Estuary: an Ecosystem and a Resource

A Reading Guide for Grades 9-12

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SCIENCE EDUCATION

FOR

BETTER CITIZENSHIP AND RICHER LIVES

1983

Address correspondence to

ESTUARY
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Curriculum Notes

The ESTUARY curriculum consists of three major activity areas.[a]

Element	Contact hours
Classroom	
slide/tape introduction	1
reading booklet	2
Laboratory	4
Field trip[b]	5

[a] A teacher's manual providing discussion guides, master worksheets, tests, answer keys, an annotated bibliography, and additional information is included.

[b] A field trip to the South Slough Sanctuary is strongly recommended and can be arranged by calling the sanctuary to schedule field trip dates and overnight housing accommodations if needed.

1

How Estuaries Fit into the Water Cycle

In this chapter you will learn

- *what causes different parts of Oregon to get different amounts of rain*
- *what the water cycle is*
- *what an estuary is*

The Water Cycle

The weather forecast calls for snow in the mountains or rain at lower elevations. It's winter and the Pacific Northwest is in for another soaking.

In the winter it rains a lot along the coast and it snows in the mountains, but Burns or John Day hardly ever seems to get any moisture. Where does this seemingly endless supply of coastal rain come from, and why does the Coos Bay area receive 150-200 centimeters (60-80 inches) of rain a year and Burns get only 25-50 centimeters (10-20 inches)?

Raindrops form when air saturated with moisture cools. We see the cool, saturated air as clouds or fog. In the Pacific Northwest the source of moisture is evaporation from the Pacific Ocean (figure 1). The moisture-laden air is made up of fresh water that is pushed eastward toward the shore by local winds, and as it rises over the

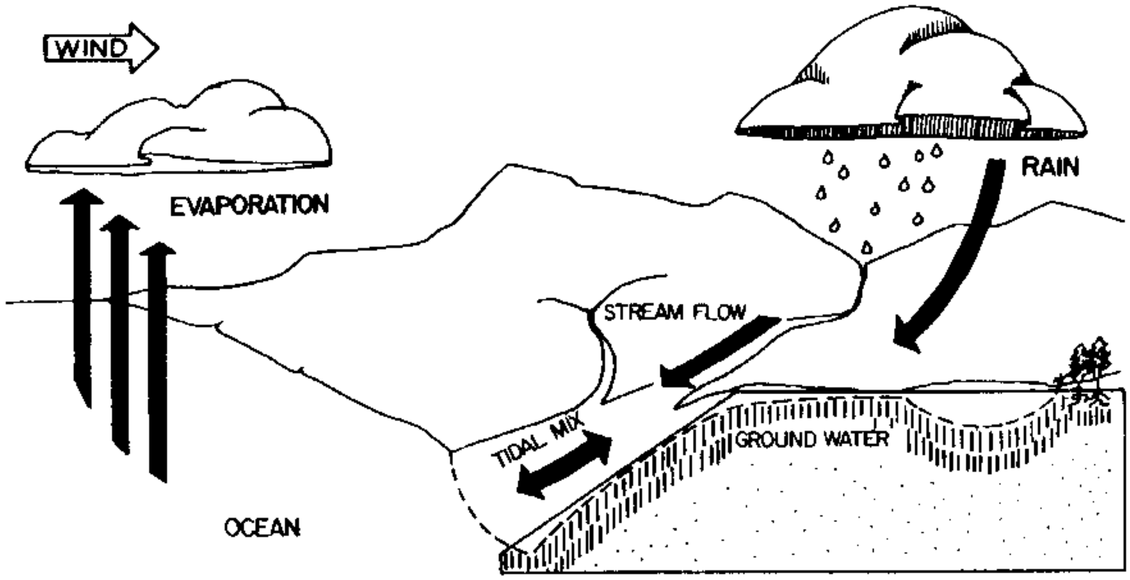


Figure 1. The water cycle.

coastal mountains, the air cools. As the air gets cooler and cooler, more and more moisture falls in the form of rain or snow. The Coos Bay area lies at the foot of the coastal mountains next to the ocean and therefore experiences air masses nearly completely saturated with moisture, so that even slight cooling causes a lot of rain. As the air masses continue eastward, more moisture is lost each time the air rises over a mountain range. By the time the air gets to eastern Oregon, most of the moisture has been lost, so even with a lot of cooling, very little rainfall occurs.

Some of the rain water evaporates right away. Steam rising from a hot road after a sudden shower is a good example of this. Much of the water is absorbed by plants. The remainder soaks into the ground or runs off directly into rivers, lakes, and streams. The ground water eventually filters its way through the soil into rivers. The final destination of all major river systems is the ocean, where the cycle starts all over again.

But why isn't our rain salty? Even though the ocean is our source of rain, the rain is not salty. Heavy materials, such as dissolved minerals like salt, remain behind when water evaporates from the surface of the ocean.

But isn't the ocean getting saltier? It would seem that since fresh water is continually being evaporated from the ocean, the ocean should be getting increasingly salty. We have to remember, though, that fresh water is continually being added to the ocean from rivers, rain, and other sources of water such as glaciers. At present scientists believe that the amount of fresh water removed from oceans by evaporation is about equal to the amount that is being returned.

Summary

Fresh water evaporates from the ocean to the atmosphere, where it is carried over the land and falls as rain and snow. Rain water that is not used by organisms or lost by evaporation eventually finds its way back into the ocean. This process is known as the water cycle.†

Estuaries and the Water Cycle

The water cycle involves the continual evaporation of fresh water from the oceans and the return of that water to the oceans by the rivers of the world. This booklet takes a close look at one very interesting part of the water cycle--estuaries. An estuary is the place where the fresh water of a river or a