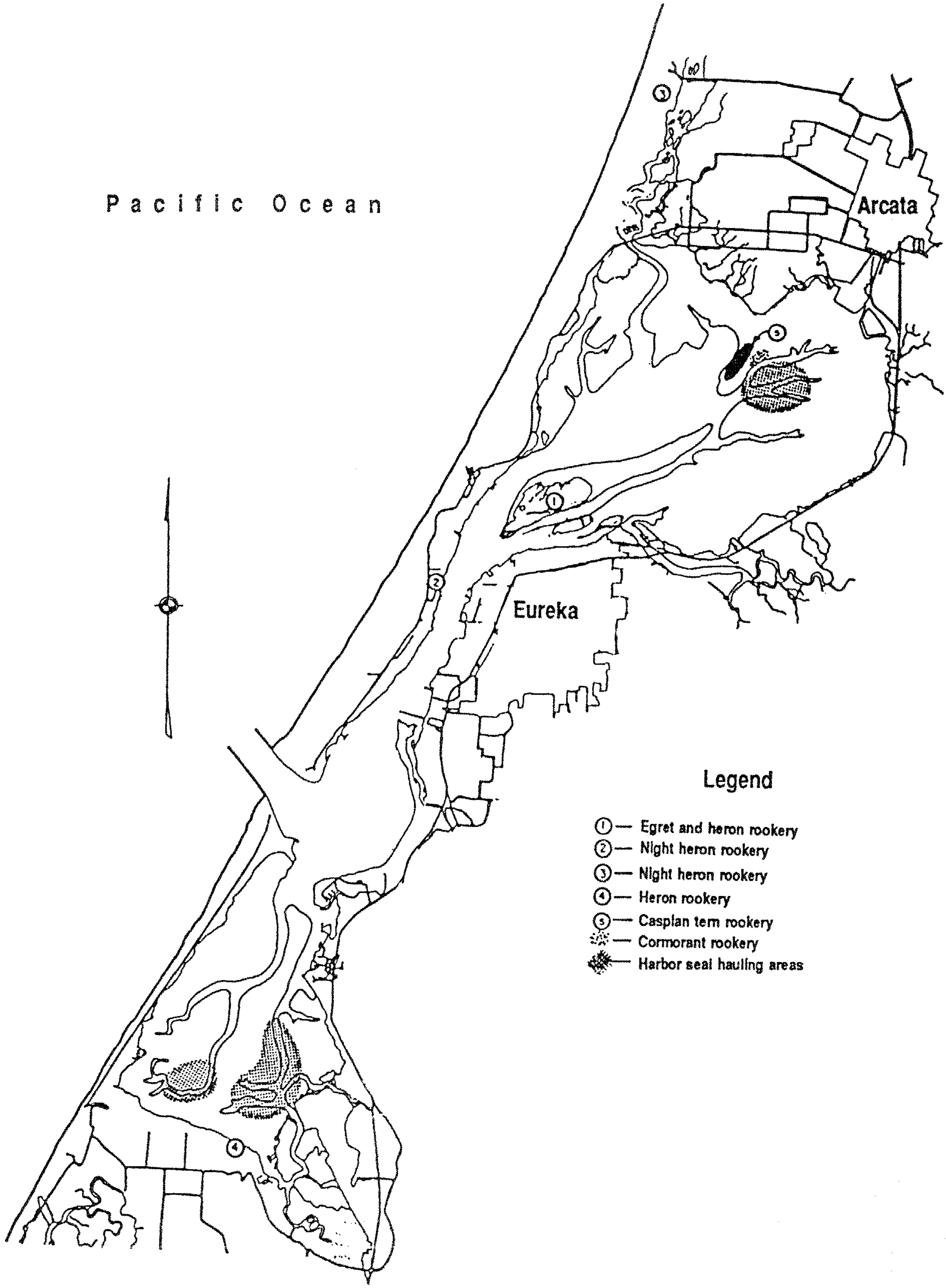

Fig. 3.10. Special wildlife use areas on Humboldt Bay. The cormorant rookery is denoted by the small *shaded patch* between the tern rookery and a seal hauling area (from Monroe 1973).

carnivores, furbearers, small mammals, and marine mammals.

Blacktailed mule deer (*Odocoileus hemionus columbianus*), the most common of the big-game animals, occur on Gunther and Woodley islands and in the lowland agricultural areas around the bay. Deer browse on shoots of shrubs and young trees, preferring leaves of blackberry (*Rubus* spp.) and salal (*Gaultheria shallon*), and twigs and stems of huckleberry (*Vaccinium* spp.), cascara (*Rhamnus purshiana*), and Douglas fir (*Pseudotsuga menziesii*) seedlings (Crouch 1966). Elk (wapiti, *Cervus elaphus*) occasionally stray into agricultural areas around the bay where they graze on meadow grasses.

Large carnivores most likely to be found around Humboldt Bay are gray fox (*Urocyon cinereoargenteus*), bobcat (*Lynx rufus fasciatus*), and coyote (*Canis latrans*), though all are uncommon. These carnivores feed on small mammals, birds, and insects. Mustelid weasels and skunks are small carnivores common to the bay environs. Weasels commonly eat other small mammals, birds, snakes, and insects. Skunks feed principally on insects, rodents, small birds, and possibly bird eggs (Ingles 1965).

Furbearers commonly observed near Humboldt Bay are river otter (*Lutra canadensis brevipilosus*) and raccoon (*Procyon lotor*). The river otter generally inhabits tributary streams but is sometimes seen in tidal sloughs of the bay. Food items include fish, amphibians, and various aquatic invertebrates.

Small mammals include all species of nonfurbearers up to the size of a jack rabbit. Shrews consume large quantities of insects to meet a very high metabolic demand. They may be important in limiting certain insect populations and are susceptible to bioamplification of environmental toxins (Shapiro and Associates, Inc. 1980).

A diverse group of small rodents inhabits the bay area, many of them part of the complex food chain supporting the larger forms of flesh-eating birds and mammals. Ground squirrels, chipmunks, gophers, rats, mice, and voles are common in wetland areas with good cover. These animals eat a variety of insects and plant foods. Among lagomorphs, black-tailed jack rabbit (*Lepus californicus*) and brush rabbit (*Sylvilagus bachmani ubericolor*) are common in agricultural and riparian areas around Humboldt Bay and provide some small-game hunting opportunities. Both mammals eat a variety of plant foods.

At least nine species of bats are common to the bay area, but little is known about their roosting sites and feeding habitat preferences. Bats can be important in limiting certain insect populations and are susceptible to the toxic effects of insecticides concentrated in the food chain (Shapiro and Associates, Inc. 1980).

The harbor seal (*Phoca vitulina*) is the most common marine mammal of Humboldt Bay and is a seasonal resident. Monroe (1973) reported that over 500 seals have been counted on a single day. Breeding populations reach a maximum of about 300 animals in late spring when pupping occurs, mainly in South Bay. The average annual population is around 200 seals. Harbor seals leave the water (haul out) for short periods of time to rest and give birth to young, primarily from April to June (Rosenthal 1968). Seals haul out onto mudflats exposed during ebb tides, primarily adjacent to small tidal channels in upper Arcata and South bays (Fig. 3.10). They feed on fish and, occasionally, invertebrates; in Humboldt Bay they feed on flatfish, surfperch, greenling, and tomcod (Shapiro and Associates, Inc. 1980). Jones (1981) found that surfperch constituted 41.9% of the harbor seal diet.

All the marine mammals are migratory, and local populations fluctuate. The harbor porpoise (*Phocoena phocoena*), a regular visitor, is the porpoise that most commonly uses Humboldt Bay. It is usually observed in deepwater channels (Monroe 1973). There are no endangered mammals inhabiting Humboldt Bay or its surrounding area.

Chapter 4. Ecological Relationships

The various ecological communities of Humboldt Bay interact with each other and with the physical environment of the bay. The potential relationships are many and the degree of interaction between species ranges from casual to essentially obligate. The model that will be followed here is related to the availability of nutrients that enable plant photosynthetic processes to occur, and to subsequent trophic interactions of major groups of organisms.

It is obviously an oversimplification to assign individual species or even groups of species to definite trophic levels. Generalizations about feeding strategies are difficult to make for even a single species. Among polychaete species of the bay, many function at more than one trophic level and may change trophic levels depending upon life stage or availability of trophic resources (Fauchald and Jumars 1979). Among higher-level vertebrate predators, chiefly fishes and birds, prey selection is wide and heavily dependent upon abundance (Collins 1978; Toole 1978; Baird et al. 1985). Nevertheless, a trophic model in which major groups of species are assigned to particular levels offers the best method of developing an understanding of significant interactions and focusing attention on where energy relations must be investigated further.

Nutrient Availability

Nutrients enter the bay from several sources, the most significant of which are runoff waters from the surrounding watershed (including agricultural lands adjacent to the bay), anthropogenic sources (in particular the two major wastewater treatment facilities serving the communities of Arcata and Eureka), and nearshore waters adjacent to the bay (particularly during periods of upwelling). Pequegnat and Butler (1981, 1982) suggested that patterns of nutrient availability and phytoplankton productivity are different in the three major compartments of Humboldt Bay (North Bay, Entrance Bay, South Bay), where nitrogen can be significantly limiting to plant growth during periods of high productivity in the summer months. Biologically available nitrogen may fall to such low levels that phytoplankton production is significantly reduced, particularly when upwelling ceases during summer months (Pequegnat and Butler 1981). Although the effects of low nitrogen levels on macrophytes have not been tested, it can be assumed that their production is also significantly impaired.

Other potentially limiting nutrients (phosphate, silicate, iron) have been added to samples of bay water taken at several locations to determine if they were potentially or actually at values low enough to limit phytoplankton productivity (Pequegnat and Butler 1981). These nutrient levels apparently do not fall low enough to limit phytoplankton growth. Pequegnat and Butler (1981) concluded that nitrogen is the nutrient that will first limit plant growth in bay waters.

It seems unlikely that nutrient levels in the bay are significantly limiting to plant growth during winter months, when seasonal rainfall is high and coliform contamination of bay oyster beds indicates the magnitude of runoff (presumably with nutrients) from adjacent agricultural lands. Production in salt marsh plants and eelgrass (*Zostera*) is also strongly seasonal in the bay (Rogers 1981; Bixler 1982), and it is probable that both mudflat algae and phytoplankton have similar patterns of seasonal productivity. During late fall, winter, and early spring, decreased light availability is probably the significant limiting factor to plant growth in bay waters (Raymont 1963). Another important factor during that same time period could be strong northwesterly winds that accompany storms beginning in the fall. Masses of mudflat algae and *Zostera* blades are piled up on the windward shores of the bay following the first storms of the season, suggesting that wind-driven waves dislodge the plant material from tenuous attachments on the mudflats. Thus, low light levels and dislodgment by surface waves are probably the most significant factors limiting plant growth in late fall, winter, and early spring.

Virtually nothing is known about nutrient cycling in bay waters. Tidal exchange with adjacent nearshore waters is a major factor in nutrient exchange, both in removing nutrients from the bay and in contributing them, particularly during periods of upwelling in coastal waters. Both bay and nearshore waters are low in plant productivity until the onset of longer days, greater intensity of solar insolation, and upwelling in mid-April (Pequegnat and Butler 1982). At that time, phytoplankton blooms begin in both bay and nearshore waters. Since rainfall and runoff are declining during the same period, it is probable that upwelling nutrients, particularly nitrogen, trigger the blooms in both the bay and the nearshore phytoplankton. Phytoplankton productivity then levels off in the bay but continues to increase in nearshore waters, probably fluctuating depending on the dynamics of upwelling, until late summer (Fig. 2.13). This suggests that nutrients from nearshore waters and those from autochthonous sources are being rapidly incorporated into plant material in the bay during this period of maximum productivity. The lower level of chlorophyll in bay phytoplankton compared to nearshore phytoplankton (Fig. 2.14) may indicate that competition for nutrients from mudflat microalgae and macroalgae, and from *Zostera*, causes limitation of the primary productivity of bay phytoplankton during this period. The phytoplankton in nearshore waters may reach a higher level of productivity because those populations have immediate access to upwelled nutrients, and there is no competition from attached macrophytes and benthic microflora for nutrients, as is true in the bay. The late summer months are thus periods of maximum productivity for all aquatic plant populations in the bay, and nutrient availability is probably significant in limiting primary productivity during that period.

It seems likely that factors other than nutrient limitations (reduced light, possibly reduced salinity, storm waves that cause mudflat algae to be removed from the substrate) are significant limitations to plant growth from late fall to early spring. During that period, massive amounts of plant material leave the bay on ebb tides or become stranded in the upper reaches of bay tidal flats. At this time, much of the plant material is undergoing decomposition, with two significant results: nutrients are probably released into the surrounding waters and then exported from the bay, and decomposing plant material with associated bacterial microflora becomes available to a variety of consumers. In both instances, nutrients are released into the surrounding waters, and the bay probably functions as a net nutrient exporter from late fall to early spring. It should again be emphasized that these are highly speculative statements, based on relatively little available data. The net nutrient status of the bay, covering at least an entire annual cycle, is largely unknown.

Plant Primary Productivity

Four major compartments of plant productivity can be recognized in the bay. These are plant production from the salt marshes that are found at higher tidal elevations around the bay, microscopic and macroscopic algae growing on tidal mudflats, production from eelgrass beds (primarily but not exclusively from *Zostera marina*), and production from bay phytoplankton. These plant materials differ greatly in their accessibility to potential consumers and suitability as food. At one extreme, direct grazing on salt marsh rooted vegetation is probably insignificant and involves only a few insect species (Cameron 1972). Much of the plant productivity of the marshes is exported as material of differing energetic quality (much of it is highly resistant to easy assimilation by consumers), which becomes available only through bacterial decomposers to the major consumers in the bay (Tenore 1977). At the other extreme, suspended phytoplankton may be readily available to many filter feeders and is probably relatively easy to process and digest. Eelgrass, benthic microflora, and macrophytic algae probably lie between these extremes.

Rogers (1981) studied the productivity of *Spartina densiflora*, *Distichlis spicata*, and *Salicornia virginica*. He chose two sites, both bordering North Bay, where study areas supported essentially monocultures of one of these species, and used three methods to calculate the aboveground net annual primary productivity of the plants. Eicher (1987) presented a more complete list of salt marsh species at several sites around the bay, but the data on primary productivity reported by Rogers (1981) remains the best available and thus were used to estimate annual net productivity components in Humboldt Bay (Table 4.1).

Rogers (1981) was fortunate in sampling during a year of much reduced rainfall in 1977, and 2 years of near-average rainfall in 1976 and 1978. All three

Table 4.1. *Primary productivity from various Humboldt Bay sources.*

Source	Area (hectare)	Productivity (g dry wt/m^2/yr)	Annual production (10^6 kg)
Salt marshes			
Spartina dominated	223	1,251 [a]	2.790
Salicornia + *Distichlis*-dominated	167	731 [a]	1.220
Mudflat microalgae and macroalgae	2,878	315 [b]	9.066
Eelgrass beds (mostly *Zostera*)	1,178	1,012 [c]	11.920
Phytoplankton	2,205 [d]	136 [b]	3.000
Bay total	6,651	3,445	27.996

[a] Rogers 1981.
[b] Pequegnat and Butler 1982.
[c] Bixler 1982.
[d] Area of shallow and deep channels.

species of salt marsh plants showed decreased annual net productivity in 1977 because of reduced precipitation, and Rogers (1981) attributed the decrease to osmotic stress caused by ion accumulation in marsh sediments. The estimates of annual net primary productivity in Table 4.1 are averages of the three methods and 3 years of data that Rogers (1981) presented. Because these estimates are based on net productivity for only the above ground portions of plants and include a year in which essentially drought conditions prevailed, the estimates must be viewed as fairly conservative. The productivities of salt marsh plant species other than those studied by Rogers (1981) are also unknown and could modify the estimates shown in Table 4.1.

The fate of plant material produced in the marshes is not certain. All of the marshes in the bay are adjacent to mudflat areas, suggesting that dead plant material would be transported onto the flats, where it would enter the food chain as detritus. Direct consumption of salt marsh plants is virtually unknown among invertebrates. The microflora on the surface of the dead plant material could be significant in the diets of both polychaetes and crustaceans of the flats (Fauchald and Jumars 1979; Morris et al. 1980), and decomposition would also release dissolved organic matter (DOM) into the surrounding water, where it might contribute to the nutrition of soft-bodied invertebrates (Stewart 1979). These pathways of energy use are not as efficient as direct consumption of plant material by herbivores, so the amount of energy that the salt marshes contribute to the bay ecosystem probably cannot be large.

The estimates of primary productivity from mudflat microalgae and macroalgae are preliminary and will require further investigation (Pequegnat and Butler 1982). Two algae species, members of genera *Enteromorpha* and *Ulva*, are obvious and abundant on the flats during the late spring through the early fall of each year. The first winter storms, with high winds from the northwest, usually result in the removal of these algae from the surface of the flats to other parts of the bay or out of the bay. The benthic microflora are essentially unknown but certainly are important in estimating the annual net primary productivity of the bay. Some species of polychaetes browse on benthic diatoms (Fauchald and Jumars 1979), and crustaceans feed on both microalgae and macroalgae (Morris et al. 1980).

Algae growing on the mudflats are more readily assimilated than marsh plants; thus, this compartment of bay productivity probably contributes much more to bay consumers than salt marsh vegetation (Table 4.1). Additionally, macrophytic algae readily leak DOM, with those compounds potentially also contributing to the nutrition of bay invertebrates. Plants are only seasonally available to consumers and their usage is therefore significantly limited. It would be unlikely that any consumer in the bay could specialize on the mudflat macroalgae as a food source, since productivity from late fall through early spring is almost nil. As with plant production from the salt marshes, a significant fraction of the mudflat algal production must pass through microbial decomposers, resulting in reduced energy transfer to bay consumers.

Eelgrass beds (mostly *Zostera marina*) are a third major compartment of primary production in Humboldt Bay (Table 4.1). Harding and Butler (1979) attempted to estimate the productivity of eelgrass in the bay by measuring oxygen evolution, a technique that is greatly hindered by entrapment of evolved O_2 in the tissues of the plant. Bixler (1982) used a direct method of leaf marking and measurement to improve the estimate of eelgrass primary productivity in the bay; the relatively conservative estimate of annual net primary productivity obtained is the one used in Table 4.1. In estimating the production of eelgrass beds in the bay, possible contributions from other plants have been ignored. This probably results in a serious underestimate of production from the eelgrass beds, since the contribution of other epiphytes and microphytic and macrophytic algae can match or exceed the production of the eelgrass itself (Phillips 1984).

The production of eelgrass in North Bay was reduced significantly following the beginning of commercially successful oyster culture there in the mid-1950's (Waddell 1964). Scattered eelgrass beds (405 ha; Shapiro and Associates, Inc. 1980) remain in North Bay, however, and contribute significantly to the primary productivity of the bay. The greatest extent (769 ha) of eelgrass is in South Bay, where it grows more densely and luxuriantly than in North Bay. A small amount of eelgrass grows in scattered locations along the shipping channels in Entrance Bay. South Bay, Entrance Bay, and North Bay are qualitatively different in eelgrass growth. The dense beds of South Bay are some of the most important locations of eelgrass growth in the Pacific Northwest (Phillips 1984), while the more scattered growth of eelgrass in Entrance and North Bays suggests that it is less significant in the energy budgets of those portions of the bay. There are marked seasonal differences in the production dynamics of eelgrass, with summer growth rates approximately twice as great as growth rates in winter, apparently because of increased insolation (Bixler 1982).

The major consumers of living *Zostera* blades are several species of aquatic birds, including black brant, American widgeon, scaup, Canada goose (*Branta canadensis*), and northern pintail (Phillips 1984). Invertebrate herbivores apparently find that the toughness of the blades renders them unpalatable or impossible to digest. In contrast to tropical seagrasses, living *Zostera* blades are not known to be consumed by invertebrates (Phillips 1984). Thus, most of the production of eelgrass at Humboldt Bay must enter a pathway to microbial decomposers during much of the year. Black brant populations have declined markedly in recent years and are only seasonally present during migrations to feed on eelgrass, with the result that even less eelgrass is probably now being consumed directly by herbivores than was true in past years. Following the onset of winter storms, massive quantities of eelgrass blades are thrown up on high intertidal flats or can be seen floating out of the bay on ebb tides. Bixler (1982) observed significant declines in standing stocks of eelgrass beginning in early winter and reaching a low point in late winter and early spring, apparently caused by storm waves breaking off blades.

Phytoplankton production in the bay is also highly seasonal, with a low point during the winter and a buildup to a high in early summer (Pequegnat and Butler 1982). Productivity (as measured by chlorophyll concentration) in North Bay and South Bay waters is generally equivalent to and sometimes lower than the productivity of nearshore oceanic waters (Fig. 2.14). The relationship of phytoplankton production to nutrient availability has been noted earlier, emphasizing the contribution of upwelled nutrients (chiefly nitrogen) to the bay during late spring and early summer. It seems likely that much of the phytoplankton is consumed directly by zooplankton or benthic filter feeders in the bay. What proportion goes to each of these major consumer groups is unknown.

The productivity estimate for phytoplankton in Table 4.1 is conservative because it was assumed that production occurs only in the shallow and deep channels of the bay (estimated at 2,205 ha by Shapiro and Associates, Inc. 1980). The actual areal coverage of water varies from this low figure to the maximum covered at high tide.

In summary, although eelgrass beds and mudflat algae appear to be the largest sources of plant production in the bay, the importance of these sources directly to consumers is probably less than for phytoplankton. Plant biomass produced in salt marshes must enter a cycle of microbial decomposition before becoming available to the bay food chain. Mudflat algae, *Zostera* blades, and salt marsh plants produce material that is too tough to be directly consumed by invertebrate herbivores of the bay. Although birds, notably black brant, can directly consume eelgrass, they are only seasonally present in the bay. Much of the plant production occurring in the bay must therefore enter an energy pathway involving microbial decomposition and animals feeding on detritus. The abundant populations of deposit feeders in the bay support this conclusion.

Primary Consumers

Primary consumers, or herbivores, are generally defined as those animals that feed directly on living plant material (Crawley 1983). That definition is too restrictive to allow an understanding of the various energy flow pathways in Humboldt Bay. As defined in our treatment, primary consumers include deposit and detritus feeders along with the strict herbivores. These animals may not feed on the resistant plant material at all, but instead digest the surface bacterial microflora (Adams and Angelovich 1970). No convenient way to separate these microbial consumers from the strict herbivores and other detritivores is available, and since the energy they consume comes ultimately from plant primary production, their inclusion with herbivores can be justified.

Two major groups of benthic infaunal animals are present in the sediments of the bay: filter feeders that draw their trophic resources from the overlying water, consuming mostly phytoplankton; and detritus feeders that have varying ability to select food particles from the surface sediments. Epifaunal animals are found at the sediment surface–water interface, selectively feeding on both plant and animal material. Many of these epifauna are small amphipod crustaceans. There can be overlap between these major feeding groups, as in the terebellid polychaetes, where feeding tentacles are spread widely on the surface, but most of the animal remains within a tube in the sediments. Another example of the same kind involves the bay bivalve *Macoma nasuta*, which extends its siphon above the surface and sucks in material from the sediment surface.

Among the filter feeders, the bivalves are the dominant group in sediments of the bay. Two major ecological categories of bivalves can be recognized, the deep burrowers (*Saxidomus* and *Tresus*) and the shallow burrowers (*Macoma, Protothaca, Clinocardium*, and several smaller species). These two groups may form functional feeding guilds, with competition between dominant species for trophic and spatial resources (Fauchald and Jumars 1979; Onuf 1987).

There are four species of large, deep-burrowing bivalves: *Tresus nuttallii, T. capax* (much more abundant in the bay than *T. nuttallii*), *Saxidomus giganteus*, and *S. nuttalli* (more abundant than *S. giganteus*). The species in the genus *Tresus* are known as "gaper clams," while those in the genus *Saxidomus* are known as "Washington clams." The bay once supported a small commercial fishery for Washington clams (Morris et al. 1980). There continues to be an active sport fishery involving the four species. *Tresus* spp. and *Saxidomus* spp. are often found together in the bay, with possibly some differences in the depth where they are positioned in the substrate (Morris et al. 1980). Peterson (1977) felt that *S. nuttalli* and *T. nuttallii* might compete for spatial resources in sediments at Mugu Lagoon, although that could not be demonstrated statistically. All four species occur in sand to muddy sand sediments in Humboldt Bay, particularly throughout much of South Bay and as far north as Indian Island (Sasaki 1967; Wendell et al. 1976). It is possible that mud and silt sediments are resistant to the burrowing (or reburrowing) activities of these large species, thus resulting in distributions restricted to predominantly sand sediments (Wendell et al. 1976; Peterson and Andre 1980). There is no doubt that these animals are important phytoplankton consumers.

Although the most important factor influencing competition for resources among these four species may be space in the sediments (Peterson and Andre 1980), trophic resources are also significant. The animals grow only when phytoplankton are abundant in bay waters, or from late spring to early fall (Wendell et al. 1976). The seasonal decline in phytoplankton standing stocks (Fig. 2.14) apparently results in the animals entering a physiological maintenance phase from late fall to early spring, during which trophic resources are not sufficiently abundant to sustain growth.

Another major association of filter-feeding consumers of bay phytoplankton are the more shallow-burrowing bivalves *Clinocardium nuttallii, Protothaca staminea, Macoma* spp., and other relatively small bivalves (*Lyonsia californica, Mysella tumida, Transennella tantilla*). In several respects, this group of bivalves forms a second layer of filter feeders, ecologically distinct from the deeper bivalves (Fig. 4.1). Unfortunately, rela-

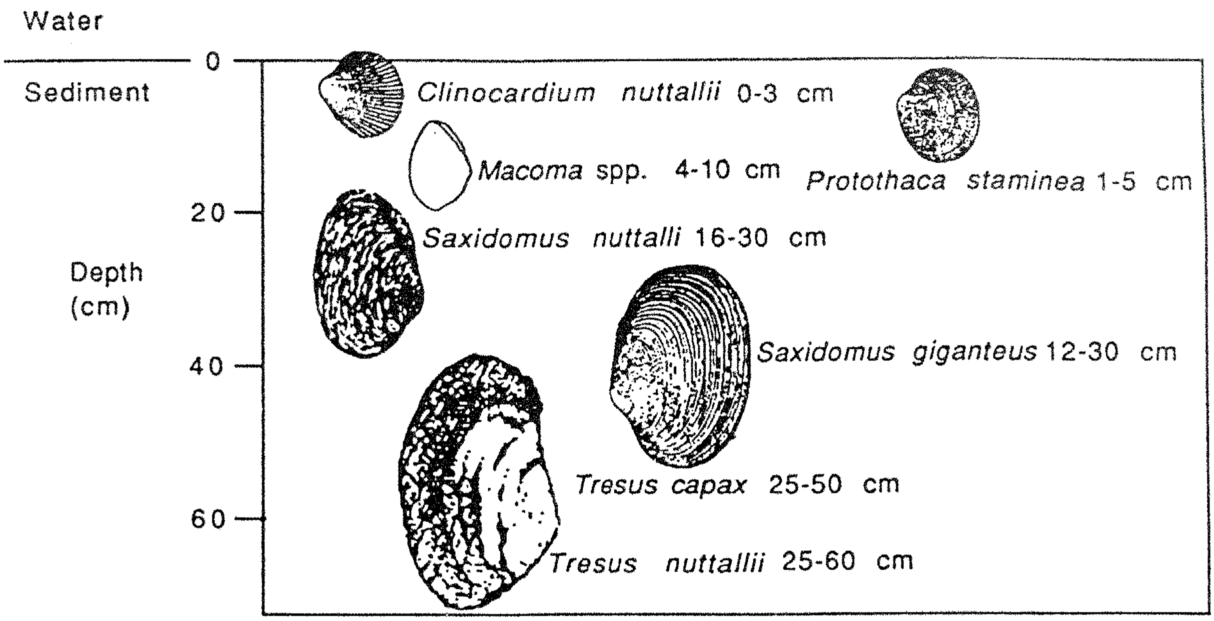

Fig. 4.1. Depth distribution of common bivalves (size not to scale) in sand and mud sediments of Humboldt Bay (M. J. Boyd, Humboldt State University; field data).

tively little quantitative information exists on the importance of these animals in the overall energy cycling of the bay. There may be a partitioning of trophic resources between the species of *Protothaca* and *Clinocardium*, with *P. staminea* consuming more benthic diatoms than phytoplankton (Peterson 1982).

Commercial oyster beds cover 324–365 ha of North Bay (Shapiro and Associates, Inc. 1980) and constitute a large fraction of the phytoplankton consumers. The estimated several million oysters in North Bay are capable of relatively efficient filter feeding and retention of food particles. Pequegnat and Butler (1982) estimated that it might be possible for oysters in North Bay to filter as much as 50% of the high-tide water volume, although they felt this figure was probably high. The pattern of seasonal growth of the oysters is similar to that seen in *Tresus* (Melvin 1980), suggesting that the seasonal availability of phytoplankton has an important influence on oyster growth.

A second major group is shallow burrowers that consume detritus on the surface and fresh plant material when it is available. Amphipods, crustaceans, and polychaetes feed on plant detritus of varying age and nutritional value. The large amount of resistant plant material (macroalgae, eelgrass, salt marsh plants) produced in the bay but not used directly by consumers suggests a diverse and abundant group of deposit-feeding consumers could be supported. In organically rich marine sediments, this assemblage is typically dominated by polychaetes (Whitlatch 1980). The increase in mud present in sediments of the flats along the wide intertidal margins of North and South bays apparently results in a decrease in the abundance of burrowing bivalves; thus the deposit-feeding assemblage may increase and ecologically dominate these habitats (Carrin 1973; authors', personal observations).

A deposit-feeding assemblage dominated by polychaetes has been in evidence for some time along the sides and bottoms of the channels in the central portion of the bay (Boyd et al. 1975; Bott and Diebel 1982). Without doubt, this area of the bay experiences some disturbance because of periodic maintenance dredging. Many of the same species that were abundant in 1974 had recolonized the dredged channels in 1980, suggesting that slumping of material from the channel margins and larval recolonization were both important mechanisms in maintaining this assemblage of polychaetes (Boyd et al. 1975; Bott and Diebel 1982).

The most abundant polychaete in the assemblage is a filter-feeding herbivore (Table 4.2). This is to be expected in an environment where tidal currents are strong and constant. Following the herbivorous species in abundance are deposit feeders, either on the surface of or in the sediments. Carnivorous species are much less abundant, as would be predicted by general ecological theory (Pianka 1988).

The abundance of deposit-feeding worms throughout a significant portion of Humboldt Bay

Table 4.2. *Approximate abundance and feeding guild (Fauchald and Jumars 1979) of widely distributed polychaetes in the central portion of Humboldt Bay, 1980 (data from Bott and Diebel 1982).*

Species	Abundance (number/m^2)	Feeding guild
Owenia collaris	8,569	Filter-feeding, discretely motile, tentaculate
Mediomastus californiensis	789	Surface deposit-feeding, motile, nonjawed
Lysilla labiata	409	Surface deposit-feeding, discretely motile, tentaculate
Tharyx monilaris	386	Surface deposit-feeding, motile, tentaculate
Spiophanes bombyx	232	Surface deposit-feeding, discretely motile, tentaculate
Glycinde polygnatha	179	Carnivore, discretely motile, jawed
Platynereis bicanaliculata	169	Surface deposit-feeding, discretely motile, jawed
Tharyx multifilis	157	Surface deposit-feeding, motile, tentaculate
Sphaerosyllis californiensis	135	Carnivore, motile, jawed
Polydora socialis	124	Surface deposit-feeding, discretely motile, tentaculate
Haploscoloplos elongatus	123	Burrowing, motile, nonjawed
Eumidia bifoliata	87	Carnivore, motile, jawed
Exogone sp.	56	Carnivore, motile, jawed
Phloe tuberculata	36	Carnivore, motile, jawed
Amaena occidentalis	31	Surface deposit-feeding, sessile, tentaculate
Nephtys caecoides	21	Carnivore, motile, jawed
Ophelia assimilis	21	Burrowing, motile, nonjawed

emphasizes the importance of detritivores in this system. It would be difficult to characterize more definitely the nature of the food material that is consumed. Obviously, most of the material is of plant origin, although it may be heavily colonized by bacteria (Tenore 1977). There may also be a small percentage of animal detritus, which must be much less abundant and only sporadically available. Several of the surface-feeding polychaetes, however, will take animal material if it becomes available (Fauchald and Jumars 1979). Within the bay, detritivores must consume much of the vast quantity of plant material that is seasonally produced on the mudflats and in salt marshes. This plant material, initially resistant to direct consumption, is eventually converted to animal and microbial biomass primarily as a result of consumption (perhaps several times) by the deposit-feeders of the benthos.

Meiofaunal animals (those that will pass through a 0.50-mm screen) may also be important consumers of detrital material in bay sediments (Tenore 1977). Although these organisms can account for a substantial portion of benthic community respiration (Fenchel 1978), nothing is known of their importance in the energy relationships of the bay. Findings in other temperate estuaries suggest that the meiofauna could account for perhaps 10–20% of benthic community respiration (Tenore 1977).

The third major group of primary consumers in Humboldt Bay includes some epifaunal species. Wherever hard surfaces occur in intertidal or subtidal habitats of the bay, a diverse assemblage of both sessile and motile invertebrates becomes established (Prince 1972). These surfaces are often associated with docks, bulkheads, or other structures of human origin. A small amount of primary production from macroalgae (*Fucus distichus*, *Ulva lactuca*, *Enteromorpha intestinalis*) occurs on these surfaces, but is insignificant in magnitude compared to production on intertidal flats. Similarly, primary consumers (mainly feeding on phytoplankton) are abundant on heavily colonized (fouled) surfaces, but would account for only a minor amount of the overall energy flow in the bay. The numerically dominant primary consumers in these assemblages are acorn barnacles (*Balanus* spp.), sabellid and serpulid polychaetes, numerous bryozoan species, several species of sponges, and colonial tunicates (especially *Botrylloides* sp.).

Brant migrants feed mainly on eelgrass and occasionally on other plants, including pickleweed (*Salicornia*) and algae, during fall and spring stopovers at Humboldt Bay (Henry 1980). These are periods of generally low plant primary productivity, and it is unknown whether the feeding activities of the brant have any significant impact on populations of the plants. The strictly seasonal feeding activities and relatively short residence time of the brant suggest that feeding activities have minimal impact on plant populations.

Despite the many primary consumers in the bay, actual measurements of growth, respiration, reproductive cycles, or other physiological correlates of energy consumption have been few. Data suggest that the bay supports an abundant and trophically complex assemblage of consumers. Seasonal patterns of primary productivity are important in influencing the growth and reproduction of many bay consumers. Both direct consumption (mainly of phytoplankton) and indirect consumption (by detritivores) of plant material are highly significant in an energy flow model of the bay. An unknown amount of the plant material produced in the bay is exported from it, with some probable correlation to the onset of late fall storms with high winds. Material transported into nearshore waters is of unknown importance in sustaining populations of both planktonic and benthic consumers there.

Predators

Many predatory species in Humboldt Bay feed on the abundant primary consumers. The major categories of secondary consumers recognized here are invertebrates (e.g., starfish, many crab species, predatory snails, and smaller predators), fish, and birds. Within each of these major groups of predators, it is often difficult to state unequivocally the actual prey species consumed. Larger predators in temperate and boreal marine habitats are often generalists in their diets, with prey size greatly influencing selection because of the energy constraints involved in capture (Schoener 1971). In several respects, the feeding activities of predaceous birds and fish are complementary in exploitation of the trophic resources of the bay. In tidal cycles, feeding fish move onto the flats during rising tides as birds retreat to higher areas adjacent to the bay for rest and digestion. Conversely, the birds actively probe bay sediments as the tide falls, and at low tide scatter widely over the mudflats while feeding.

The relative magnitude of benthic secondary production consumed by predators in the bay is unknown. Other than making the statement that feeding by birds (easily observed), invertebrates, and fish (not easily observed) is a constant occurrence over the bay flats, little quantitative information exists on the flow of energy to major predators. A recent review of energy flow patterns in temperate zone estuaries (Baird et al. 1985) supports the following generalities: birds consume about 20% of the annual secondary production from shallow estuaries and embayments, fish consume 20%, and invertebrates 12%. These estimates vary, however, from one area to another. In European and South African estuaries, 6–44% of the energy in secondary consumer production went to shorebirds. While it is disturbing to note this degree of variation, the outlying values are believed to be somewhat atypical (Baird et al. 1985). Available data suggested that 50–60% of the total secondary production passes to predators in shallow water marine systems, a much higher ecological efficiency than is typical of terrestrial or oceanic systems (Whittaker 1975).

There are a number of potentially important predaceous invertebrates in the bay. Dungeness crab juveniles may be seasonally abundant and are known to feed on crustaceans, bivalves, polychaetes, and fish (Wendell et al. 1976; Gotshall 1977). Probably the most significant large predaceous asteroid is *Pisaster/brevispinus*, although *P. ochraceous* is also abundant in Entrance Bay. *Pisaster ochraceous* is essentially confined to feeding on prey items attached to solid substrates (Morris et al. 1980). *Pisaster/brevispinus* is capable of taking bivalves from sediments (Mauzey et al. 1968), and probably preys on both large and small bivalves in sand and mud. Predatory snails are frequent in benthic samples (Boyd et al. 1975; Bott and Diebel 1982) and are important predators of both small and larger macroinvertebrates (Wendell et al. 1976). Numerous species of predatory polychaetes occur in the bay (Appendix B), but their significance in terms of energy flow is unknown. Their chief prey items are most likely other polychaetes and a variety of small crustaceans (Fauchald and Jumars 1979).

Speckled sanddabs and juvenile English sole are two significant predators on benthic infauna and epifauna of the bay. Shiner perch appear to feed opportunistically on epifaunal organisms, with the majority of prey items taken from the nekton. Speckled sanddabs take prey primarily from the sediment–water interface; they then prey on organisms burrowed into the sediments. Juvenile English sole concentrate their feeding activities primarily on animals buried in the sediments and then on those on the sediment surface. Collins (1978) was able to compare prey selection to prey availability on and in sediments of the central

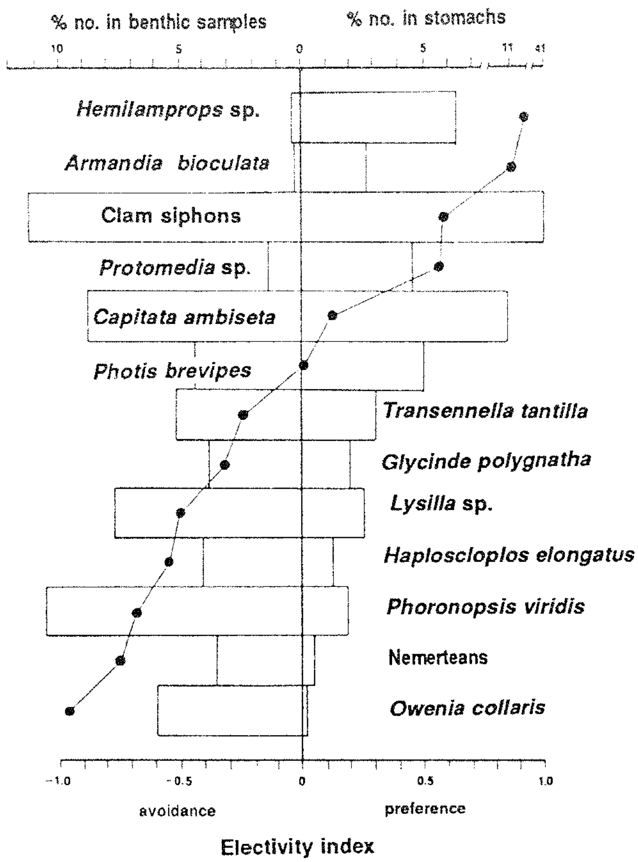

Fig. 4.2. The relative abundance of the 10 most numerous prey taxa found in 54 benthic grab samples; the relative abundance of the 10 most numerous prey taxa found in the stomachs of 99 speckled sanddab; and Ivlev's index of electivity (from Collins 1978).

portion of the bay (Figs. 4.2 and 4.3) and determined relationships between prey availability and selection by speckled sanddabs and English sole. It appears that these two species ecologically partition the benthic food resources available to them. As the juvenile English sole grow during the first year, changes in gut and external morphology accompany a gradual switch from feeding on copepods to feeding on burrowing polychaetes. Toole (1980) hypothesized that this change in prey preference with growth (Fig. 4.4) was a result of the increasing energy demands placed on the fish by a switch in predation strategy from "sit and wait" to active pursuit (Schoener 1971).

Oysters and shallow-burrowing bivalves in sandy substrates are preyed on by the bat ray (*Myliobatis californica*). The importance of predation by bat rays in Humboldt Bay has not been quantitatively assessed.

Smelt, Pacific herring, and northern anchovy are seasonally quite abundant in Humboldt Bay. These fish, during their residence in Humboldt Bay, are primarily phytophagous and should be assigned to a low trophic level. In turn, they provide a forage base for larger predaceous fish (salmon, rockfishes, sharks), some birds (pelicans, cormorants), and harbor seals. Predaceous birds and fish are attracted to Pacific herring spawn deposits and contribute significantly to egg loss. In Tomales Bay, diving birds greatly reduce the density of eelgrass in herring spawning beds,

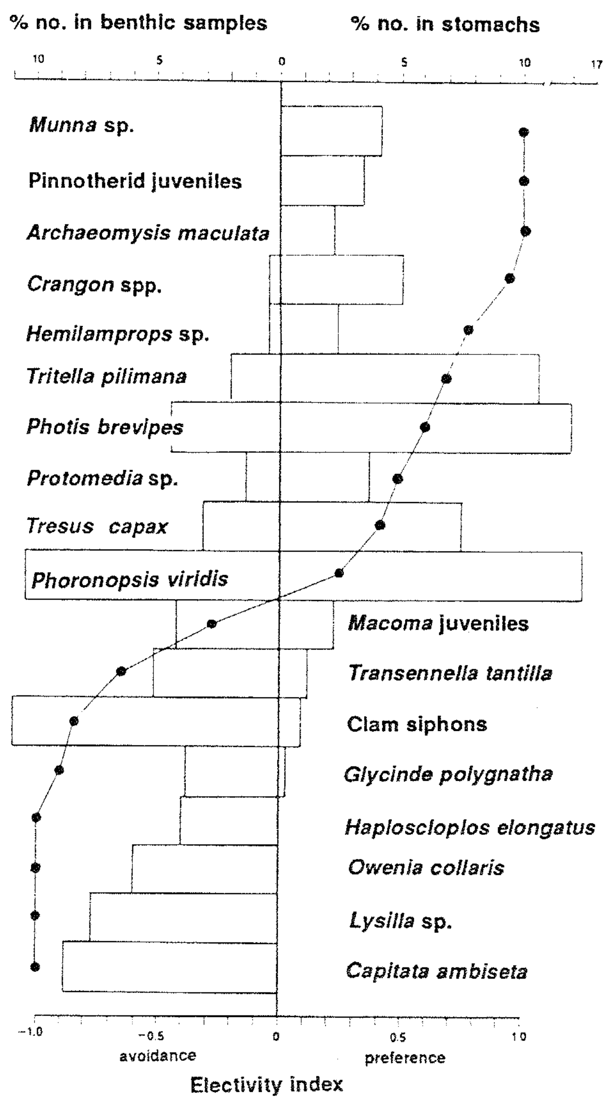

Fig. 4.3. The relative abundance of the 10 most numerous prey taxa found in 54 benthic grab samples; the relative abundance of the 10 most numerous prey taxa found in the stomachs of 142 English sole; and Ivlev's index of electivity (from Collins 1978).

cropping the grass to obtain the deposited eggs (Spratt 1981). No information is available on energy or biomass transfer for these species. Hay and Fulton (1983) estimated that the carbon contribution of herring milt and eggs to the ecosystem is high relative to primary production. This material is a source of energy for secondary producers, particularly microzooplankton, which in turn serve as food for larval herring, anchovy, and smelt.

The feeding activities of shorebirds are highly seasonal, coinciding with the annual migrations of millions of birds (Springer 1982). Despite the obvious predatory activities of shorebirds, their influence on benthic populations remains controversial. Quammen (1984) studied the influence of predaceous fishes, invertebrates, and birds on benthic organisms in two southern California estuaries and concluded that benthic populations are influenced most by shorebird predation, followed by crabs (*Pachygrapsus crassipes*); fishes had the least impact on benthic populations. The long-term impact of all predators on benthic community structure and populations of individual

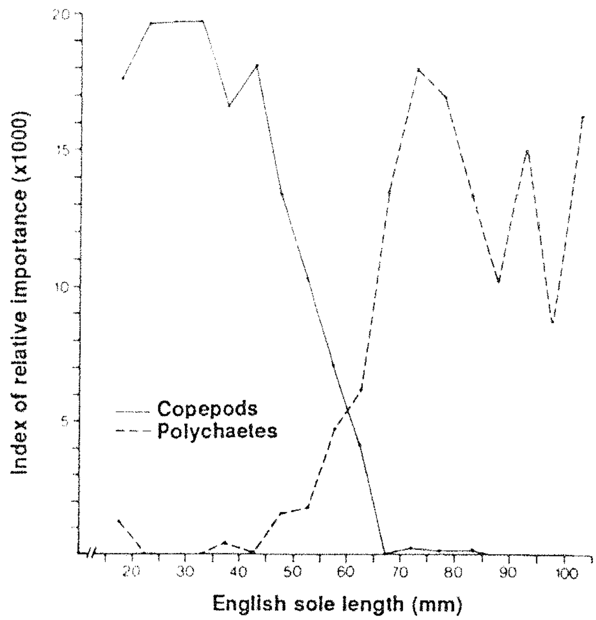

Fig. 4.4. Index of Relative Importance for copepods and polychaetes in stomachs of English sole captured intertidally, June 1976 through May 1977 (Toole 1980).

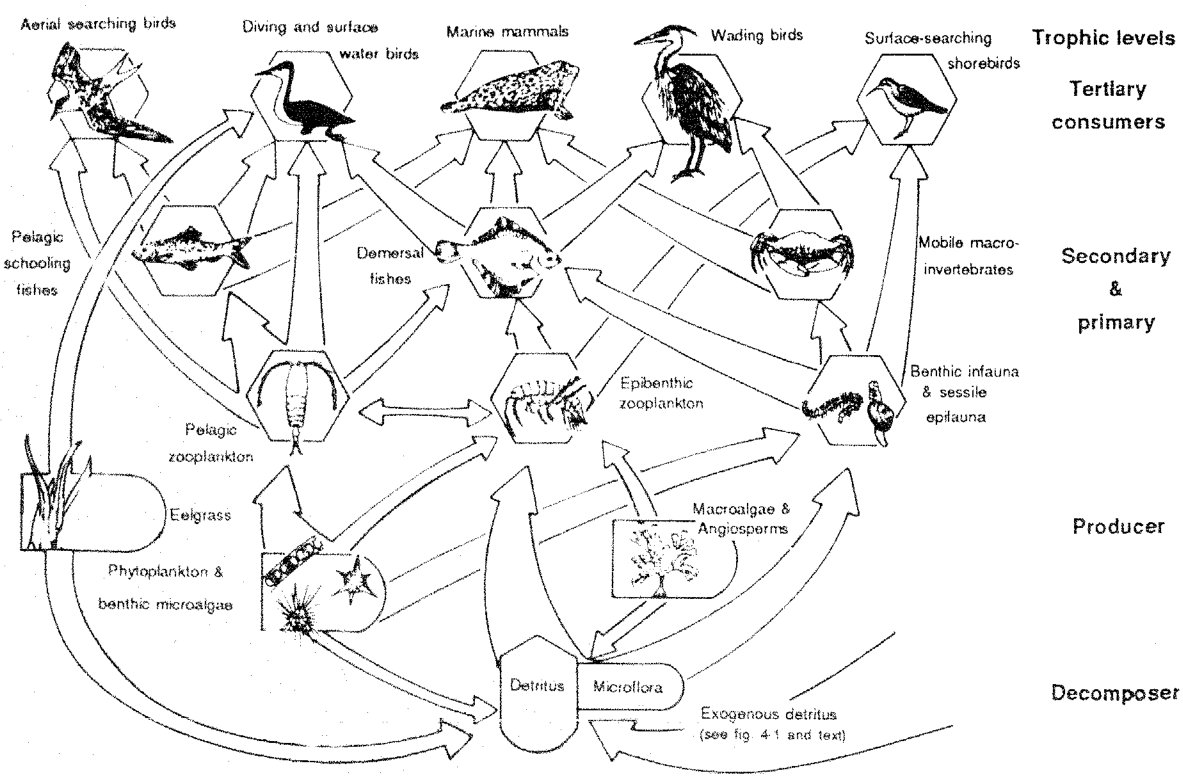

Fig. 4.5. Generalized food web for Humboldt Bay; size of linkage arrows illustrates relative biomass transfer (modified from Simenstad 1983).

species was less significant than physical factors (sediment composition). Baird et al. (1985) hypothesized that the effects of predaceous birds and fishes are complementary, with migratory birds arriving in European estuaries just as predatory invertebrates are leaving the shallow waters to spend the winter in deeper adjacent waters. Predaceous fish species (English sole and speckled sanddabs) as well as predaceous invertebrates leave Humboldt Bay to forage in nearshore waters just as major numbers of migratory shorebirds are arriving in late fall and winter.

Adult harbor seals are opportunistic feeders on fish and larger crustaceans, consuming about 5 kg (6,000 Kcal) of prey items per day (Scheffer 1958). Significant prey items in Humboldt Bay are anchovies, herring, small crabs, and occasionally octopus or bottom fishes.

The fauna and flora of Humboldt Bay are integrally linked through trophic and other ecological relations. However, no quantitative data on the carbon or energy flow through the food web are available. Figure 4.5 is an adaptation of a generalized food web for estuarine channels of the Pacific Northwest coast (Simenstad 1983); with the addition of an eelgrass component, this food web is a probable representation of the general trophic relations in Humboldt Bay.

Chapter 5. Comparison with Other Estuaries

Humboldt Bay ranks fifth in size for west coast estuaries from Grays Harbor on the central coast of Washington to San Diego Bay at the southern tip of California; in California it is second only to San Francisco Bay (Table 5.1; Fig. 5.1). Estuarine areas in Oregon are size-limited: all of Oregon's estuaries combined would fit into Willapa Bay, Washington (Lauman et al. 1972). Humboldt Bay is somewhat unusual because it has relatively low freshwater inflow for its size. Because of this and a shallow average depth, it is a tidally driven, well mixed estuary, as indicated by its flow ratio of 0.013 (Table 5.1). According to Schultz and Simmons (1957), a flow ratio >1.0 indicates a highly stratified estuary, around 0.25 indicates a partially mixed estuary, and about <0.1 indicates a well mixed estuary. Although the dynamic mixing in tidal channels reduces temperature and salinity extremes, tidal marshes with little freshwater input are subjected to higher temperatures and salinities. Such conditions exist in Willapa Bay, Humboldt Bay, and all southern California estuaries. In estuaries with larger drainage areas, such as the Columbia River, Winchester Bay (Umpqua River), and San Francisco Bay, there is a greater dilution of the seawater and more variability in channel salinities and temperatures. Estuaries north of Humboldt Bay have more precipitation annually, and estuaries to the south experience lower rainfall (Table 5.1).

The characteristics of nearshore ocean water influence estuary dynamics because of the semidiurnal tidal exchange that brings ocean water into the bays. Point Conception, approximately 210 km north of Los Angeles, is recognized as a transition area for marine biota, many of whose northern or southern boundaries coincide with this landmark. The California current parallels the Oregon and California coast, but flows offshore at Point Conception, creating a countercurrent that brings warm southern waters to southern California estuaries. During summer months, strong northwest winds along Oregon and northern California cause the surface water of the California current to move westward; near shore, the water is replaced from below by upwelling of nutrient-enriched colder water that flows into adjacent estuaries. Further north, upwelling is masked on the surface by the Columbia River plume, which produces its own river-induced upwelling by pushing surface water seaward, thus

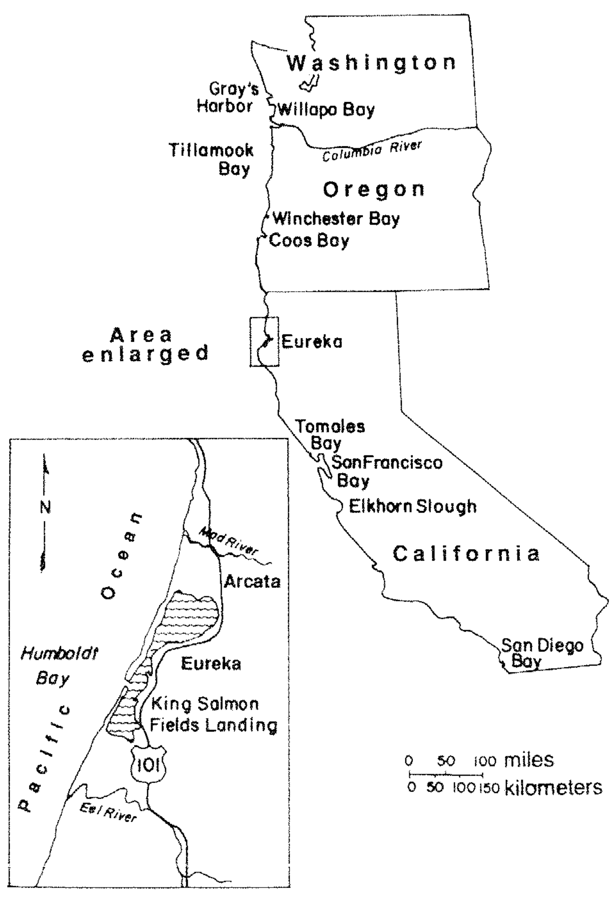

Fig. 5.1. Location of west coast estuaries and bays of Washington, Oregon, and California in relation to Humboldt Bay.

Table 5.1. *Comparison of physical and hydrologic characteristics of selected estuaries along the west coast of the United States (Proctor et al. 1980; National Oceanic and Atmospheric Administration 1985).*

Estuary	Distance[a] (km)	Relative size	Size (km^2)	Flow rate[b] (m^3/sec)	Flow ratio[c]	Tide range[d] (m)	Average depth (m)	Precipitation (cm)	Urban (%)
Grays Harbor	725	4	223	382	0.045	2.1	4.3	178	2
Willapa Bay	675	3	347	167	0.015	1.9	3.2	203	1
Columbia River	635	2	380	7,715	0.567	1.7	7.3	203	9
Tillamook Bay	555	8	34	—	—	1.7	—	229	—
Yaquina Bay	450	11	16	—	—	1.8	—	178	—
Winchester Bay	357	10	28	263	0.317	1.6	3.7	178	1
Coos Bay	335	6	50	82	0.072	1.6	4.0	152	3
Humboldt Bay	0	5	62	20	0.013	1.4	3.3	102	7
Tomales Bay	305	9	29	—	—	—	3.7	76	—
San Francisco Bay	370	1	1,240	917	0.032	1.3	6.8	51	17
Elkhorn Slough	500	12	4	—	0.003	1.1	—	58	21
San Diego Bay	1,125	7	46	3	0.0005	1.1	5.9	28	23

[a] Air-kilometers north or south of Humboldt Bay.
[b] Long-term average daily flow (m^3/sec).
[c] Proportion of fresh water entering estuary during tidal cycle to the tidal prism volume.
[d] Mean difference in tidal elevation between flood tide and ebb tide near entrance station.

allowing nutrients to come close to the surface. In the winter, the Columbia River plume flows northward and greatly affects the estuarine waters of Grays Harbor and Willapa Bay.

A comparison of ecological characteristics of Pacific coast estuaries is difficult because comprehensive studies are lacking on many of the estuaries and because of the variability in sampling design and methods among studies that have been done. The phytoplankton productivity of Humboldt Bay tidal channels is low compared to most Atlantic and Gulf of Mexico coastal estuaries, but compares well with the productivity of San Francisco Bay waters (Table 5.2). Although the net productivity of Humboldt Bay phytoplankton is not high, the large area occupied by phytoplankton in deep channels, tidal channels, and shallow bays makes phytoplankton an important contributor to Humboldt Bay food webs.

Humboldt Bay salt marshes are floristically distinct from other Pacific coast marshes, yet contain many species common to both northern and southern marshes (Eicher 1987). *Spartina densiflora*, the dominant salt marsh plant around Humboldt Bay, has not been reported anywhere else in North America except for a small patch in San Francisco Bay, where it was introduced from Humboldt Bay in 1976 (Spicher and Josselyn 1985). North of Humboldt Bay, salt marshes on the Pacific coast do not have *Spartina* (Eilers 1975), except for the introduction of exotic species in spots. Most of the other species found in Humboldt Bay are also found in San Francisco Bay, with four notable exceptions: the two rare Humboldt Bay endemics, Humboldt Bay owl's clover (*Orthocarpus castillejoides* var. *humboldtiensis*) and Humboldt Bay gumplant (*Grindelia stricta* ssp. *blakei*); a species of *Carex* that has previously been listed as *Carex lyngbyei*; and *Parapholis strigosa*, an Old World introduction.

Carex lyngbyei dominates Oregon salt marshes. A form that was previously identified as *C. lyngbyei* is also common in Humboldt Bay; however, its taxonomic determination is currently in question. The plant does not fit the characteristics given in the literature for *C. lyngbyei*; its leaves are not flat, but channeled, similar to *C. obnupta*. While this taxon is being studied, the old name continues to be used. Another form, *Parapholis strigosa*, appears to have been mistaken by some authors as a species of *Puccinellia*, to which it is similar in overall appearance.

In addition to the presence of unique species, Humboldt Bay is distinct because of the absence of some species common to central California marshes (notably San Francisco Bay), including *Frankenia grandifolia*, *Suaeda californica*, *Puccinellia* sp., and *Salicornia europaea*. *Limonium californicum*, however, reaches its northern extension in Humboldt Bay.

The number of fish species recorded as present in other estuaries is small when compared to Humboldt Bay, probably due in part to the limited amount of sampling (Table 5.3). Major groups of fishes using Pacific coast estuaries from the central coast of Washington to southern California are quite similar (Table 5.3). Surfperches, gobies, and flatfishes are common. The shiner perch, which ranges from Port Wrangell, Alaska, to San Quintín Bay, Baja California (Odenweller 1975), usually ranks among the most numerous of fishes taken by seine or trawl except for estuaries in the extreme southern portion of California. The English sole, a commercially important species using estuaries as nursery areas, ranks high in numbers as far south as Elkhorn Slough. Commercial flatfish most often cited as using estuarine channels as nursery grounds in southern California (Zedler 1982) are the California halibut (*Paralichthys*

Table 5.2. *Comparison of phytoplankton net primary productivity of selected estuaries; Humboldt Bay data from Harding (1973), data for all other locations from Nixon (1983).*

Estuary	Productivity ($g/m^2/yr$)	Rating
Humboldt Bay	300–450	Low
San Francisco Bay		
Suisun Bay	210	Low
San Pablo Bay	220–290	Low
South Bay	330	Low
Chesapeake Bay	990	Medium
Apalachicola Bay	800	Medium

Table 5.3. *Comparison of juvenile and adult fish assemblages of Pacific coast estuaries from trawl and seine surveys.*[a]

Bay	Distance[a] (km)	Number of species	Rank of most numerous fishes				
			1	2	3	4	5
Tillamook Bay[b]	555	56	Northern anchovy	Surf smelt	Shiner perch	Pacific herring	English sole
Yaquina Bay[c]	450	29	Surf smelt	English sole	Shiner perch	Buffalo sculpin	Pacific herring
Humboldt Bay[d]	0	110	Shiner perch	English sole	Speckled sanddab	Longfin smelt	Staghorn sculpin
San Francisco Bay[e]	370	60	Northern anchovy	Longfin smelt	Pacific herring	Shiner perch	Striped bass
Elkhorn Slough[f]	500	81	Shiner perch	White seaperch	Black surfperch	Speckled sanddab	English sole
Morrow Bay[g]	690	66	Surfperch spp.	Flatfish spp.	Northern anchovy	Goby spp.	Staghorn sculpin
Anaheim Bay[h]	965	57	Topsmelt	Shiner perch	Deepbody anchovy	Goby spp.	Staghorn sculpin
Tijuana Estuary[i]	1,140	—	Arrow goby	Cheekspot goby	California killifish	Topsmelt	Striped mullet

[a] Air-kilometers north or south of Humboldt Bay.
[b] Forsberg et al. 1977.
[c] Pearcy and Myers 1974.
[d] Sopher 1974.
[e] Brown 1986.
[f] Nybakken et al. 1977.
[g] Fierstine et al. 1973.
[h] Lane and Hill 1975.
[i] Zedler 1982.

Table 5.4 *Comparison of larval fish assemblages of Pacific coast estuaries.*

Estuary	Distance[a] (km)	Number of families	Dominant fish: Groups	Dominant fish: % of total
Columbia River[b]	635	18	Eulachon, longfin smelt	90
Yaquina Bay[c]	450	17	Pacific herring, bay goby	90
Humboldt Bay[d]	0	17	Bay goby, Pacific herring	82
San Francisco Bay[e]	370	20	Pacific herring, goby spp.	91
Elkhorn Slough[f]	500	16	Northern anchovy, goby spp.	65
Tijuana Estuary[g]	1,140	—	Goby spp., silverside spp.	96

[a]Air kilometers north or south of Humboldt Bay.
[b]Laroche 1976.
[c]Pearcy and Myers 1974.
[d]Eldridge and Bryan 1972.
[e]Eldridge 1977.
[f]Nybakken et al. 1977.
[g]Zedler 1982.

californicus) and the diamond turbot (*Hypsopsetta guttulata*).

Larval and juvenile northern anchovy and Pacific herring are common in Pacific coast estuaries during the summer except in extreme southern California (Table 5.4). Osmerids (smelts) are common, mostly as larvae or juveniles, in estuaries along the coast of Washington, Oregon, and California, but are replaced primarily by atherinids (topsmelt, grunion) in estuaries south of Point Conception. Reproducing populations of striped bass occur in San Francisco Bay and in Coos Bay and Winchester Bay, the only three such populations on the west coast; Humboldt Bay lacks a river with high enough volume and sustained velocity for successful spawning of this anadromous species. In a larval fish survey of Humboldt Bay, Eldridge and Bryan (1972) reported that larvae of the bay goby and Pacific herring composed 82% of the total larvae collected. In similar studies, Pearcy and Myers (1974) found that Pacific herring and the bay goby ranked first and second, respectively, and made up 90% of all larvae sampled from Yaquina Bay, Oregon. Eldridge (1977) reported that Pacific herring and species of gobies comprised 91% of larvae taken from San Francisco Bay (Table 5.4).

Humboldt Bay is an important ecological unit in the Pacific Flyway for migratory waterfowl. It is the largest bay and supports the greatest number of wetland wildlife species and the largest populations of those species along the Pacific coast between San Francisco Bay and the Columbia River (Springer 1982), a distance of 1,005 km. Table 5.5, which compares numbers of brant and ducks counted in early January from 1985 to 1987, helps to substantiate the importance of Humboldt Bay. Table 5.5 also demonstrates the importance of San Francisco Bay to the south and Willapa Bay and Grays Harbor north of the Columbia River to waterfowl.

Although brant numbers and brant-use days have declined markedly for Humboldt Bay, the bay remains an important resting area for the birds as they travel northward in the spring. Brant-use days were estimated to be 240,000 in 1984–85; 315,000 in 1985–86; and 270,000 in 1986–87 (Nelson, Humboldt Bay National Wildlife Refuge, personal communication). Brant use is greater in Willapa Bay, averaging about 490,000 for the same year (Willapa National Wildlife Refuge, unpublished data), but is much less in Oregon estuaries.

Table 5.5. *Early January counts of black brant and ducks on west coast estuaries, 1985–87.*[a]

				Ducks					
	Black brant			Dabblers			Divers		
Estuary	1985	1986	1987	1985	1986	1987	1985	1986	1987
Grays Harbor	0	114	350	284	10,683	2,322	33	373	802
Willapa Bay	2,413	950	856	3,646	4,989	5,509	453	836	1,087
Tillamook Bay	134	76	320	1,410	3,511	6,080	160	968	533
Yaquina Bay	105	427	382	347	4,313	227	264	1,816	936
Winchester Bay	0	0	0	260	638	400	201	1,780	1,525
Coos Bay	0	0	1	3,243	2,873	2,630	957	2,742	4,380
Humboldt Bay	50	0	86	6,150	3,035	5,639	8,135	4,071	2,339
Tomales Bay	145	186	0	1,242	315	145	13,922	7,766	4,416
San Francisco Bay	0	0	0	42,893	86,746	26,239	117,979	166,989	42,803

[a] From U.S. Fish and Wildlife Service national wildlife refuges, unpublished data.

Chapter 6. Management Considerations

Bay Management and Protection

Humboldt Bay is a valuable resource to its surrounding communities and much of its value relates to its biological resources. The Northcoast Region Comprehensive Basin Plan, adopted by the State Water Resources Control Board in 1975, identified 13 beneficial uses for Humboldt Bay, 10 of which are directly related to biological resources: shellfish harvest, ocean commercial and sport fishing, marine habitat, wildlife habitat, fish spawning, fish migration, nonwater-contact recreation, (bird watching, boating, marine life study, hunting), water-contact recreation (fishing, clamming, swimming, surfing), preservation of rare and endangered species, cold freshwater habitat, navigation, agricultural supply, and industrial service supply.

There are a number of federal, state, county, municipal, and special agencies whose functions include making management decisions regarding uses of Humboldt Bay resources. These agency roles were reviewed in some detail by Shapiro and Associates, Inc. (1980).

Projects or activities that might affect habitat or alter bay resources generally require permits. The permitting process usually involves the U.S. Army Corps of Engineers, the California Coastal Commission, Humboldt Bay Harbor, Recreation and Conservation District; and Humboldt County, or the cities of Eureka or Arcata. It may also involve the Regional Water Control Board, the U.S. Environmental Protection Agency, the California Department of Fish and Game, and the North Coast Unified Air Quality Management District. Other agencies such as the U.S. Fish and Wildlife Service and the National Marine Fisheries Service may also be involved as referral agencies for required environmental review.

The U.S. Army Corps of Engineers (Corps), pursuant to Section 404 of the Federal Water Pollution Control Act, has permit jurisdiction for diking, dredging, filling, shoreline structure building, and other activities in and adjacent to the navigable waters in the United States. The Corps determines whether granting a permit would be in the public interest. Under the Fish and Wildlife Coordination Act of 1934, any federal agency proposing to modify or control any body of water must first consult with the U.S. Fish and Wildlife Service (Service). The Service evaluates the possible effects of the activities on fish and wildlife resources. This required consultation is typically carried out through the Corps permit process. Both the Corps and Service have guidelines that limit the impacts that various uses have on wetlands. Where alteration or conversion of wetland habitat is allowed, replacement habitat is typically required.

The California Coastal Commission is usually the lead state agency to review development permits in and around Humboldt Bay. In administering the California Coastal Act, the State Coastal Commission has retained permit authority on most of the lands immediately adjacent to Humboldt Bay. The policies of the California Coastal Act were used to prepare Local Coastal Programs (LCP's) for each of the local jurisdictions around Humboldt Bay (Humboldt County, Eureka, and Arcata). The LCP's provide the standards and guidelines by which decisions are made by both the local jurisdictions and the State Coastal Commission. In exercising permit jurisdiction, both local governments and the State Coastal Commission use the California Department of Fish and Game as a referral agency on matters affecting fish and wildlife resources of the state.

The Humboldt Bay Harbor, Recreation and Conservation District, established in April 1973, is empowered by state statutes to develop Humboldt Bay to its ultimate potential as a harbor and a port while conserving the natural resources of the area. The Harbor District has adopted Ordinance Number 7, the Humboldt Bay Master Plan, which designates land and water areas and uses of the bay as follows: conservation water, development water, public open-space land, agricultural land, service-commercial land, port-related industrial land, water-related industrial land, nonwater-related industrial land. The designations are defined and their locations given in Shapiro and Associates, Inc. (1980). The Humboldt Bay Harbor District currently owns and operates a 237-slip marina that was constructed in 1981, owns 17 ha of developable land, and holds 32 ha of land in reserve for mitigation or conservation. The Harbor District has actively supported the deepening of skip channels in Humboldt Bay to a depth of 12.2 m for new maritime business, the improvement and modernization of commercial fishing facilities, and the improvement or expansion of waterfront facilities.

The Humboldt Bay Wetlands Review and Baylands Analysis carried out for the U.S. Army Corps of Engineers by Shapiro and Associates, Inc. (1980), summarized its findings by providing advisory categories for the lands and waters of the Humboldt Bay environs based on their resource values:

- *Areas of importance.* Those areas unique or so important to the functioning of the Humboldt Bay ecosystems and its aquatic resources that potential destruction or alteration should be discouraged unless found to be in the best public interest. Areas of importance are especially critical areas which should generally be maintained in their present state.
- *Areas of environmental concern.* Those areas that are environmentally sensitive, in which any use or activity should be carefully controlled. Areas of environmental concern may have multiple uses consistent with maintenance of their habitat values.
- *General areas.* Those areas in which new development would cause minimal impacts on wetlands and other valuable habitat types. Such areas might include already altered or damaged areas or expansions of existing development modes.

In addition to providing federal consultation on permit applications, the U.S. Fish and Wildlife Service also manages the Humboldt Bay National Wildlife Refuge, which is authorized to encompass approximately 3,162 ha. To date, only 843 ha of the approved refuge area has been acquired. The completed refuge would encompass most of South Bay and portions of North Bay. The refuge will protect key wildlife habitat associated with migratory birds, fish nursery grounds, shellfish, and marine life. A principal objective of refuge managers is to restore wintering brant populations on the bay. About 226 ha of diked pasture may ultimately be returned to salt marsh or fresh ponds.

Permit jurisdictions, policies, and guidelines of the various local, state and federal agencies can serve to protect critical natural resource habitat in Humboldt Bay. These policies should provide adequate protection for the open-water areas of South Bay, North Bay, and the areas around various bay islands. Other areas of Humboldt Bay with less restrictive designations are more subject to alteration. As pointed out in the Humboldt County Industrial Siting Study (Humboldt County 1981), it is important for various agencies involved in reviewing permit activities and formulating permit conditions in the study area to agree on which ecosystem characteristics are important to maintain—a difficult task because agencies have different policies and responsibilities. Hofweber (1982) stated that although a variety of management goals exist for individual projects, there is no overall management plan regarding Humboldt Bay wetland resources. Woodruff (1982) pointed out that proposed projects are currently handled on a case-by-case basis with neither long-term goals nor objectives for planning wetlands mitigation. Compensation is the replacement or creation of habitat types lost due to development activities. The Humboldt County Industrial Siting Study (Humboldt County 1981) suggested the formation of a compensation area land bank, consisting of developmental agencies and industries interested in purchasing compensation land; each member would be assessed according to its compensation needs. A large compensation site would allow for coordination of habitat evaluation and environmental impact assessment and offer the possibility of developing an area with greater diversity and greater habitat value than several smaller, isolated sites.

Socioeconomic Factors

The most significant obstacle to economic development of the Humboldt Bay region is its remote location. The economic base of Humboldt County is primarily dependent upon natural resources; related industries are timber and wood products, fisheries, agriculture (primarily dairy products), and tourism. From 1965 to 1975, the lumber and wood products manufacturing sector supplied the highest private insured employment. However, these industries have been slowly declining in actual total employment. The major industrial facilities of the forest industry, particularly those in the Humboldt Bay area, however, are expected to continue at their present level of operation, with some modernization of equipment, but without significant additional land-use demands (Table 6.1). It is anticipated that some smaller facilities may close down, making additional land available for industrial use (Humboldt County 1981).

Agriculture has historically been one of the major economic resources of Humboldt County. Related employment was estimated at 1,900 jobs in 1977, down from 2,500 in the early 1960's (QRC Corporation 1978), a decrease Dean et al. (1973) forecasted because of advances in agricultural technology. Agricultural land-use study of the Humboldt Bay area (California Department of Water Resources 1978) showed that of 7,392 ha in agricultural use, 6,967 ha (94%) was in pasture.

Of the natural resource-dependent industries important in Humboldt County, fishing appears to be one with significant expansion potential (Humboldt County 1981). Since 1981, the Humboldt Bay Harbor Recreation and Conservation District has completed construction of the Woodley Is-

Table 6.1. *Projected employment and growth rates by industry, Humboldt and Del Norte Counties, 1976, 1980, and 1985 (Humboldt County 1981).*

	Number of employed individuals			Compound annual average growth rate	
Industry	1976	1980	1985	76–80	80–85
Agriculture, forestry, fisheries	3,200	3,800	4,000	4.4	1.0
Construction and mining	2,200	2,500	2,900	3.3	3.0
Manufacturing	10,800	10,800	10,200	0	-1.1
Lumber and wood products	8,700	8,500	7,700	-0.6	-2.0
Food and kindred products	900	1,000	1,100	2.7	1.9
Other manufacturing	1,200	1,300	1,400	2.0	1.5
Transportation, communications and utilities	3,100	3,200	3,300	0.8	0.6
Transportation	1,800	1,800	1,800	0	0
Communications and utilities	1,300	1,400	1,500	1.9	1.4
Trade	9,800	11,200	12,800	3.4	2.7
Wholesale trade	1,300	1,500	1,600	3.6	1.3
Retail trade	8,500	9,700	11,200	3.4	2.9
General merchandise, apparel	1,400	1,500	1,600	1.7	1.3
Food and dairy stores	1,300	1,400	1,600	1.9	2.7
Auto dealers, gas stations	1,300	1,400	1,500	1.9	1.4
Eating and drinking places	2,600	3,200	3,900	5.3	4.0
All other retail trade	1,900	2,200	2,600	3.7	3.4
Finance, insurance, and real estate	1,400	1,600	1,900	3.4	3.5
Finance	700	800	1,000	3.4	4.6
Insurance	300	300	400	0	5.9
Real estate	400	500	500	5.7	0
Services	16,700	18,800	21,900	3.0	3.1
Hotels and lodging places	1,400	1,700	2,100	5.0	4.3
Medical, other health	3,700	4,100	5,000	2.6	4.1
Education	5,600	6,300	7,200	3.0	2.7
All other services	6,000	6,700	7,600	2.8	2.6
Public administration	2,400	2,700	3,000	3.0	2.1
Federal public administration	400	500	500	5.7	0
State public administration	300	300	300	0	0
Local public administration	1,700	1,900	2,200	2.8	3.0
Total, all industries	49,500	54,500	59,900	2.4	1.9

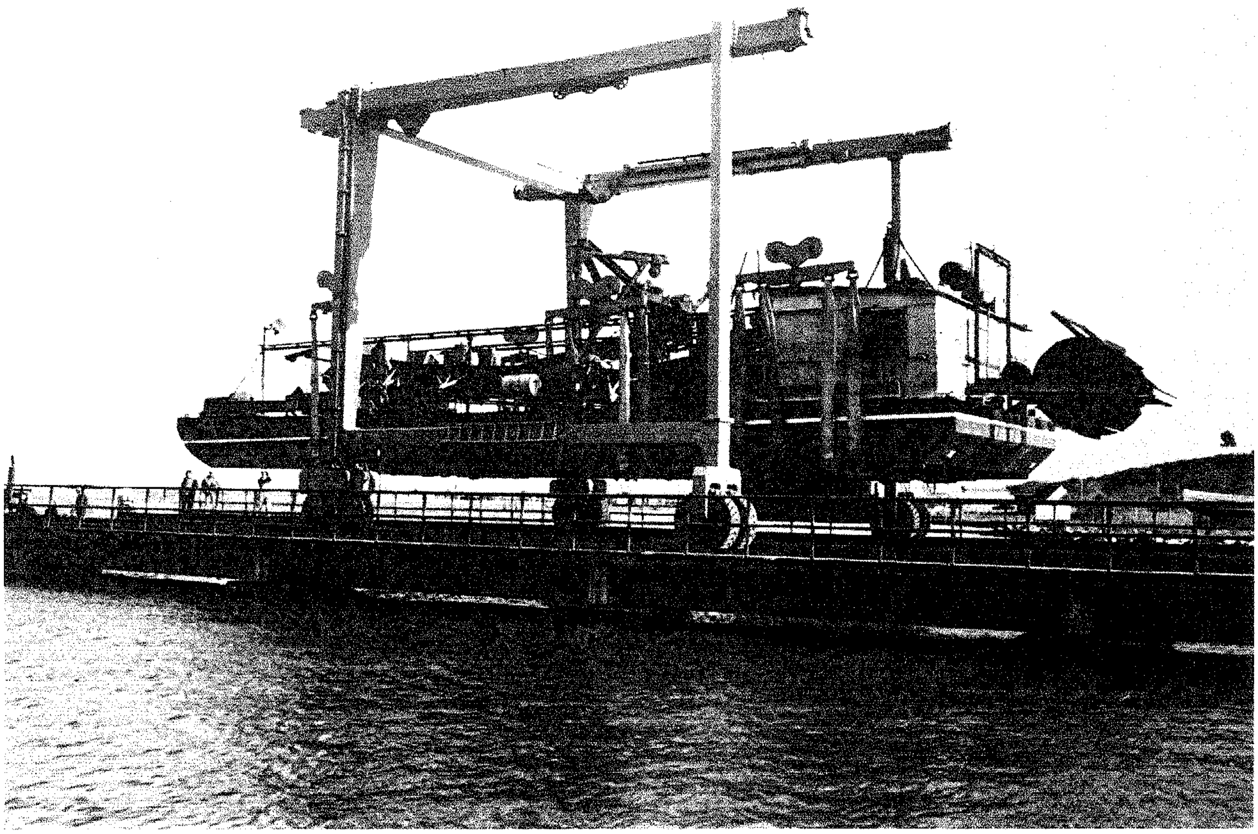

Fig. 6.1. Marine lift in South Humboldt Bay launching a commercial oyster dredge.

land Marina, which has significantly expanded boat-berthing facilities on the bay. In addition, a boat building and repair yard with a 150-ton marine lift has been built in South Bay (Fig. 6.1). The Pacific Coast Fisheries Information Network (PACFIN) listed 38 trawling vessels and 267 trolling vessels that made the majority of their income from fish landings in Humboldt County in 1983. With the exception of the Pacific oyster, all of the major fish species harvested in the commercial fishery are taken outside Humboldt Bay. The primary fish groups are groundfishes (flatfishes and rockfishes), albacore, Dungeness crab, and salmon (Table 6.2). The

Table 6.2. *Commercial fishery landings and ex-vessel value in Humboldt Bay (Eureka–Fields Landing), 1981–85 (California Department of Fish and Game, unpublished data).*

	Landings per year (1,000 kg)					1981–85 average	Average value/year
Species	1981	1982	1983	1984	1985	(1,000 kg)	($1,000)
Flatfishes	5,376	4,678	3,746	4,036	4,962	4,560	2,487
Rockfishes	5,213	4,592	3,017	2,655	3,248	3,745	1,782
Dungeness crab	1,324	498	355	656	772	721	1,440
Albacore	1,662	82	172	278	1,130	665	1,005
Salmon	422	389	116	52	21[a]	200	991
Other	3,027	4,660	2,005	2,005	2,655	2,909	1,736
Total	17,024	14,899	9,411	9,682	12,788	12,800	9,441

[a] No commercial salmon season in Eureka–Trinidad zone in 1985.

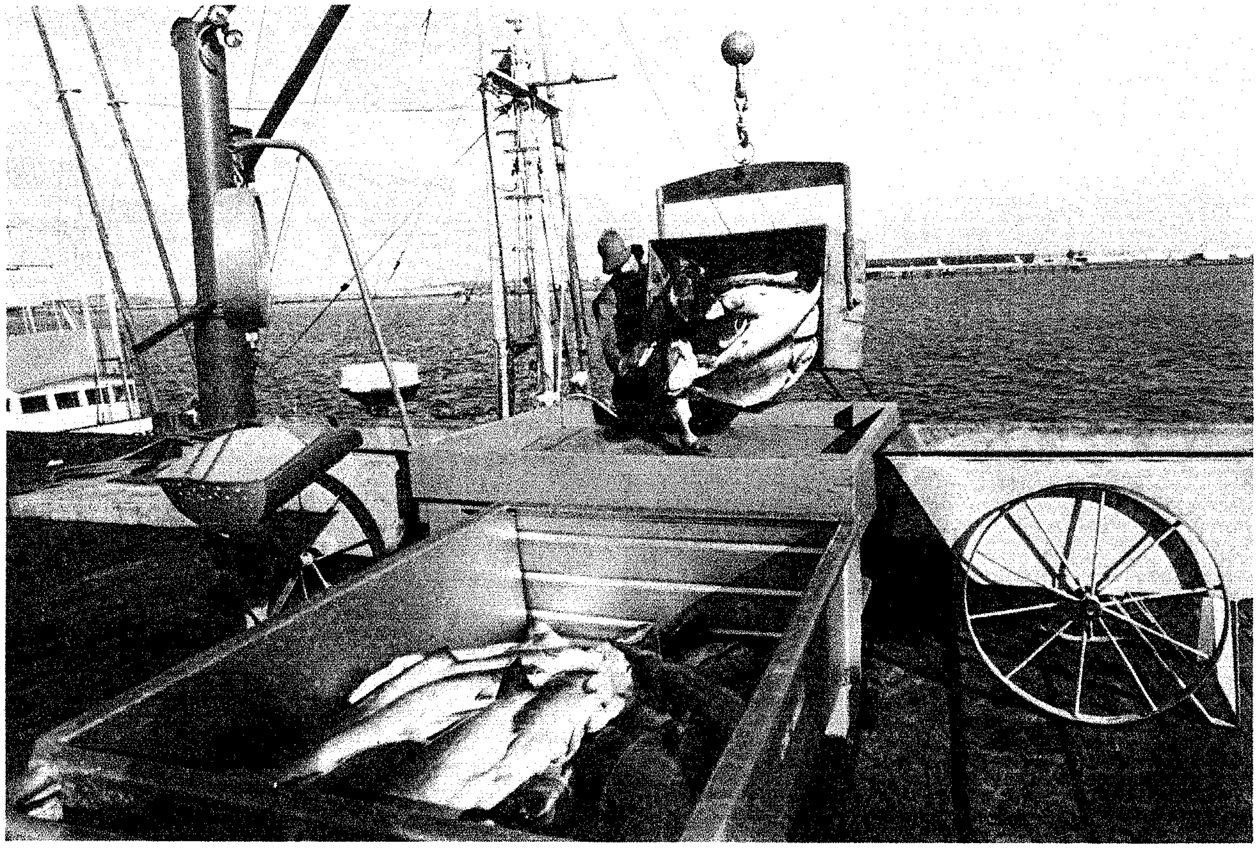

Fig. 6.2. Commercial troll-caught salmon are bought by several Humboldt Bay seafood processors.

average annual value of fish landed in Humboldt Bay from 1981 to 1985 was almost $9.5 million. Salmon is the most valuable finfish on a per-pound basis; in 1985 the average price per pound paid to commercial fishermen was $2.44 for chinook salmon and $1.54 for coho salmon (University of California Cooperative Extension Sea Grant Advisory Program, Eureka, California, unpublished data; Fig. 6.2). However, salmon landings have declined markedly since the late 1970's, and only in 1986 and 1987 were there indications of increase in salmon stocks (Table 6.3). The largest commercial fishery inside Humboldt Bay is oyster farming. In 1985, over 907,000 kg (live weight) of oysters were harvested, representing a value of approximately $864,000 (University of California Cooperative Extension, unpublished data).

Although the fishery industry is an important business, it is not a large employer; annual insured employment in the fisheries and agriculture sector was about 10% of the annual insured employment in the lumber manufacturing sector in 1975. Expansion of the fishing industry is faced with formi-

Table 6.3. *Eureka–Trinidad troll-caught chinook and coho salmon landings. (Pacific Fishery Management Council 1987; J. Lesh, California Department of Fish and Game, personal communication).*

Year	Landings (thousands) Chinook	Landings (thousands) Coho
1971–75 Average	142.1	133.9
1976	165.4	204.8
1977	161.2	19.3
1978	155.2	140.3
1979	218.4	66.0
1980	131.3	19.8
1981	99.7	35.9
1982	96.0	28.6
1983	35.2	26.6
1984	14.0	3.7
1985[a]	3.7	0.3
1986[b]	47.4	5.2
1987[b]	70.5	12.0

[a] No commercial salmon season in Eureka–Trinidad zone in 1985

[b] Unpublished preliminary data, California Department of Fish and Game.

dable constraints; marketing and seasonal fluctuations are major problems, and negative economic impacts have been associated with fishery closures imposed by Pacific Fisheries Management Council. A basic problem in expanding shellfish culture in the bay is pollution from human sewage and nonpoint sources. Presently, if more than 1.27 cm of rain falls within 24 h, the bay is closed to harvesting for the next 5 days. During wet winters, significant long periods of closure can occur; for example, in 1981 Coast Oyster Company lost 82 working days. These closures result in an unreliable supply to the wholesaler.

The importance of tourism and recreation to the Humboldt County economy is difficult to estimate because secondary indicators must be used. Dean et al. (1973) forecasted significant growth for tourism-related sectors of the economy for the period 1975–85. The Redwood Economic Development Commission (1987), using motel revenue figures, estimated a 13% average annual growth rate for Eureka in 1980–85. The same reports stated that during the summer months of 1985, approximately 12,000 campers were turned away at Prairie Creek State Park, a few kilometers north of Eureka, because all campgrounds were full. The Eureka–Humboldt County Convention and Visitors Bureau 1986–87 annual report estimated the dollar impact from motorcoach tours in 1987 to be $1,080,000.

Humboldt Bay and its natural resources are important in attracting people to the area. Water-related recreational activities include sport fishing, waterfowl hunting, clam digging, crabbing, sailing, small-craft boating, surfing, skin diving, birdwatching, and beachcombing. Van Kirk and Ahern (1984) surveyed nonresident anglers visiting Humboldt and Del Norte Counties in 1982. The mean length of stay by all visiting anglers was 42 days with an average expenditure of $31/day. Most of these anglers fished for salmon. In a survey from 1957 to 1960, Miller and Gotshall (1965) determined that an average of 27,144 angler-days was expended annually in Humboldt Bay. The Pacific Fishery Management Council (1987) estimated 33,700 days were expended in recreational fishing for salmon by anglers fishing out of Eureka from May to September 1985. In 1986 a new public boat ramp was completed in Eureka Channel directly opposite the Woodley Island Marina to improve boating access to the bay. A 1985 planning advisory committee report to the Humboldt Bay Harbor Recreation and Conservation District recommended the development of fishing piers and fishing "parks" and the promotion of sport-fishing opportunities for Humboldt Bay.

Shipping facilities in Humboldt Bay primarily serve the forest products and petroleum industries. Commodity flows in and out of the bay are principally the export of forest products and the import of petroleum products for local consumption and chemicals for wood pulp processing by the two pulp mills located on the Samoa Spit (Figs. 6.3 and 6.4). The number of vessels calling on Humboldt Bay average about 350 per year (Shapiro and Associates, Inc. 1980). Deep-draft navigation uses and related industrial areas occupy about 182 ha of land, about 1.3% of the total land in the Humboldt Bay area, and about 10% of the bay's shoreline parcels. Ray (1982) stated that significant increase in deep-draft navigation is unlikely in the near future.

One area of potential new coastal-dependent industrial development on Humboldt Bay is support facilities for Outer Continental Shelf (OCS) oil and gas development. Through the exploratory drilling phase, the only facility required would be a temporary service base to serve as a materials storage and transfer site to the offshore drilling location. If commercial quantities of oil or gas were found, onshore facilities that could be required are a permanent service base, pipelines from OCS facility to shore, gas processing facilities, and an oil export terminal. Such facilities would boost the local economy, but at the same time would require dredging and pier or dock construction at selected sites in Humboldt Bay (Humboldt County 1981).

Environmental Concerns

A report by the California Department of Health Service (1988) gave the status of Humboldt Bay water quality since the completion of wastewater treatment projects in Eureka and Arcata (1982–87). Improvements made by these projects virtually eliminated a chronic wet-weather problem associated with the discharge of raw or partially treated sewage. Commercial shellfish-growing areas with a conditionally approved classification, such as Humboldt Bay, are usually closed to harvesting during and after rain storms. These closures are necessary because bay water quality degrades following rainfall from surface runoff, surface turbulence, and overloading of wastewater collection facilities. Until 1987, the closure rule stated that whenever there was

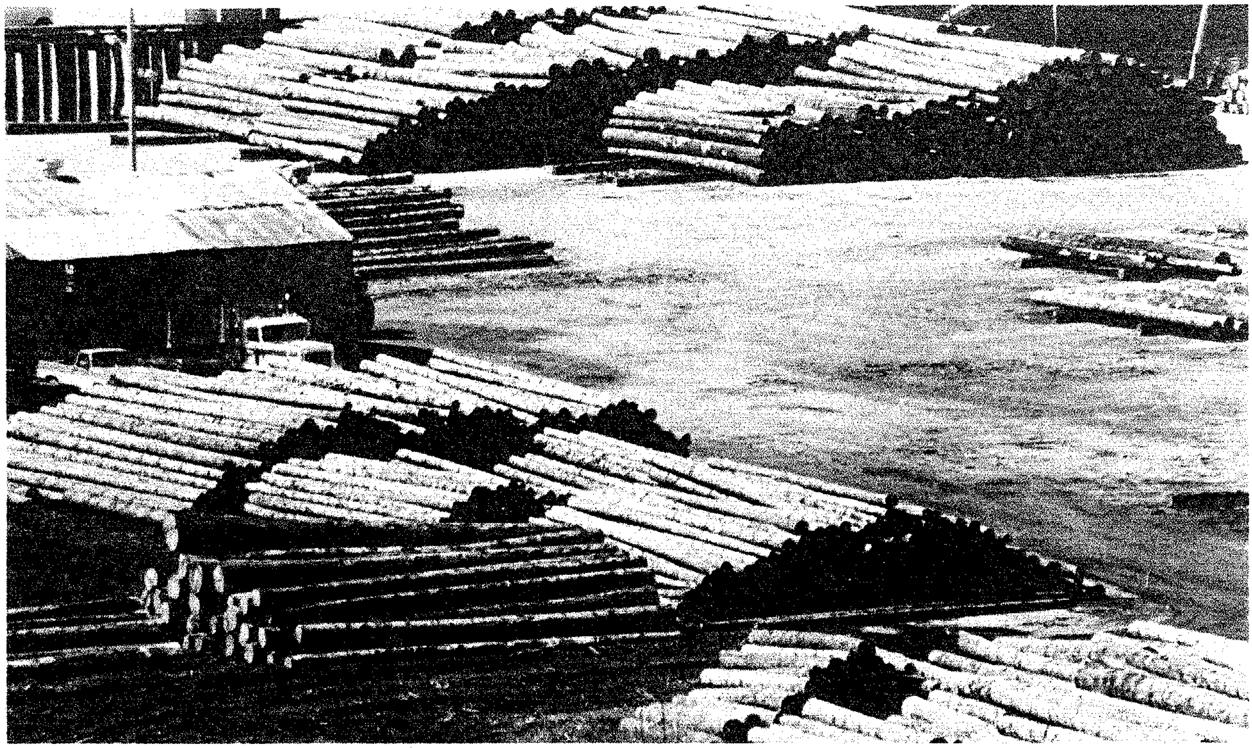

Fig. 6.3. Export log storage area located adjacent to south Humboldt Bay.

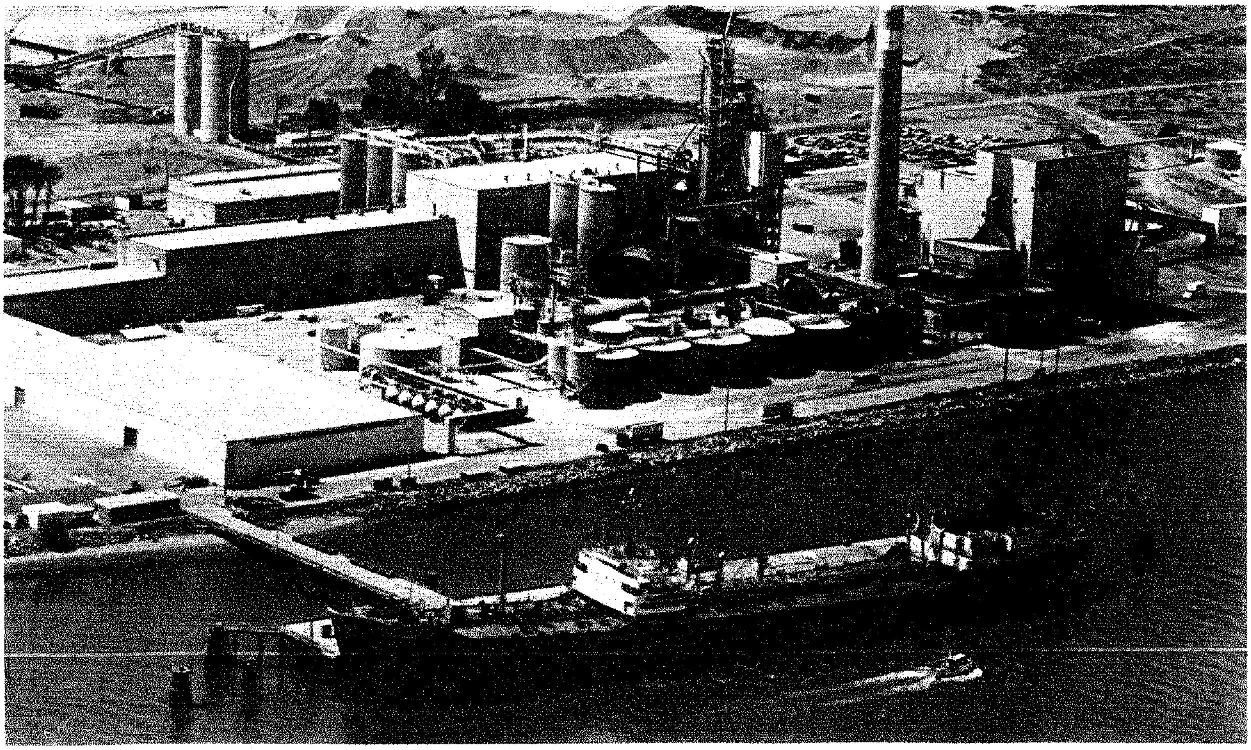

Fig. 6.4. One of two pulp mills located on the North Spit of Humboldt Bay.

1.27 cm of rainfall or more in any 24-h period, the bay would be closed to shellfish harvesting for 5 days afterwards. With the completion of the wastewater treatment projects in 1987, the rule was modified; the 5day closure time was reduced to 2 days for 1.27–2.54 cm rainfall and 3 days for rainfall exceeding 2.54 cm in 24 h.

The 1988 report stated that land surveys of the Humboldt Bay area revealed many locations where livestock animals pastured along bay tributaries with little to prevent their wastes from being washed into the bay during rainy periods. Two areas of prime concern were the Elk River valley and the Arcata Bottoms between the city of Arcata and Mad River Slough. Changes in farm management practices may help to alleviate this problem. Included in the report were the results of a study on the impacts of seagull concentrations on water quality. During winter months, thousands of seagulls congregate on the bay mudflats at low tide to feed on herring eggs deposited on eelgrass. During high tide periods, the gulls move to the local solid waste landfill where they feed on various waste materials or to the Arcata wastewater treatment plant where they feed on raw sewage entering the plant at the primary clarifiers. Data indicate that seagulls returning to the mudflats after these feeding excursions contribute significant levels of fecal coliform to bay waters. In 1988, Arcata screened the primary clarifiers to prevent gull access.

Tributylin (TBT), an effective antifouling agent used in marine paints, is also highly toxic to most aquatic life. Stallard et al. (1987) monitored TBT in California coastal waters and noted that where TBT concentrations are above 100 parts per trillion (pptr), there are usually absences of fauna, especially mussels and macrophytes. In general, California coastal waters contain less than 20 pptr TBT. Except for a sample taken from a shipyard in South Bay, all 1986 Humboldt Bay water samples were well below 20 pptr TBT. The shipyard has installed a particulate separator through which all water used to clean boats passes. This has helped to alleviate the TBT problem and oysters are now being grown commercially at the shipyard boat dock. Since 1987, most boats less than 24.4 m cannot use TBT as an antifouling agent.

At the Woodley Island Marina in Humboldt Bay, storage tanks are located below each dock into which tenants are allowed to pump oil and water from boat bilges. These tanks are periodically emptied and the oil and water separated; the water is directed to Eureka's sewer system, and the oil is sent to the local recycling center. In addition, trash cans are provided on all docks near the water so that plastic and other wastes are less likely to end up in the bay (Jack Alderson, Humboldt Bay Harbor Recreation and Conservation District, personal communication).

Other possible pollutants in Humboldt Bay are pesticides from agriculture runoff and synthetic organic chemicals from industrial discharge. Pentachlorophenols (PCP's) and possibly dioxin, an unintentional contaminant associated with PCP's, can enter the bay during storm events from lumberyards that use PCP's as a fungicide. Dioxin also occurs in the wastewater of the two pulpmills on the North Spit. Even though this wastewater is discharged on the ocean side of the North Spit, aerial photographs of the effluent plume indicate that the plume is sometimes carried by currents and the incoming tide into Humboldt Bay (Frank Palmer, Regional Water Quality Control Board, personal communication).

Selenium (Se) concentrations in water and in the tissues of scoters were compared for Humboldt Bay and Suisun and San Pablo bays (part of the San Francisco Bay-Delta complex; White et al. 1989). Surf scoters from Humboldt Bay average 0.60 parts per million (ppm) Se in muscle and 2.5 ppm in liver. These levels were significantly lower than those from Suisun and San Pablo bays, which, in early winter, averaged 5–6 times higher than Humboldt Bay in muscle and 10–11 times higher in liver. By late winter, Suisun and San Pablo samples were 10–14 times higher than Humboldt Bay samples in muscle and 14–22 times higher in liver samples. Water collected from Humboldt Bay in January 1988 contained 0.05 parts per billion (ppb) and 0.06 ppb dissolved total Se on low and high tide, respectively. All water samples from Suisun Bay and 14 of 16 samples from San Pablo Bay contained Se concentrations higher than in Humboldt Bay. Maximum concentrations were 3–4 times higher than in Humboldt Bay. Dissolved Se concentrations of 0.05–0.06 ppb indicated that there is no Se enrichment of Humboldt Bay waters from anthropogenic sources.

Despite past human activities that have altered the pristine character of Humboldt Bay, the bay is still cleaner and healthier than any enclosed bay in California (Pequegnat and Butler 1982). Current environmental laws and requirements regarding proposed bay projects provide opportunities to make the most effective use of bay resources while preserving the biological integrity of the bay.

Chapter 7. Research and Management Information Needs

Despite the efforts of academic, agency, and other researchers, information on biological communities and their structure in Humboldt Bay is rudimentary. Available evidence suggests that the distribution of many plants and animals is linked to the occurrence and distribution of various sediments. The sources of sediment, the general physical profile, and distribution of sediments in the bay are known in broad terms. To provide detailed information on the relations of the physical and chemical characteristics of bay sediments with the various plants and animals that live on and in them, a sediment study should be made of three compartments of the bay; sediment pH, oxidation–reduction potential (Eh), organic content, biological oxygen demand (BOD), presence of potentially toxic metals or compounds, and factors, including human, which influence the sedimentary environment should be determined.

Although several years of sampling have resulted in a reasonably accurate list of macroscopic plants and animals for Humboldt Bay, there is still little understanding of how these biological entities interact. Common patterns of competition and predation are known from general ecological principles and studies in other temperate marine embayments. Important estimates of primary and secondary productivity are mostly dependent on extrapolations of data from marine estuaries of the Atlantic coast and even the coast of Europe. Detailed investigations should be focused on precisely how numerically abundant species interact. Such investigations will require field and laboratory approaches and should use technical advances such as remote monitoring devices to document interactions.

The ecological energetics of the bay can be sketched only in general terms. A significant part of the primary productivity of the bay appears to pass through important microproducers (bacteria, algae, diatoms) and microconsumers (bacteria, protozoans, meiofaunal organisms) before it becomes available to other consumers. It would be useful to document the fate of primary plant productivity and the relationship of macroscopic plant productivity to microbial processes. Such information would improve our understanding of the population dynamics of deposit-feeding animals found in benthic sediments, which are fed upon by many secondary consumers.

The navigational channels of the bay are periodically dredged. There are proposals to deepen these channels an additional 1.5 m for use by larger, deeper-draft commercial shipping. Deepening the Entrance Channel will allow more wave energy to reach Entrance Bay, which will likely cause additional erosion problems in the King Salmon area. Deepening the channels will change the low tide holding capacity of the bay, which will influence circulation patterns and flushing characteristics. Velocity of the tide wave moving up and down the channels will change significantly. All these changes will have an impact on the chemistry and biology of the bay. An understanding of circulation and flushing, the nutrient budget, and bay productivity is necessary to assess changes caused by deepening the channels.

Humboldt Bay has extensive mudflats, marshes, and adjacent diked agricultural fields. In the next few decades, sea level will continue to rise, and although the predicted rise is small (5–50 cm), it, too, will cause changes in circulation and flushing patterns, accelerate erosion of marsh lands, dikes and sand spits, and cause flooding in some areas. These problems should be addressed now to protect bay resources for the future. Bay development, restoration, and mitigation projects should take into account future changes in sea level and attendant problems.

As the Humboldt Bay National Wildlife Refuge expands through acquisition of land adjacent to the bay, opportunities for the addition of freshwater, brackish water, and saltwater marshes will be available. Each kind of marsh provides optimal conditions for some species of flora and fauna but is limiting to others. Refuge managers need information on marsh productivity, species interactions, and marsh design and construction to best use land management opportunities.

Humboldt Bay is experiencing a steady increase in use for various types of recreation as well as for certain types of commercial enterprise. Increased use may be causing negative changes in the abundance and distribution of some plants and animals. One activity may cause only a slight change, but combined, the negative impacts of many uses can be cumulative and perhaps multiplicative. For example, what effect does increased boating (fishing, hunting, sailing, clamming, sightseeing, commercial) have on the distribution, abundance, and use patterns of waterfowl, particularly brant? How do increases in commercial oyster-growing operations affect eelgrass abundance and distribution and organisms associated with the eelgrass community? From a management perspective, the California Department of Fish and Game would like additional abundance, distribution, and life history information on commercially important fish species, particularly sharks, surfperches and Pacific herring populations (J. Spratt, R. Warner, and A. Petrovitch, California Department of Fish and Game, personal communications).

As use of Humboldt Bay and the surrounding area increases, incidences of pollution will probably also increase. The California Department of Fish and Game (Klein and Gulling, Eureka, California, unpublished data) cataloged 177 outfalls as possible pollution sources into Humboldt Bay. That survey should be updated and samples from suspected sources should be collected and analyzed periodically. The contamination of bay water, bottom sediments, and organisms is a major concern, and studies to test contaminant effects on the system and its function should be carried out.

Decisions concerning the bay are now being made without the information previously discussed. Many actions taken may be irreversible, and some may have long-term adverse impacts on fish, birds, mammals, and other biota of the bay. Addressing these information needs in the near future is important to the preservation and enhancement of bay resources and to the region's economy as well.

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Appendix A. Plants of Humboldt Bay

Appendix data are from reports and records compiled by Monroe (1973), Shapiro and Associates, Inc. (1980), Eicher (1987), and K. . . . Rasmussen (Department of Biological Sciences, Humboldt State University, unpublished data).

Taxa	Common name	Abundance[a]	Habitat[b]	Remarks
Algae				
Chlorophyta				
Bryopsis hypnoides	Moss alga	O	Ro	Near bay mouth
Enteromorpha intestinalis	Green alga	A	Ro,Pi,Sa,Mu	
Spongomorpha coalita	Sponge alga	O	Ro,Pi	Near bay mouth
Ulva lactuca	Sea lettuce	A	Ro,Pi,Sa,Mu	
Phaeophyta				
Alaria marginata	Wing kelp	C	Ro	Near bay mouth
Egregia menziesii	Feather boa kelp	C	Ro	Near bay mouth
Fucus gardneri	Rock weed	C	Ro,Pi	
Fucus distichus	Rock weed	C	Ro,Pi	
Fucus spiralis	Rock weed	R	Ro	Near bay mouth
Pelvetiopsis limitata	Rock weed	C	Ro	Near bay mouth
Sargassum muticum	Grape kelp	O	Ro	Introduced
Rhodophyta				
Botryoglossum farlowianum	Grape tongue alga	O	Ro	Near bay mouth
Botryoglossum ruprectianum	Grape tongue alga	O	Ro	Near bay mouth
Corallina spp.	Coralline alga	C	Ro	Jetties by bay mouth
Endocladia muricata	Red alga	C	Ro,Pi	
Gigartina papillata	Grapestone alga	C	Ro,Pi	
Gracilaria verrucosa	Slender red alga	C	Ro,Sa	In eelgrass beds
Iridaea cordata	Iridescent red alga	C	Ro,Pi	Near bay mouth
Microcladia borealis	Red alga	O	Ro	Near bay mouth
Microcladia coulteri	Red alga	O	Ro	Near bay mouth
Polysiphonia paniculata	Red alga	C	Ro	Near bay mouth
Polysiphonia pacifica	Red alga	C	Ro	
Porphyra lanceolata	Laver, nori	C	Ro	Near bay mouth
Porphyra perforata	Laver, nori	C	Ro,Pi	
Porphyra sanjuanensis	Laver, nori	R	Ro	Near bay mouth
Rhodomela larix	Red alga	O	Ro	Near bay mouth

Taxa	Common name	Abundance[a]	Habitat[b]	Remarks
Rhodophyta *(continued)*				
Rhodymenia oweniae	Red alga	O	Ro	Near bay mouth
Chrysophyta				
Vaucheria longicaulis	Yellow-brown alga	O	Sa,Mu	Intertidal
Flowering plants (Anthophyta)				
Atriplex patula var. *hastata*	Fat hen	C		In salt marshes
Carex lyngbyei	Lyngby's sedge	A		In salt marshes, brackish
Cordylanthus maritimus var. *palustris*	Point Reyes bird's beak	C		In salt marshes
Cuscuta salina	Dodder	A		In salt marshes
Deschampsia caespitosa var. *beringensis*	Tufted hairgrass	A		In salt marshes
Distichlis spicata	Saltgrass	A		In salt marshes
Grindelia stricta ssp. *blakei*	Humboldt Bay gumplant	C		In salt marshes
Jaumea carnosa	Jaumea	C		In salt marshes
Juncus lesueurii var. *lesueurii*	Salt rush	A		In salt marshes
Limonium californicum	Sea lavender	C		In salt marshes
Orthocarpus castillejoides var. *humboldtiensis*	Humboldt Bay owl's clover	C		In salt marshes
Parapholis incurva	Sicklegrass	C		In salt marshes
Parapholis strigosa	Sicklegrass	C		In salt marshes
Plantago maritima var. *juncoides*	Sea plantain	C		In salt marshes
Salicornia virginica	Pickleweed	A		In salt marshes
Scirpus maritimus	Saltmarsh bulrush	A		In salt marshes, brackish
Spartina densiflora	Cordgrass	A		In salt marshes
Spergularia macrotheca	Sand spurry	C		In salt marshes
Triglochin concinnum	Arrow grass	O		In salt marshes
Triglochin maritimum	Arrow grass	C		In salt marshes
Zostera marina	Eelgrass	A	Sa,Mu	Forms dense beds

[a] A = abundant, C = common, O = occasional, R = rare.
[b] Ro = rocks, Pi = pilings or other artificial structures, Sa = sand, Mu = mud.

Appendix B. Selected Aquatic Invertebrates of Humboldt Bay

Appendix data are from reports and records compiled by Monroe (1973), Boyd et al. (1975), Shapiro and Associates (1980), and Bott and Diebel (1982). Nomenclature follows usage of the American Fisheries Society for mollusks (Turgeon et al. 1988) and decapods (Williams et al. 1989).

Taxa	Common name	Abundance[a]	Habitat[b]	Remarks
Porifera				
Haliclona permollis	Sponge	C	Ro,Epi	
Haliclona sp.				
Cliona sp.	Sponge	C	Sym	On shells
Cnidarians				
Aequorea sp.	Hydromedusa	C	Pk	
Campanularia integra	Hydroid	C	Sym	With other hydroids
Obelia borealis	Hydroid	A	Ro,Epi,Pi	
Obelia longissima	Hydroid	A	Pi	
Plumularia spp.	Hydroid			
Sertularia spp.	Hydroid	C	Epi	On algae
Thuiaria similis	Hydroid			
Tubularia crocea	Hydroid	A	Ro,Pi,Epi	
Tubularia marina	Hydroid	A	Ro	
Velella lata	By-the-wind sailor	A	Pk	
Aurelia spp.	Jellyfish	C	Pk	
Chrysaora sp.	Jellyfish	O	Pk	
Pelagia sp.	Jellyfish	O	Pk	
Anthopleura artemisia	Sand anemone	C	Sa	
Anthopleura elegantissima	Aggregating anemone	C	Ro	
Anthopleura xanthogrammica	Great green anemone	C	Ro	
Cerianthus sp.	Burrowing anemone	O	Sa, Mi	
Diadumene spp.	Orange striped anemone	C	Ro,Pi	
Epiactis prolifera	Brooding anemone	C	Ro,Pi	
Gersemia rubriformis	Sea strawberry	O	Ro	Near bay mouth
Haliplanella luciae	Anemone	C	Pi	
Metridium senile	White anemone	C	Pi	
Nematostella vectensis	Salt marsh anemone	C	Mu	In salt marshes
Tealia crassicornis	Splotched anemone	C	Ro,Pi	

Species	Common name	Abundance[a]	Habitat[b]	Remarks
Ctenophora				
Pleurobrachia bachei	Comb jelly	A	Pk	
Nemertea				
Amphiporus imparispinosus	Ribbon worm	C	Ro,Pi	
Carinoma mutabilis	Ribbon worm	C	Sa,Mu	
Carinomella lactea	Ribbon worm	O	Sa,Mu	
Cerebratulus californiensis	Ribbon worm	C	Sa,Mu	
Emplectonema sp.	Ribbon worm	O	Sa	On shell fragments
Paranemertes californica	Ribbon worm	C	Sa,Mu	
Tubulanus pellucidus	Ribbon worm	C	Sa,Mu	
Tubulanus polymorphus	Ribbon worm	C	Sa,Mu	
Annelida				
Polychaeta				
Abarenicola antebranchia	Lugworm	O	Mu	
Abarenicola humboldtensis	Lugworm	O	Mu	
Abarenicola pacifica	Lugworm	O	Sa	
Amaena occidentalis	Hairy-gill worm	O	Mu	
Ampharete arctica	Bristle worm	O	Sa	
Anaitides groenlandica	Paddle worm	R	Sa	
Anaitides williamsi	Paddle worm	C	Sa,Mu	
Aricidea suecica	Paranoid worm	O	Sa,Mu	
Armandia brevis	Bristle worm	C	Sa,Mu	
Autolytus sp.	Bristle worm	C	Sa,Mu	
Boccardia berkeleyorum	Spionid worm	O	Sym	Bores *podoesmus* shells
Brania sp.	Bristle worm	R	Sa	
Capitella capitata	Tube worm	A	Mu	
Caulleriella alata	Thread worm	O	Sa	
Caulleriella hamata	Thread worm			
Caulleriella sp.	Thread worm	O	Sa	
Chaetozone setosa	Hairy-gill worm	C	Sa,Mu	
Chaetozone sp.	Hairy-gill worm	C		
Cheilonereis cyclurus	Hermit crab worm	C	Sym	With hermit crabs
Chone gracilis	Paddle worm	O	Sa	
Chone sp.	Paddle worm			
Cirratulus cirratus	Bristle worm	R	Sa	

Species	Common name	Abundance[a]	Habitat[b]	Remarks
Polychaeta (*continued*)				
Cistenides brevicoma	Tube worm	O	Mu	
Cossura pygodactylata	Bristle worm	R	Mu	
Dodecaceria concharum	Bristle worm	R	Sa	
Drilonereis falcata	Bristle worm	C	Sa,Mu	
Eteone californica	Paddle worm	C	Sa,Mu	
Eteone dilatae	Paddle worm	C	Sa	
Eteone pacifica	Paddle worm	C	Sa,Mu	
Euclymene delineata	Polychaete worm	C	Sa,Mu	
Eulalia aviculiseta	Paddle worm	O	Sa	With shell debris
Eumidia bifoliata	Paddle worm	C	Sa,Mu	
Eumidia sanguinea	Paddle worm	C	Sym	With algae
Eunereis sp.	Mussel worm			
Eupolymnia crescentis	Terebellid worm	R	Sa,Mu	
Eusyllis assimilis	Paddle worm	O	Sa	
Euzonus mucronata	Bristle worm	C	Sa	
Exogone lourei	Bristle worm	A	Sa,Mu	
Exogone sp.	Bristle worm		Sa,Mu	
Glycera americana	Bristle worm	O	Sa	
Glycera capitata	Bristle worm	O	Sa	
Glycera oxycephala	Bristle worm	C	Sa,Mu	
Glycera tenuis	Bristle worm	A	Sa	
Glycinde polygnatha	Bristle worm	A	Sa,Mu	
Glycinde sp.	Bristle worm			
Gyptis brevipalpa	Bristle worm	O	Sa,Mu	
Halosydna brevisetosa	Scale worm	O	Sa,Mu	
Halosydna latior	Scale worm	O	Sa	
Haploscoloplos elongatus	Orbinid worm	A	Sa,Mu	
Harmothoe imbricata	Scale worm	A	Ro	
Harmothoe lunulata	Scale worm	A	Sa,Mu	
Harmothoe priops	Scale worm	O	Sa	
Hemipodus borealis	Slaty blue worm	O	Sa,Mu	
Hemipodus imbricata	Slaty blue worm			
Hesperone adventor	Scale worm	O	Sym	In *Urechis* burrows
Heteromastus filobranchus	Capitellid worm	A	Mu	
Lumbrineris californiensis	Bristle worm	O	Mu	
Lumbrineris japonica	Bristle worm	O	Sa,Mu	
Lumbrineris tetraura	Bristle worm	A	Sa,Mu	
Lumbrineris zonata	Bristle worm	C	Mu	
Lysilla labiata	Polychaete worm	A	Sa,Mu	

Species	Common name	Abundance[a]	Habitat[b]	Remarks
Polychaeta *(continued)*				
Magelona pacifica	Bristle worm	O	Mu	
Magelona pitelkai	Bristle worm	O	Sa,Mu	
Magelona sacculata	Bristle worm	O	Sa	
Mediomastus californiensis	Lugworm	A	Sa,Mu	
Mellina oculata	Polychaete worm			
Mesochaetopterus taylori	Bristle worm	O	Sa	In eelgrass beds
Nainereis sp.	Bristle worm	R	Sa	
Neanthes sp.	Bristle worm	C	Sa,Ro	
Nephtys caecoides	Bristle worm	C	Sa,Mu	
Nephtys californiensis	Bristle worm	C	Sa	
Nephtys ferruginea	Bristle worm	R	Mu	
Nephtys parva	Bristle worm	C	Sa,Mu	
Nereis procera	Bristle worm	C	Sa,Mu	
Nereis sp.	Bristle worm	O	Sa	
Nothria sp.	Bristle worm	O	Sa	
Notomastus tenuis	Thin red worm	O	Mu	
Ophelia assimilis	Bristle worm	A	Sa,Mu	
Ophelia magna	Bristle worm		Sa,Mu	
Owenia collaris	Tube worm	A	Sa,Mu	
Paleonotus bellis	Bristle worm	C	Sa,Mu	
Paraonis gracilis	Bristle worm	R	Sa,Mu	
Phloe glabra	Polychaete worm	O	Sa,Mu	
Phloe tuberculata	Polychaete worm	A	Sa,Mu	
Pholoides aspera	Polychaete worm	O	Sa,Mu	
Phragmatopoma californica	Tube worm		Ro	
Pilargis maculata	Polychaete worm	R	Sa,Mu	
Pisione remota	Polychaete worm	R	Sa	
Pista cristata	Bristle worm	O	Sa	
Pista pacifica	Bristle worm	C	Sa,Mu	
Platynereis agassizi	Bristle worm			
Platynereis bicanaliculata	Tube worm	A	Sa,Mu,Ro	
Polydora brachycephala	Spionid worm	A	Sa,Mu	
Polydora ligni	Spionid worm			
Polydora pygidialis	Spionid worm	R	Sa	
Polydora socialis	Spionid worm	A	Sa,Mu	
Polydora websteri	Spionid worm		Sym	Bores in shell
Prionospio cirrifera	Spionid worm	R	Sa	
Protodorvillea gracilis	Bristle worm	O	Sa	
Pseudopolydora kempi	Spionid worm	O	Sa,Mu	

Species	Common name	Abundance[a]	Habitat[b]	Remarks
Polychaeta *(continued)*				
Sabellaria cementarium	Plume worm	C	Ro	Attached to shell debris
Sabellaria gracilis	Plume worm	C	Ro	Attached to shell debris
Scalibregma inflatum	Bristle worm	O	Sa,Mu	
Schistomeringos longicornis	Polychaete worm	A	Sa,Mu	
Scolelepis sp.	Spionid worm	R	Mu	
Scoloplos sp.	Bristle worm		Sa,Mu	
Serpula vermicularis	Plume worm	C	Ro	On shell debris
Sphaerosyllis californiensis	Syllid worm	A	Sa,Mu	
Spio filicornis	Spionid worm	O	Sa	
Spiophanes anoculata	Spionid worm			
Spiophanes berkeleyorum	Spionid worm	O	Sa,Mu	
Spiophanes bombyx	Spionid worm	A	Sa,Mu	
Sternapsis fossor	Bristle worm	R	Mu	
Sthenelais berkeleyi	Bristle worm	C	Sa,Mu	
Sthenelais tertiaglabrata	Bristle worm	R	Mu	
Streblosoma crassibranchia	Bristle worm	R	Mu	
Streblospio benedicti	Spionid worm	O	Mu	
Tenonia kitsapensis	Polychaete worm	O	Sa,Mu	
Tharyx monilaris	Bristle worm	A	Sa,Mu	
Tharyx multifilis	Bristle worm	A	Sa,Mu	
Trochochaeta franciscanum	Bristle worm	R	Mu	
Typosyllis fasciata	Syllid worm	C	Sa,Mu	
Typosyllis hyalina	Syllid worm	C	Sa,Mu	
Archiannelida				
Polygordius sp.		O	Sa	
Saccocirrus sp.		O	Sa	
Sipuncula				
Goldfingia hespera	Peanut worm	C	Mu	Among eelgrass rhizomes
Echiura				
Listriolobus pelodes	Spoon worm	R	Mu	In eelgrass beds
Urechis caupo	Fat innkeeper	C	Sa	
Phoronida				
Phoronopsis viridis	Green plume worm	A	Sa,Mu	
Phoronis pallida	Plume worm	R	Sym	In *Upogebia* burrows

Species	Common name	Abundance[a]	Habitat[b]	Remarks
Crustacea				
Amphipoda				
Allorchestes angusta	Beach hopper	C	Sa	Intertidal on algae
Anisogammarus confervicolus	Gammarid	C	Mu	In intertidal marshes
Anisogammarus pugettensis	Gammarid	C	Mu	In marshes
Aoroides columbiae	Gammarid	C	Sa,Mu	In tubes
Atylus tridens	Gammarid	O	Sa,Mu	Nestles in algae and debris
Caprella angusta	Skeleton shrimp	C	Epi	
Caprella californica	Skeleton shrimp	C	Epi	
Caprella equilibra	Skeleton shrimp	C	Epi	
Caprella gracilior	Skeleton shrimp	C	Epi	
Caprella laeviuscula	Skeleton shrimp	C	Epi	
Corophium acherusicum	Gammarid	A	Epi	On pilings, algae
Corophium spinicorne	Gammarid	A	Mu	Estuarine
Corophium stimpsoni	Gammarid	A	Mu	Estuarine
Cymadusa sp.	Gammarid			Builds tubes on algae
Eohaustorius sp.	Gammarid	O	Sa	
Ischyrocerus anguipes	Gammarid	O	Sa	
Jassa falcata	Gammarid	C	Sa	
Megamphopus martesia	Gammarid		Epi	Builds tubes on algae
Melita dentata	Gammarid	C	Sa	
Metacaprella kennerlyi	Skeleton shrimp	C	Epi	
Orchestia traskiana	Beach hopper	C	Mu	Intertidal marshes
Orchestoidea benedicti	Beach hopper	C	Sa	Intertidal
Orchestoidea californiana	Beach hopper	C	Sa	Intertidal
Paraphoxus spp.	Gammarid	O	Sa	
Photis brevipes	Gammarid	C	Sa,Mu	
Podocerus cristatus	Gammarid	O	Sa	
Protomedia articulata	Gammarid	C	Sa,Mu	
Synchelidium rectipalmum	Gammarid	O	Sa,Mu	
Synchelidium shoemakeri	Gammarid	O	Sa,Mu	
Tritella pilimana	Skeleton shrimp	O	Epi	
Cirripedia				
Balanus crenatus	White barnacle	A	Ro,Pi	
Balanus glandula	Chalky white barnacle	A	Ro,Pi	
Balanus nubilus	Piling barnacle	O	Pi	
Chthamalus dalli	Gray barnacle	A	Ro,Pi	
Pollicipes polymerus	Goose barnacle	C	Ro,Pi	

Species	Common name	Abundance[a]	Habitat[b]	Remarks
Cirripedia (*continued*)				
Semibalanus cariosus	Thatched barnacle	C	Ro,Pi	
Copepoda				
Acartia clausi	Copepod	A	Pk	
Acartia logiremis	Copepod	A	Pk	
Acartia tonsa	Copepod	A	Pk	Estuarine
Calanus finmarchicus	Copepod	C	Pk	
Clausidium vancouverense	Copepod		Sym	On *Callianassa*
Coryceaus affinis	Copepod		Pk	
Eucalanus bungii	Copepod		Pk	
Eurytemora affinis	Copepod		Pk	Estuarine
Mytilicola orientalis	Copepod	O	Sym	In gut of *Mytilus edulis*
Oithona similus	Copepod		Pk	
Oithona spinirostris	Copepod		Pk	
Paracalanus parva	Copepod		Pk	
Pseudocalanus minutus	Copepod		Pk	
Tortanus discaudatis	Copepod		Pk	
Cumacea				
Cumacea sp.	Cumacean			
Cumella vulgaris	Cumacean	O	Mu	
Diastylis sp.	Cumacean	C	Sa,Mu	
Diastylopsis dawsoni	Cumacean	C	Sa	
Eudorella pacifica	Cumacean	C	Mu	
Lamprops sp.	Cumacean	C	Sa,Mu	
Decapoda				
Callianassa californiensis	Ghost shrimp	O	Mu	
Callianassa gigas	Ghost shrimp	O	Sa,Mu	
Cancer antennarius	Rock crab	C	Sa,Mu	
Cancer anthonyi	Yellow crab	O	Ro	
Cancer gracilis	Slender crab	O	Sa	
Cancer magister	Dungeness crab	C	Sa	
Cancer productus	Red crab	C	Sa,Mu	
Crangon franciscorum	Bay shrimp	C	Sa,Mu	
Crangon nigricauda	Black-tailed shrimp	C	Sa	
Crangon nigromaculata	Black-tailed shrimp	C	Sa,Mu	
Crangon stylirostris	Bay shrimp	O	Sa	
Emerita analoga	Sand crab	O	Sa	Intertidal, beaches
Hemigrapsus nudus	Purple shore crab	C	Sa	Intertidal

Species	Common name	Abundance[a]	Habitat[b]	Remarks
Decapoda *(continued)*				
Hemigrapsus oregonensis	Green shore crab	C	Sa,Mu	Intertidal
Heptacarpus brevirostris	Grass shrimp	O	Sa	
Hippolyte californiensis	Grass shrimp	C		On eelgrass blades
Lophopanopeus bellus	Pebble crab	R	Ro	Near bay mouth
Pachycheles rudis	Porcelain crab	C	Ro	
Pachygrapsus crassipes	Lined shore crab	C	Ro	
Pagurus spp.	Hermit crabs	C	Ro	Intertidal
Pandalus danae	Coon stripe shrimp	O	Sa	
Petrolisthes cinctipes	Porcelain crab	C	Ro	Intertidal
Pinnixia franciscana	Pea crab	O	Sym	In burrows of *Urechis*
Pugettia producta	Kelp crab	C	Ro,Pi	Among large algae
Upogebia pugettensis	Blue mud shrimp	O	Mu	
Isopoda				
Alloniscus perconvexus	Isopod	C	Sa	Intertidal beaches
Armadilloniscus coronacapitalis	Isopod	O	Mu	Intertidal marshes
Cirolana harfordi	Isopod	C	Ro,Pi	Intertidal
Gnorimosphaeroma oregonensis	Isopod	C	Mu	Intertidal marshes
Idotea stenops	Isopod			
Idotea wosnesenskii	Isopod	C	Epi	On eelgrass, algae
Limnoria quadripunctata	Isopod	C	Pi	Bores into wood
Limnoria tripunctata	Isopod	C	Pi	Bores into wood
Littorophiloscia richardsonae	Isopod	O	Mu	Intertidal marshes
Munna sp.	Isopod	O	Sa	
Porcellio sp.	Isopod	C	Mu	Intertidal marshes
Synidotea sp.	Isopod	O	Sa	
Mysidacea				
Archaeomysis grebnitzkii	Mysid	O	Sa	
Tenaidacea				
Leptochelia dubia	Cheliferan	C	Sa,Mu	
Tenais sp.	Cheliferan	O	Sa	
Pycnogonida				
Achelia chelata	Sea spider	O	Sa,Ro	
Achelia nudiuscula	Sea spider	O	Sa	
Halosoma viridintestinale	Green sea spider		Epi	On eelgrass and hydroids

Species	Common name	Abundance[a]	Habitat[b]	Remarks
Mollusca				
Bivalvia				
Adula diegensis	Mytilid	A	Sa,Mu	Bores in shale, mudstone
Axinopsida serricata		O	Mu	
Bankia setacea	Pacific shipworm	C	Pi	Bores into pilings, wood
Clinocardium nuttallii	Basket cockle	C	Sa,Mu	
Crassostrea gigas	Giant Pacific oyster	A	Sa,Mu	Introduced, harvested
Gemma gemma	Gem clam	A	Mu	
Hinnites giganteus	Rock scallop	C	Ro,Pi	
Lyonsia californica	California lyonsia	A	Mu	
Macoma balthica	Baltic macoma	O	Mu	Estuarine, possibly introduced
Macoma identata	Identate macoma	O	Mu	
Macoma inquinata	Inquinate macoma	C	Sa,Mu	
Macoma nasuta	Bent-nose clam	A	Sa,Mu	
Mercenaria mercenaria	Quahog clam	R	Mu	Introduced
Mya arenaria	Soft-shell clam	A	Mu	Introduced
Mysella tumida	Clam	A	Sa,Mu	
Mytilus edulis	Bay mussel	A	Ro,Pi	
Mytilus californianus	California mussel	C	Ro,Pi	
Ostrea lurida	Native oyster	C	Ro,Pi	
Ostrea edulis	European oyster	O	Ro,Pi	Introduced, cultured
Panopea generosa	Geoduck	O	Mu	Very deep burrowing
Penitella penita	Common piddock	O	Ro	Bores in mudstone
Petricola carditoides	Petricolid clam	R	Mu	
Pododesmus cepio	Rock oyster	O	Ro	
Protothaca staminea	Pacific littleneck	A	Sa,Mu	
Protothaca tenerrima	Thin-shelled littleneck	O	Sa,Mu	
Saxidomus giganteus	Smooth Washington clam	C	Sa,Mu	
Saxidomus nuttalli	Common Washington clam	C	Sa,Mu	
Siliqua patula	Razor clam	O	Sa	Near bay mouth
Solen sicarius	Sickle razor clam	O	Sa,Mu	
Tagelus californianus	Jackknife clam	R	Sa,Mu	
Tapes japonica	Manila clam	R,C	Mu	Introduced, cultured
Tellina bodegensis	Bodega tellin	O	Sa	
Tellina modesta	Modesta tellin	C	Sa,Mu	
Tellina nuculoides	Tellin clam	C	Sa,Mu	
Transennella tantilla	Little transennella	A	Sa,Mu	
Tresus capax	Gaper clam	A	Sa,Mu	
Tresus nuttallii	Gaper clam	O	Sa,Mu	

Species	Common name	Abundance[a]	Habitat[b]	Remarks
Bivalvia *(continued)*				
Zirfaea pilsbryi	Rough piddock	O	Ro,Mu	Bores in rock, mudstone
Gastropoda				
Acmaea mitra	Dunce cap limpet	O	Ro	Near bay mouth
Aglaja diomedea	Sea slug	A	Sa,Mu	
Alvinia compacta	Snail	C	Sa,Mu	
Anisodoris nobilis	Sea lemon nudibranch	O	Ro	Near bay mouth
Assiminea californica	Translucent assiminea	A	Mu	In *Salicornia* marshes
Calliostoma canaliculatum	Top shell	O	Ro	Near bay mouth
Collisella asmi	Limpet	O	Sym	On *Tegula funebralis*
Collisella digitalis	Common limpet	O	Ro	Near bay mouth
Collisella pelta	Sheild limpet	C	Ro	Near bay mouth
Collisella scabra	Rough limpet	C	Ro	Intertidal near bay mouth
Cyclostremella sp.	Snail	R	Sa	
Cylichna alba	Snail	O	Sa	
Dendronotus giganteus	Giant nudibranch	O	Ro	
Dialula sandiegensis	Nudibranch	O	Ro	
Diodora aspera	Rough keyhole limpet	O	Ro	
Dirona albolineata	Nudibranch	O	Ro	
Epitonium sawinae	Snail	O	Sa	
Fartulum occidentale	Snail	R	Sa	
Haminoea vesicula	Snail	R	Sa	
Hermissenda crassicornis	Nudibranch	A	Ro,Sa	
Lacuna sp.	Snail	C	Sa,Mu,Ro	
Littorina newcombiana	Newcomb's littorine	R	Mu	In salt marshes
Littorina planaxis	Periwinkle	C	Ro	Near bay mouth, intertidal
Littorina scutulata	Periwinkle	C	Ro	Near bay mouth, intertidal
Mitrella gouldii	Snail	C	Sa,Mu	
Nassarius fossatus	Channeled dog whelk	A	Sa,Mu	
Nassarius mendicus	Lean dog whelk	C	Sa,Mu	
Nucella emarginata	Dog winkle	O	Ro	Near bay mouth
Nucella lamellosa	Dog winkle	O	Ro	Near bay mouth
Odostomia sp.	Snail	A	Sa,Mu	
Olivella biplicata	Purple olive shell	C	Sa	Near bay mouth
Olivella pycna	Olive shell	C	Sa	Near bay mouth
Ovatella myosotis	Mud snail	A	Mu	In salt marshes
Phyllaplysia taylori	Tectibranch	A	Epi	On eelgrass
Polinices lewisii	Moon snail	C	Sa,Mu	
Rictaxis punctocaelatus	Barrel shell	R	Sa,Mu	Sporadic recruitment
Searlesia dira	Snail	O	Ro	Near bay mouth

Species	Common name	Abundance[a]	Habitat[b]	Remarks
Gastropoda *(continued)*				
Tegula brunnea	Brown tegula	O	Ro	Near bay mouth
Tegula funebralis	Black tegula	O	Ro	Near bay mouth
Turbonilla sp.	Snail	R	Sa	
Octopoda				
Octopus dolfleini	Octopus	O	Ro	Near bay mouth
Polyplacophora				
Ischnochiton regularis	Blue chiton	R	Ro	Near bay mouth
Katharina tunicata	Black chiton	O	Ro	Near bay mouth
Mopalia ciliata	Notched chiton	C	Ro,Pi	
Mopalia lignosa	Hairy chiton	C	Ro,Pi	
Echinodermata				
Amphiodia occidentalis	Brittle star	C	Sa,Mu	
Amphipholis sp.	Brittle star	O	Sa	
Dendraster excentricus	Sand dollar	C	Sa	Near bay mouth
Eupentacta quinquesemita	White sea cucumber	C	Ro,Pi	
Leptasterias pusilla	Six-rayed sea star	C	Ro	
Leptosynapta albicans	Sea cucumber	O	Sa	
Pisaster brevispinus	Short spined sea star	C	Sa	
Pisaster ochraceous	Common sea star	C	Ro	Near bay mouth
Pycnopodia helianthoides	Sun star	O	Ro	Near bay mouth
Strongylocentrotus purpuratus	Purple urchin	O	Ro	Near bay mouth
Bryozoa				
Bowerbankia gracilis	Bryozoan	C	Ro, Epi, Pi	
Bugula pacifica	Bryozoan	C	Ro	
Crisia occidentalis	Bryozoan	C	Ro,Epi	
Membranipora membranacea	Bryozoan	C	Epi	On eelgrass blades
Schizoporella unicornis	Bryozoan	C	Pi,Epi	
Tricellaria occidentalis	Bryozoan	C	Ro,Epi,Pi	

[a] A = abundant, C = common, O = occasional, R = rare.

[b] Epi = epifaunal or epiphytic, Mu = mud, Pi = pilings or other artificial structures, Pk = planktonic, Ro = rocks, Sa = sand, Sym = symbiotic.

Appendix C. Fishes of Humboldt Bay

Data on relative abundance, life history, habitat use, and season of occurrence are adapted from reports and records compiled by Gotshall et al. (1980) and Shapiro and Associates, Inc. (1980). Nomenclature follows usage of the American Fisheries Society (Robins et al. 1980), as updated.

Taxa	Common name	Abundance[a]	Life history type[b] E	L	J	A	Habitat[c]	Season of occurrence[d]	Remarks
Family Petromyzontidae									
Lampetra tridentata	Pacific lamprey	C			X	X	TCSFW, CR	SP, S	Spawns in bay tributaries
Family Hexanchidae									
Notorynchus maculatus	Sevengill shark	C				X	DTS, STS	SP, S, F	Current small commercial and recreational fishery
Family Carcharhinidae									
Galeorhinus zyopterus	Soupfin shark	R							One record, caught by angling
Mustelus henlei	Brown smoothhound	C			X	X	STS, MF	All	
Triakis semifasciata	Leopard shark	C			X	X	DTS, STS, MF	All	Current small commercial and recreational fishery
Family Squalidae									
Squalus acanthias	Spiny dogfish	O			X	X	STS, MF	S	
Family Rajidae									
Raja binoculata	Big skate	O			X	X	STS, MF	SP, S	Sometimes taken from TCSSW piers by anglers
Family Dasyatidae									
Urolophus halleri	Round stingray	R				X	DTS, MF	SP, S	One record
Family Myliobatidae									
Myliobatis californica	Bat ray	C			X	X	DTS, STS, MF	SP, S, F	Sometimes taken from piers by anglers; preys on commercial oysters in bay

Taxa	Common name	Abundance[a]	Life history type[b] E	L	J	A	Habitat[c]	Season of occurrence[d]	Remarks
Family Chimaeridae									
Hydrolagus colliei	Spotted ratfish	R					DTS		One record, dipnetted
Family Acipenseridae									
Acipenser medirostris	Green sturgeon	O			X	X	DTS, STS, MF	S, F, W	
Family Ophichthidae									
Ophichthus zophochir	Yellow snake eel	O			X	X	DTS, STS	W	One record
Family Clupeidae									
Alosa sapidissima	American shad	O			X	X	STS, MF, CR	SP, S	Not known to spawn in bay tributaries
Clupea harengus pallasi	Pacific herring	A	X	X	X	X	DTS, STS, MF, P	All	Spawn on eel grass in winter; larvae and juveniles in bay to fall; small commercial fishery on adults
Dorosoma petenense	Threadfin shad	O				X	STS	S	Only three recorded from the bay
Family Engraulidae									
Engraulis mordax	Northern anchovy	A	X	X	X	X	DTS, STS, P, J	All	Throughout the bay in scattered schools in summer and fall; fewest in winter; eggs and larvae in spring; important forage fish
Family Salmonidae									
Oncorhynchus clarki	Cutthroat trout	O			X	X	TCSSW, CR, TCSFW	All	Remnant populations in bay tributary streams; numbers severely depressed

Taxa	Common name	Abundance[a]	Life history type[b] E	L	J	A	Habitat[c]	Season of occurrence[d]	Remarks
Family Salmonidae (*continued*)									
Oncorhynchus kisutch	Coho salmon	C			X	X	DTS, STS, TCSFW, CR	All	Adults migrate through bay to spawning tributaries; juveniles use bay as nursery habitat; summer adults move in with tides to feed; anglers take from jetties
Oncorhynchus mykiss	Rainbow trout	C			X	X	TCSSW, CR, TCSFW	All	Adult migrate through bay to spawning tributaries; juveniles may use bay as nursery habitat for short time; abundant in tributaries
Oncorhynchus tshawytscha	Chinook salmon	C			X	X	DTS, STS, TCSFW, CR, J	All	Same as coho salmon
Family Osmeridae									
Allosmerus elongatus	Whitebait smelt	O			X	X	STS, DTS	F, W, S	Spawning habits unknown
Hypomesus pretiosus	Surf smelt	C		X	X	X	STS, DTS	All	Spawns in marine waters on exposed sandy beaches
Spirinchus starksi	Night smelt	C		X	X	X	STS, DTS	All	Same as surf smelt
Spirinchus thaleichthys	Longfin smelt	A	X	X	X	X	STS, DTS, CR	All	Probably spawns in freshwater tributaries on Humboldt Bay
Thaleichthys pacificus	Eulachon	O				X	STS, DTS	W	Ascends freshwater streams to spawn but not reported in Humboldt Bay tributaries
Family Gonostomatidae									
Cyclothone acclinideus	Benttooth bristlemouth	R		X			DTS	W	Mesopelagic species
Family Myctophidae									
Stenobrachius leucopsarus	Northern lampfish	O		X			DTS	W, SP	Oceanic species, probably carried into Humboldt Bay during very high tides
Tarletonbeania crenularis	Blue lanternfish	O		X			DTS		Same as northern lampfish

Taxa	Common name	Abundance[a]	Life history type[b] E	L	J	A	Habitat[c]	Season of occurrence[d]	Remarks
Family Gadidae									
Microgadus proximus	Pacific tomcod	A			X	X	DTS, STS, MF	All	Use the bay as a nursery area
Family Ophidiidae									
Chilara taylori	Spotted cusk-eel	O			X	X	DTS	W, S	
Family Atherinidae									
Atherinops affinis	Topsmelt	C			X	X	DTS, STS, MF	All	Spawns over mudflats, though eggs and larvae have not been collected in Humboldt Bay
Atherinopsis californiensis	Jacksmelt	C	X	X	X	X	STS, TCSW, MF P, J	All	Spawns over vegetation in shallow tidal channels and mudflats; adults commonly taken by pier and jetty anglers
Family Trachipteridae									
Trachipterus altivelis	King-of-the-salmon	R					DTS		One record
Family Gasterosteidae									
Aulorhynchus flavidus	Tube-snout	C			X	X	DTS, STS	All	
Gasterosteus aculeatus	Threespine stickleback			X	X	X	STS, TCSW, TCFW, CR	All	
Family Syngnathidae									
Syngnathus leptorhynchus	Bay pipefish	C	X	X	X	X	STS, MF, TCSW	All	
Family Percichthyidae									
Morone saxatilis	Striped bass	R							One record, angler caught
Stereolepis gigas	Giant sea bass	R							One record, angler caught
Family Sciaenidae									
Atractoscion nobilis	White seabass	O		X			DTS, STS	W	
Genyonemus lineatus	White croaker	O				X	DTS, J	S, F	

Taxa	Common name	Abundance[a]	Life history type[b] E	L	J	A	Habitat[c]	Season of occurrence[d]	Remarks
Family Embiotocidae									
Amphistichus koelzi	Calico surfperch	O			X	X	DTS, J	W, SP, S	
Amphistichus rhodoterus	Redtail surfperch	C			X	X	DTS, STS, P	All	Popular recreational fish in Humboldt Bay
Cymatogaster aggregata	Shiner perch	A			X	X	DTS, STS, TCSW, P, J	All	One of most abundant species in Humboldt Bay
Embiotoca lateralis	Striped seaperch	C			X	X	DTS, STS, P, J	All	Recreational species
Hyperprosopon anale	Spotfin surfperch	R				X	J		One record
Hyperprosopon argenteum	Walleye surfperch	A			X	X	DTS, STS, P, J	All	Recreational species
Hyperprosopon ellipticum	Silver surfperch	C			X	X	STS, DTS, TCSW, P, J	All	Recreational species
Phanerodon furcatus	White seaperch	A			X	X	DTS, STS, P, J	All	Recreational species
Rhacochilus vacca	Pile perch	C			X	X	DTS, STS, P, J	All	Recreational species
Family Trichodontidae									
Trichodon trichodon	Pacific sandfish	O			X	X	DTS, STS		One record
Family Stichaeidae									
Anoplarchus purpurescens	High cockscomb	O			X	X	DTS, STS	Sp	
Cebidichthys violaceus	Monkeyface prickleback	R				X	J, DTS		
Chirolophis decoratus	Decorated warbonnet	R					J		One record
Lumpenus sagitta	Snake prickleback	O			X	X	DTS, STS	Sp, S	
Family Pholidae									
Apodichthys flavidus	Penpoint gunnel	C			X	X	DTS, STS, MF	All	
Pholis ornata	Saddleback gunnel	C			X	X	DTS, STS, MF, J	All	
Family Anarhichadidae									
Anarrhichthys ocellatus	Wolf-eel	R			X	X	J, DTS		All
Family Cryptacanthodidae									
Delolepis gigantea	Giant wrymouth	O			X	X	DTS, STS	W	One record

Taxa	Common name	Abundance[a]	Life history type[b] E	L	J	A	Habitat[c]	Season of occurrence[d]	Remarks
Family Ammodytidae									
Ammodytes hexapterus	Pacific sand lance	C		X	X	X	DTS, STS	All	Important food item for salmon at times
Family Gobiidae									
Clevelandia ios	Arrow goby	C		X	X	X	MF, TCSW, STS, DTS	All	Strongly euryhaline
Coryphopterus nicholsi	Blackeye goby	O			X	X	STS, DTS	All	
Eucyclogobius newberryi	Tidewater goby	O			X	X	STS, DTS	All	
Lepidogobius lepidus	Bay goby	A	X	X	X	X	MF, TCFW, TCSW, STS	All	One of most abundant species in Humboldt Bay; strongly euryhaline
Family Luvaridae									
Luvarus imperialis	Louvar	O				X	DTS		One record
Family Stromateidae									
Icichthys lockingtoni	Medusafish	O			X	X	DTS, STS	F	One record
Peprilus simillimus	Pacific pompano	O			X	X	DTS, STS		
Family Scorpaenidae									
Sebastes auriculatus	Brown rockfish	C		X	X	X	DTS, STS	All	
Sebastes caurinus	Copper rockfish	C		X	X	X	DTS, STS, J, P	All	
Sebastes flavidus	Yellowtail rockfish	O			X		DTS, STS		One record
Sebastes melanops	Black rockfish	C		X	X	X	DTS, STS, P, J	All	Common recreational species off jetties
Sebastes miniatus	Vermilion rockfish	O			X		DTS, STS		One record
Sebastes mystinus	Blue rockfish	O			X	X	DTS, STS, J	S, F, W	
Sebastes paucispinis	Bocaccio	O			X	X	DTS, STS	S, F, W	
Sebastes rastrelliger	Grass rockfish	C		X	X	X	DTS, STS, P, J	All	
Family Hexagrammidae									
Hexagrammos decagrammus	Kelp greenling	C	X	X	X	X	DTS, STS MF, J, P	All	Common recreational species off jetties
Hexagrammos lagocephalus	Rock greenling	O	X	X	X	X	DTS, STS	All	

Taxa	Common name	Abundance[a]	Life history type[b] E	L	J	A	Habitat[c]	Season of occurrence[d]	Remarks
Family Hexagrammidae (*continued*)									
Ophiodon elongatus	Lingcod	C	X	X	X	X	DTS, STS, J, MF	All	Popular recreational species because of large size
Oxylebius pictus	Painted greenling	C	X	X	X	X	DTS, J		All
Family Cottidae									
Artedius fenestralis	Padded sculpin	C		X	X	X	DTS, STS, P, J	All	
Artedius harringtoni	Scalyhead sculpin	O				X	DTS, STS	Sp	
Artedius notospilotus	Bonehead sculpin	R				X	DTS		One record
Ascelichthys rhodorus	Rosylip sculpin	O		X	X	X	DTS, STS, J	All	
Blepsias cirrhosus	Silverspotted sculpin	R				X	DTS		One record
Clinocottus acuticeps	Sharpnose sculpin	R							One record
Cottus aleuticus	Coastrange sculpin	R				X	CR		One record, freshwater sculpin
Cottus asper	Prickly sculpin	O				X	CR		Freshwater sculpin occasionally carried into bay by tributary floods
Enophrys bison	Buffalo sculpin	C	X	X	X	X	DTS, STS, P, J	All	
Hemilepidotus hemilepidotus	Red Irish lord	C	X	X	X	X	DTS, STS, J	All	
Hemilepidotus spinosus	Brown Irish lord	C	X	X	X	X	DTS, STS, J	All	
Leptocottus armatus	Pacific staghorn sculpin	A	X	X	X	X	DTS, STS, TCSW, TCFW, P, J	All	Strongly euryhaline
Nautichthys oculofasciatus	Sailfin sculpin	O			X	X	TS, STS, J	All	
Oligocottus snyderi	Fluffy sculpin	R			X				Two specimens, taken in baytide pool
Scorpaenichthys marmoratus	Cabezon	C	X	X	X	X	DTS, STS, P, J	All	Important bay sportfish, particularly off jetties
Family Agonidae									
Odontopyxis trispinosa	Pygmy poacher	O		X	X		DTS, STS	W	
Pallasina barbata	Tubenose poacher	R				X	DTS	W	
Stellerina xyosterna	Pricklebreast poacher	O		X	X	X	DTS, STS	S, F, W	

Taxa	Common name	Abundance[a]	Life history type[b] E	L	J	A	Habitat[c]	Season of occurrence[d]	Remarks
Family Cyclopteridae									
Liparis fucensis	Slipskin snailfish	O	X	X	X	X	DTS, STS MF	All	
Liparis pulchellus	Showy snailfish	R				X	DTS, STS, MF	All	
Liparis rutteri	Ringtail snailfish	R				X	J		One record
Family Bothidae									
Citharichthys sordidus	Pacific sanddab	O			X	X	DTS, STS, MF	All	
Citharichthys stigmaeus	Speckled sanddab	A	X	X	X	X	MF, STS, DTS, J	All	
Paralichthys californicus	California halibut	R			X	X	DTS, STS	S, F	
Family Pleuronectidae									
Isopsetta isolepis	Butter sole	O			X	X	DTS, STS	W, S	
Microstomus pacificus	Dover sole	O			X	X	DTS, STS		Important commercial species outside the bay
Parophrys vetulus	English sole	A		X	X	X	DTS, STS, MF	All	Juveniles very abundant in bay; important commercially outside bay
Platichthys stellatus	Starry flounder	C	X	X	X	X	DTS, STS, MF, TCSW, TCFW	All	
Pleuronichthys coenosus	C-O sole	O			X		DTS, STS	W	
Pleuronichthys decurrens	Curlfin sole	O			X	X	DTS, STS	All	
Psettichthys melanostictus	Sand sole	O			X	X	DTS, STS, J	All	
Family Cynoglossidae									
Symphurus atricauda	California tonguefish	O			X	X	DTS, STS	F, W	
Family Molidae									
Mola mola	Ocean sunfish	O			X				One record

[a] Abundance: A = abundant, C = common, O = occasional, R = rare.
[b] Life history type: E = egg, L = larva, J= juvenile, A = adult.
[c] Habitat: DTS = deep tidal channel; STS = shallow tidal channels; MF = mudflats; TCSSW = tidal creeks and sloughs, salt water; TCSFW = tidal creeks and sloughs, fresh water; CR = creeks and rivers; P = piers; J = jetties.
[d] Season of occurrence: SP = spring, S = summer, F = fall, W = winter.

Appendix D. Birds of Humboldt Bay Environs

Appendix data are from reports and records compiled by Shapiro and Associates, Inc. (1980) and S.W. Harris (Department of Wildlife, Humboldt State University, Arcata, California, unpublished data). Nomenclature follows usage adopted by the U.S. Fish and Wildlife Service (Banks et al. 1987).

		Status[a]				Habitat use[b]												
Taxa	Common name	Sp	S	F	W	Ent	Deep	Smal	Eelg	Sand	Mudf	Open	Salt	Wrac	Dike	Shrub	Pond	Jett
Family Gaviidae																		
Gavia stellata	Red-throated loon	C	Ca	C	C	P	P	S				S					S	
Gavia pacifica	Pacific loon	C	R	C	R	P	P	S				S					S	
Gavia immer	Common loon	C	U	C	C	P	P	S				S					S	
Gavia adamsii	Yellow-billed loon	—	—	Ca	Ca	P	P	S				S						
Family Podicipedidae																		
Podilymbus podiceps	Pied-billed grebe	U	U	U	U			S				S					P	
Podiceps auritus	Horned grebe	C	Ca	C	C	S	P	P				P					S	
Podiceps grisegena	Red-necked grebe	U	Ca	U	U	P	S											
Podiceps nigricollis	Eared grebe	C	—	C	C		S	S				S					P	
Aechmophorus occidentalis	Western grebe	C	U	C	C	P	P	S				S					S	
Aechmophorus clarkii	Clark's grebe	Ca	—	Ca	Ca	P	P	S				S					S	
Family Procellariidae																		
Fulmarus glacialis	Northern fulmar	—	—	Ac	Ac	S						S						
Family Hydrobatidae																		
Oceanodroma furcata	Fork-tailed storm-petrel	—	Ac	Ac	—	S	S											
Oceanodroma leucorhoa	Leach's storm-petrel	Ac	—	—	—		S											
Family Pelecanidae																		
Pelecanus erythrorhynchos	American white pelican	Ca	—	Ca	Ca						S	S						
Pelecanus occidentalis	Brown pelican	R	C	C	R	P	P	S				S			P		S	S
Family Phalacrocoracidae																		
Phalacrocorax auritus	Double-crested cormorant	C	C	C	C	S	P	P			S	S			S		S	P
Phalacrocorax penicillatus	Brandt's cormorant	C	C	C	R	P	P	S									S	S
Phalacrocorax pelagicus	Pelagic cormorant	C	C	C	C	P	P											P

Taxa	Common name	Status[a] Sp	S	F	W	Habitat use[b] Ent	Deep	Smal	Eelg	Sand	Mudf	Open	Salt	Wrac	Dike	Shrub	Pond	Jett
Family Fregatidae																		
Fregata magnificens	Magnificent frigatebird	—	Ca	Ca	—	S	S											
Family Ardeidae																		
Botaurus lentiginosus	American bittern	R	R	R	R												P	
Ardea herodias	Great blue heron	C	C	C	C		S	P	P	S	S	P	S		S	P	P	S
Casmerodius albus	Great egret	C	C	C	C			P	P	S	P	P	S		S	P	P	S
Egretta thula	Snowy egret	C	C	C	C			P	P	S	P	S	S		S	P	P	S
Bubulcus ibis	Cattle egret	C	Ca	C	C										S	S	S	S
Butorides striatus	Green-backed heron	U	U	U	R											S	S	S
Nycticorax nycticorax	Black-crowned night-heron	C	C	C	C			S	S	S	S	S	S		S	P	P	S
Family Threskiornithidae																		
Plegadis chihi	White-faced ibis	—	—	Ac	Ac						S						S	
Family Anatidae																		
Cygnus columbianus	Tundra swan	R	—	R	R							S					S	
Anser albifrons frontalis	Greater white-fronted goose	—	—	R	R						S							
Chen c. caerulescens	Lesser snow goose	—	—	R	R							S						
Chen rossii	Ross' goose	—	—	R	R							S					S	
Chen canagica	Emperor goose	Ac	—	Ac	Ac				S			S						
Branta bernicla nigricans	Black brant	C	Ca	U	R	S	S	S	P	P	S	P		S	S			
Branta canadensis	Canada goose	Ca	—	Ca	Ca							S					S	
Aix sponsa	Wood duck	R	—	R	R							S					S	
Anas crecca carolinensis	Green-winged teal	C	Ca	C	C				S	S	P	S	S	S	S		P	
Anas platyrhynchos	Mallard	C	U	C	C	S	S	S	S	S	S	S	S		S		P	
Anas acuta	Northern pintail	C	R	C	C	S	S	S	S	S	P	P	S		S		S	
Anas discors	Blue-winged teal	R	R	Ca	Ca												P	
Anas cyanoptera	Cinnamon teal	C	C	C	R							S			S		P	
Anas clypeata	Northern shoveler	C	Ca	C	C				S		S	S	S		S		P	
Anas strepera	Gadwall	R	Ca	R	R							S					S	
Anas penelope	Eurasian wigeon	R	—	R	R			S	P		S	P	S		S		S	
Anas americana	American wigeon	C	Ca	C	C			S	P		S	P	S		S		S	

Taxa	Common name	Status[a]				Habitat use[b]												
		Sp	S	F	W	Ent	Deep	Smal	Eelg	Sand	Mudf	Open	Salt	Wrac	Dike	Shrub	Pond	Jett
Family Anatidae (*continued*)																		
Aythya valisineria	Canvasback	U	Ca	U	U			S	S		S	P					P	
Aythya americana	Redhead	U	Ca	U	U	P	S	S	P			P					S	
Aythya collaris	Ring-necked duck	U	Ca	U	U			S	S			S					P	
Aythya fuligula	Tufted duck	Ca	Ca	Ca	Ca			S	S			S					P	
Aythya marila	Greater scaup	C	R	C	C	P	S	P	S	S	S	P	S		S		S	
Aythya affinis	Lesser scaup	U	R	U	U	S	S	S	S	S	S	P	S		S		P	
Somateria spectabilis	King eider	—	—	Ac	Ac		S											
Polysticta stelleri	Steller's eider	—	—	Ac	—		S											
Histrionicus histrionicus	Harlequin duck	Ca	Ca	Ca	Ca	S	S											S
Clangula hyemalis	Oldsquaw	R	Ca	R	R	P	P	S				S					S	
Melanitta nigra	Black scoter	R	Ca	R	R	P	S											
Melanitta perspicillata	Surf scoter	C	U	C	C	P	P	S				S					S	
Melanitta fusca	White-winged scoter	C	U	C	C	P	P	S				S					S	
Bucephala clangula	Common goldeneye	R	—	R	R	S	P	S				S					S	
Bucephala islandica	Barrow's goldeneye	—	—	Ca	Ca												S	
Bucephala albeola	Bufflehead	C	Ca	C	C	S	S	P				P					P	
Lophodytes cucullatus	Hooded merganser	Ca	Ca	Ca	Ca												S	
Mergus merganser	Common merganser	Ca	—	Ca	Ca		S										S	
Mergus serrator	Red-breasted merganser	C	Ca	C	C	P	P	S				P					S	
Oxyura jamaicensis	Ruddy duck	C	R	C	C	S	S	P				P					P	
Family Cathartidae																		
Cathartes aura	Turkey vulture	C	C	C	R								S	S	S	S	S	
Family Accipitridae																		
Pandion haliaetus	Osprey	C	C	C	Ca	S	P	P				P					P	S
Elanus caeruleus	Black-shouldered kite	U	U	U	U								S		S	S	S	
Circus cyaneus	Northern harrier	U	U	U	U								S		S	S	S	
Accipiter striatus	Sharp-skinned hawk	U	R	U	U											S	S	
Accipiter cooperii	Cooper's hawk	R	R	R	R											S	S	
Buteo lineatus	Red-shouldered hawk	U	R	U	U											S	S	
Buteo jamaicensis	Red-tailed hawk	C	U	C	C								S		S	S	S	
Buteo lagopus	Rough-legged hawk	U	—	U	U								S		S	S	S	

Taxa	Common name	Status[a]				Habitat use[b]												
		Sp	S	F	W	Ent	Deep	Smal	Eelg	Sand	Mudf	Open	Salt	Wrac	Dike	Shrub	Pond	Jett
Family Falconidae																		
Falco sparverius	American kestrel	C	U	C	C										S	S	S	
Falco columbarius	Merlin	U	—	U	U				S	S	P				P	S	P	
Falco peregrinus	Peregrine falcon	U	R	U	U				S	S	P				P		P	
Falco mexicanus	Prairie falcon	Ca	—	Ca	Ca					S	S				S		S	
Family Phasianidae																		
Callipepla californica	California quail	R	R	R	R											S		
Family Rallidae																		
Rallus limicola	Virginia rail	C	U	C	C							P					P	
Porzana carolina	Sora	U	R	U	U							P					P	
Fulica americana	American coot	C	U	C	C			S	P	S	S	P	S	S	S		P	
Family Charadriidae																		
Pluvialis squatarola	Black-bellied plover	C	R	C	C				S	S	P		S	S	P		S	P
Pluvialis dominica	Lesser golden-plover	Ca	—	Ca	Ca					S	S				S			
Charadrius alexandrinus	Snowy plover	R	R	R	Ca					S				S				
Charadrius semipalmatus	Semipalmated plover	U	Ca	U	U					P	S			S	S		S	
Charadrius vociferus	Killdeer	C	C	C	C								S	S	S		S	
Family Haematopodidae																		
Haematopus bachmani	Black oystercatcher	Ca	Ca	Ca	Ca													P
Family Recurvirostridae																		
Himantopus mexicanus	Black-necked stilt	R	R	R	R												P	
Recurvirostra americana	American avocet	Ca	Ca	C	C					S	P	P	S		P		S	
Family Scolopacidae																		
Tringa melanoleuca	Greater yellowlegs	C	R	C	C				S		S	S	S		S		P	
Tringa flavipes	Lesser yellowlegs	R	Ca	C	R						S						P	
Tringa solitaria	Marsh sandpiper	Ca	Ca	Ca	—												S	
Catoptrophorus semipalmatus	Willet	C	Ca	C	C				S	S	P	S	S	S	P		S	S

Taxa	Common name	Status[a]				Habitat use[b]												
		Sp	S	F	W	Ent	Deep	Smal	Eelg	Sand	Mudf	Open	Salt	Wrac	Dike	Shrub	Pond	Jett
Family Scolopacidae (*continued*)																		
Heteroscelus incanus	Wandering tattler	U	R	U	U												P	
Actitis macularia	Spotted sandpiper	U	U	U	R					S				S	S		S	S
Numenius phaeopus	Whimbrel	C	U	U	R				S	S	S		S	S	S		S	S
Numenius americanus	Long-billed curlew	U	R	U	U				S	S	P		S	S	S		S	S
Limosa haemastica	Hudsonian godwit	Ac	Ac	Ac	—						S						S	
Limosa lapponica	Bar-tailed godwit	—	Ac	Ac	—						S				S			
Limosa fedoa	Marbled godwit	A	U	A	A				P	S	P	P	S	S	P		S	S
Arenaria interpres	Ruddy turnstone	U	R	U	R					P	S		S	S	S		S	S
Arenaria melanocephala	Black turnstone	C	R	C	C				S	S	S		S	S	S		S	P
Aphriza virgata	Surfbird	U	R	U	U													P
Calidris canutus	Red knot	U	Ca	U	Ca				S	S	P		S	S	P			
Calidris alba	Sanderling	U	Ca	C	C					P					S			S
Calidris pusilla	Semipalmated sandpiper	Ca	Ca	Ca	—									S			S	
Calidris mauri	Western sandpiper	A	U	A	C				S	S	P		S	S	P		S	S
Calidris ruficollis	Red-necked stint	Ac	Ac	—	—						S						S	
Calidris minutilla	Least sandpiper	C	U	C	C				S	S	P		S	P	P		P	S
Calidris bairdii	Baird's sandpiper	Ca	Ca	U	—						S				S		P	
Calidris melanotos	Pectoral sandpiper	Ca	Ca	C	—												P	
Calidris acuminata	Sharp-tailed sandpiper	—	—	Ca	—												P	
Calidris ptilocnemis	Rock sandpiper	R	—	R	R													P
Calidris alpina	Dunlin	A	Ca	A	C				S	S	P		S	S	P		P	S
Calidris himantopus	Stilt sandpiper	—	R	R	—						S						S	
Philomachus pugnax	Ruff	—	Ac	R	—												P	
Limnodromus griseus	Short-billed dowitcher	A	C	A	R			S	S	S	P		S	S	P		S	
Limnodromus scolopaceus	Long-billed dowitcher	C	—	C	U				S		S		S		S		P	
Gallinago gallinago	Common snipe	C	Ca	C	C								S				P	
Phalaropus tricolor	Wilson's phalarope	R	R	R	—												P	
Phalaropus lobatus	Red-necked phalarope	C	Ca	C	—		S	S				S					P	
Phalaropus fulicarius	Red phalarope	U	Ca	U	R		S	S				S					P	
Family Laridae																		
Stercorarius pomarinus	Pomarine jaeger	—	—	U	—	P	P	S				S						
Stercorarius parasiticus	Parasitic jaeger	—	—	U	—	P	P	S				S						
Larus atricilla	Laughing gull	—	Ac	Ac	—												S	
Larus pipixcan	Franklin's gull	R	Ca	R	Ca							S					S	
Larus minutus	Little gull	Ac	—	Ac	Ac							S					S	

Taxa	Common name	Status[a]				Habitat use[b]												
		Sp	S	F	W	Ent	Deep	Smal	Eelg	Sand	Mudf	Open	Salt	Wrac	Dike	Shrub	Pond	Jett
Family Laridae (*continued*)																		
Larus ridibundus	Common black-headed gull	Ac	Ac	—	Ac							S					S	
Larus philadelphia	Bonaparte's gull	C	R	C	R		S	S	P			P			S		S	S
Larus heermanni	Heermann's gull	Ca	C	C	Ca	P	P	S	S	S	S	P			S		S	S
Larus canus	Mew gull	C	—	C	C	S	S	S	S	S	S	S			S		S	
Larus delawarensis	Ring-billed gull	C	R	C	C	S	S	S	S	S	S	S	S	S	S		S	
Larus californicus	California gull	C	R	C	U	S	S	S				S			S			
Larus argentatus	Herring gull	R	Ca	R	R	S	S	S				S			S			S
Larus thayeri	Thayer's gull	Ca	—	Ca	Ca	S	S	S				S			S			S
Larus occidentalis	Western gull	A	C	A	A	S	S	P	P	S	S	P	S	S	P		S	P
Larus glaucescens	Glaucous-winged gull	C	U	C	C	S	S	P	P	S	S	P	S	S	P		S	P
Larus hyperboreus	Glaucous gull	R	—	R	R	S	S	S	S		S	S	S		S		S	S
Rissa tridactyla	Black-legged kittiwake	R	Ca	R	R	S	S					S						P
Xema sabini	Sabine's gull	—	—	Ac	—												S	
Sterna caspia	Caspian tern	C	C	C	—	P	P	P				P	S		P		S	S
Sterna elegans	Elegant tern	—	Ca	R	—	S	P	S		P		P			S		S	
Sterna hirundo	Common tern	U	R	U	—	S	P	S		P		P			S		S	S
Sterna forsteri	Forster's tern	R	R	U	Ca	S	S	S				P			S		P	S
Sterna antillarum	Least tern	Ac	Ac	Ac	—							S			S			
Chlidonias niger	Black tern	Ca	Ca	Ca	—							S					S	
Family Alcidae																		
Uria aalge	Common murre	U	C	U	Ca	P	P	S				S						
Cepphus columba	Pigeon guillemot	R	U	R	—	P	S											
Brachyramphus marmoratus	Marbled murrelet	R	R	R	Ca	P	S											
Family Columbidae																		
Columba livia	Rock dove	C	C	C	C													P
Zenaida macroura	Mourning dove	R	R	R	—											S	S	
Family Tytonidae																		
Tyto alba	Common barn-owl	U	U	U	U								S			S		
Family Strigidae																		
Bubo virginianus	Great horned owl	R	R	R	R													
Nyctea scandiaca	Snowy owl	Ca	—	Ca	Ca								P		S	S		

Taxa	Common name	Status[a]				Habitat use[b]												
		Sp	S	F	W	Ent	Deep	Smal	Eelg	Sand	Mudf	Open	Salt	Wrac	Dike	Shrub	Pond	Jett
Family Strigidae (*continued*)																		
Athene cunicularia	Burrowing owl	Ca	—	Ca	Ca										S			
Asio flammeus	Short-eared owl	U	—	U	U								S		S			
Family Apodidae																		
Chaetura vauxi	Vaux's swift	C	C	U	—											S	S	
Family Trochilidae																		
Calypte anna	Anna's hummingbird	U	U	U	R											S		
Selasphorus sasin	Allen's hummingbird	C	C	U	—											S		
Family Alcedinidae																		
Ceryle alcyon	Belted kingfisher	C	C	C	C		S	S				S			S		S	P
Family Picidae																		
Sphyrapicus ruber	Red-breasted sapsucker	R	R	R	R											S		
Picoides pubescens	Downy woodpecker	R	R	R	R											S		
Picoides villosus	Hairy woodpecker	R	R	R	R											S		
Colaptes auratus	Northern flicker	C	C	C	C											S		
Family Tyrannidae																		
Empidonax traillii	Willow flycatcher	R	Ca	R	—											S		
Empidonax difficilis	Western flycatcher	C	C	U	—											S		
Sayornis nigricans	Black phoebe	C	C	C	C									S	S	S	P	S
Myiarchus cinerascens	Ash-throated flycatcher	R	R	R	—											S		
Family Alaudidae																		
Eremophila alpestris	Horned lark	Ac	—	Ac	Ac										S			
Family Hirundinidae																		
Progne subis	Purple martin	U	U	U	—												S	
Tachycineta bicolor	Tree swallow	C	C	C	R								S	S	S	S	S	
Tachycineta thalassina	Violet-green swallow	C	C	C	R								S	S	S	S	S	
Stelgidopteryx serripennis	Northern rough-winged swallow	U	U	U	—								S	S	S	S	S	
Riparia riparia	Bank swallow	Ac	Ac	Ac	—												S	

Taxa	Common name	Status[a]				Habitat use[b]												
		Sp	S	F	W	Ent	Deep	Smal	Eelg	Sand	Mudf	Open	Salt	Wrac	Dike	Shrub	Pond	Jett
Family Hirundinidae (*continued*)																		
Hirundo pyrrhonota	Cliff swallow	C	C	C	—								S	S	S	S	S	
Hirundo rustica	Barn swallow	C	C	C	R								S	S	S	S	S	
Family Corvidae																		
Corvus brachyrhynchos	American crow	C	C	C	C										S	S	S	
Corvus corax	Common raven	C	C	C	C								S	S	S	S	S	S
Family Paridae																		
Parus rufescens	Chestnut-backed chickadee	C	C	C	C											S		
Family Aegithalidae																		
Psaltriparus minimus	Bushtit	R	R	R	R											S		
Family Sittidae																		
Sitta canadensis	Red-breasted nuthatch	Ca	—	Ca	Ca											S		
Family Certhiidae																		
Certhia americana	Brown creeper	R	R	R	R											S		
Family Troglodytidae																		
Thryomanes bewickii	Bewick's wren	U	U	U	U											S		
Troglodytes troglodytes	Winter wren	U	U	U	U											S		
Troglodytes aedon	House wren	Ca	Ca	Ca	—											S		
Cistothorus palustris	Marsh wren	C	C	C	C								P		S	S	P	
Family Muscicapidae																		
Regulus calendula	Ruby-crowned kinglet	C	—	C	C											S		
Regulus satrapa	Golden-crowned kinglet	U	R	U	U											S		
Catharus guttatus	Hermit thrush	R	—	U	C											S		
Catharus ustulatus	Swainson's thrush	R	U	R	—											S		
Turdus migratorius	American robin	C	C	C	C										S	S	S	
Chamaea fasciata	Wrentit	R	R	R	R											S		

Taxa	Common name	Status[a]				Habitat use[b]												
		Sp	S	F	W	Ent	Deep	Smal	Eelg	Sand	Mudf	Open	Salt	Wrac	Dike	Shrub	Pond	Jett
Family Motacillidae																		
Anthus spinoletta	Water pipit	C	—	U	C									S	P		P	
Family Bombycillidae																		
Bombycilla cedrorum	Cedar waxwing	U	U	U	Ca											S		
Family Laniidae																		
Lanius excubitor	Northern shrike	R	—	R	R											S		
Lanius ludovicianus	Loggerhead shrike	Ca	—	Ca	Ca											S		
Family Sturnidae																		
Sturnus vulgaris	European starling	A	C	A	A								S	S	S	S	S	S
Family Vireonidae																		
Vireo solitarius	Solitary vireo	R	R	R	—											S		
Vireo huttoni	Hutton's vireo	R	R	R	R											S		
Vireo gilvus	Warbling vireo	R	R	R	—											S		
Family Emberizidae																		
Vermivora peregrina	Tennessee warbler	Ac	—	Ac	—											S		
Vermivora celata	Orange-crowned warbler	C	C	C	R										P			
Vermivora ruficapilla	Nashville warbler	R	R	R	Ca											S		
Dendroica petechia	Yellow warbler	R	R	C	—											S		
Dendroica tigrina	Cape May warbler	—	Ac	—	—											S		
Dendroica coronata	Yellow-rumped warbler	C	—	C	C											P		
Dendroica nigrescens	Black-throated gray warbler	R	R	R	—											S		
Dendroica townsendi	Townsend's warbler	R	—	R	R											S		
Dendroica palmarum	Palm warbler	R	—	R	R										S	S	S	
Dendroica castanea	Bay-breasted warbler	—	Ca	—	—											S		
Dendroica striata	Blackpoll warbler	—	—	Ca	—											S		
Mniotilta varia	Black-and-white warbler	Ca	—	Ca	Ca										S			
Seiurus aurocapillus	Ovenbird	—	—	Ca	—											S		
Seiurus noveboracensis	Northern waterthrush	—	—	Ca	—											S		
Oporornis tolmiei	MacGillivray's warbler	R	Ca	R	—											S		

Taxa	Common name	Status[a]				Habitat use[b]												
		Sp	S	F	W	Ent	Deep	Smal	Eelg	Sand	Mudf	Open	Salt	Wrac	Dike	Shrub	Pond	Jett
Family Emberizidae (*continued*)																		
Geothlypis trichas	Common yellowthroat	C	C	C	R								P		S	S	P	
Wilsonia pusilla	Wilson's warbler	C	C	C	Ca											S		
Piranga ludoviciana	Western tanager	U	U	U	—											S		
Pheucticus melanocephalus	Black-headed grosbeak	R	R	R	—											S		
Pipilo erythrophthalmus	Rufous-sided towhee	U	—	U	U											S		
Spizella passerina	Chipping sparrow	U	U	U	—											S		
Spizella pallida	Clay-colored sparrow	—	—	Ca	—											S		
Pooecetes gramineus	Vesper sparrow	Ca	U	Ca	—										S		S	
Chondestes grammacus	Lark sparrow	Ca	Ca	Ca	—										S		S	
Passerculus sandwichensis	Savannah sparrow	C	C	C	C								P	S	S	S	S	
Passerella iliaca	Fox sparrow	U	—	U	U										S			
Melospiza melodia	Song sparrow		C	C	C	C							P	S	S	P	S	
Melospiza lincolnii	Lincoln's sparrow	U	—	U	U								S	S	S	S	S	
Melospiza georgiana	Swamp sparrow	Ca	—	Ca	Ca								S	S	S	S	S	
Zonotrichia albicollis	White-throated sparrow	R	—	R	R											S		
Zonotrichia atricapilla	Golden-crowned sparrow	C	—	C	C									S	S			
Zonotrichia leucophrys	White-crowned sparrow	C	C	C	C										S	S		
Junco hyemalis	Dark-eyed junco	C	—	C	C											S		
Calcarius lapponicus	Lapland longspur	—	—	Ac	Ac										S			
Plectrophenax nivalis	Snow bunting	—	—	Ac	Ac										S			
Dolichonyx oryzivorus	Bobolink	Ca	Ca	R	—								S		S	S		
Agelaius phoeniceus	Red-winged blackbird	C	C	C	U								P	S	S	S	P	
Sturnella neglecta	Western meadowlark	U	U	U	U								S	S	S	S	S	
Euphagus cyanocephalus	Brewer's blackbird	C	C	C	C								S	S	S	P	S	
Euphagus carolinus	Rusty blackbird	—	—	Ca	—												S	
Molothrus ater	Brown-headed cowbird	C	C	C	R								S		S	S	S	
Xanthocephalus xanthocephalus	Yellow-headed blackbird	Ca	—	Ca	—												S	
Icterus galbula	Northern oriole	U	U	U	Ca											S		
Family Fringillidae																		
Fringilla montifringilla	Brambling	—	—	Ac	—											S		
Carpodacus purpureus	Purple finch	U	R	U	U											S		
Carpodacus mexicanus	House finch	C	C	C	C								S	S	S	P	S	
Carduelis pinus	Pine siskin	R	—	R	R										S	S	S	
Carduelis psaltria	Lesser goldfinch	U	U	U	Ca										S	S	S	
Carduelis tristis	American goldfinch	U	C	U	Ca										S	S	S	
Loxia curvirostra	Red crossbill	R	—	—	—											S		

Taxa	Common name	Status[a]				Habitat use[b]												
		Sp	S	F	W	Ent	Deep	Smal	Eelg	Sand	Mudf	Open	Salt	Wrac	Dike	Shrub	Pond	Jett
Family Passeridae																		
Passer domesticus	House sparrow	C	C	C	C										P	P	S	

[a] Status: Sp = spring; S = summer; W = winter; F = fall; A = abundant; C = common; U = uncommon; R = rare; Ca = casual; Ac = accidental.
[b] Habitat use: Ent = entrance bay; Deep = deep channels; Smal = small, shallow channels; Eelg = eelgrass beds; Sand = sand flats; Mudf = mud flats; Open = open waters; Salt = salt marsh; Wrac = shoreline eelgrass wracks; Dike = dikes and elevated islands; Shrub = shrub and tree patches; Pond = fresh and brackish ponds; Jett = jetties, piers and ruins; P = primary use; S = secondary use.

Appendix E. Mammals of Humboldt Bay Environs

Appendix data are from reports and records compiled by Monroe (1973) and Shapiro and Associates, Inc. (1980). Nomenclature follows usage adopted by the U.S. Fish and Wildlife Service (Banks et al. 1987).

			Habitat designation[b]							
Taxa	Common name	Status[a]	Agri	Ripn	Salt	Frsw	Mudf	Smal	Open	Jett
Family Didelphidae										
Didelphis virginiana	Virginia opossum	?	?	?						
Family Soricidae										
Sorex pacificus	Pacific marsh shrew	U								
Sorex vagrans	Vagrant shrew	U		+						
Sorex bendirii	Marsh shrew	U		+						
Sorex trowbridgii	Trowbridge's shrew	U		+						
Family Talpidae										
Neurotrichus gibbsii	Shrew-mole	U		+						
Scapanus townsendii	Townsend's mole	C	+	?						
Scapanus orarius	Coast mole			+						
Family Vespertilionidae										
Myotis lucifugus	Little brown bat	C	+	+	?	+	+	?	?	
Myotis thysanodes	Fringed myotis	U?	+	+	?	+	+	?	?	
Myotis californicus	California myotis	C	+	+	?	+	+	?	?	
Myotis volans	Long-legged myotis	C?	+	+	?	+	+	?	?	
Myotis evotis	Long-eared myotis	C?	?	+	?	+		?		
Myotis yumanensis	Yuma myotis	C?	?	+	?	+		?		
Lasiurus cinereus	Hoary bat	C?	?	+	?	+	?	?	?	
Lasionycteris noctivagans	Silver-haired bat	C?	?	+	?	+		?		
Plecotus townsendii	Townsend's big-eared bat	C?	+		?	+	?	?	?	
Eptesicus fuscus	Big brown bat	C?	+	?	?	+	?	?	?	
Family Leporidae										
Lepus californicus	Black-tailed jack rabbit	C	+	+						
Sylvilagus bachmani	Brush rabbit	C	+	+						

Taxa	Common name	Status[a]	Habitat designation[b]							
			Agri	Ripn	Salt	Frsw	Mudf	Smal	Open	Jett
Family Aplodontiidae										
Aplodontia rufa	Mountain beaver	U		X						
Family Sciuridae										
Spermophilus beecheyi	California ground squirrel	C	+	+						
Tamias townsendii	Townsend's chipmunk	C								
Sciurus griseus	Western gray squirrel	C		+						
Tamiasciurus douglasii	Douglas' squirrel	C								
Glaucomys sabrinus	Northern flying squirrel	U		?						
Family Geomyidae										
Thomomys bottae	Botta's pocket gopher	C	+							
Family Castoridae										
Castor canadensis	Beaver	U		+						
Family Muridae										
Reithrodontomys megalotis	Western harvest mouse	C	?	?	?					
Peromyscus truei	Piñon mouse	C?								
Peromyscus maniculatus	Deer mouse	C?	+	+						
Neotoma fuscipes	Dusky-footed woodrat	C								
Arborimus albipes	White-footed vole	R								
Arborimus longicaudus	Red tree vole	U								
Clethrionomys californicus	Western red-backed vole	C?								
Microtus longicaudus	Long-tailed vole	U		+						
Microtus oregoni	Creeping vole	U		+						
Microtus californicus	California vole	C	+							
Microtus townsendii	Townsend's vole	U	?							
Rattus norvegicus	Norway rat	C	+							
Rattus rattus	Black rat	C	+	+						
Mus musculus	House mouse	C	+							
Family Dipodidae										
Zapus trinotatus	Pacific jumping mouse	C?								

Taxa	Common name	Status[a]	Habitat designation[b]							
			Agri	Ripn	Salt	Frsw	Mudf	Smal	Open	Jett
Family Erethizontidae										
Erethizon dorsatum	Porcupine	C	+	+						
Family Delphinidae										
Delphinus delphis	Saddle-backed dolphin	U								
Lagenorhynchus obliquidens	Pacific white-sided dolphin	C								
Family Phocoenidae										
Phocoena phocoena	Harbor porpoise	C							X	
Phocoenoides dalli	Dall's porpoise	C								
Family Eschrichtiidae										
Eschrichtius robustus	Grey whale	R*								
Family Otariidae										
Eumetopias jubatus	Northern sea lion	C								
Zalophus californianus	California sea lion	C								
Family Phocidae										
Phoca vitulina	Harbor seal	A					X		X	
Family Canidae										
Urocyon cinereoargenteus	Gray fox	U	?	?						
Canis latrans	Coyote	U	+	+	?					
Family Ursidae										
Ursus americanus	Black bear	U		+						
Family Procyonidae										
Procyon lotor	Raccoon	C	+	+	+		+			
Bassariscus astutus	Ringtail	U		+						

Taxa	Common name	Status[a]	Habitat designation[b]							
			Agri	Ripn	Salt	Frsw	Mudf	Smal	Open	Jett
Family Mustelidae										
Martes americana	Marten	U								
Martes pennanti	Fisher	R								
Mustela vison	Mink	U		+						
Mustela frenata	Long-tailed weasel	U		+						
Mustela erminea	Ermine	U								
Mephitis mephitis	Striped skunk	C		+						
Spilogale putorius	Spotted skunk	O								
Lutra canadensis	River otter	C		X		X		X	X	
Family Felidae										
Felis concolor	Mountain lion	U		+						
Lynx rufus	Bobcat	U		+						
Family Cervidae										
Odocoileus hemionus	Mule deer	C	+	+						
Cervus elaphus	Elk (wapiti)	U	+							

[a] Status: C = common; U = uncommon; R = rare; R* = protected by federal law = rare.
[b] Habitat Designation: Agri = agricultural land; Ripn = riparian brush and forest; Salt = salt marsh; Frsw = freshwater marsh; Mudf = mud flats; Smal = small tidal channels, creeks, sloughs; Open = open baywaters; Jett = jetties, reefs, ruins; X = for species use based on voucher material or published records.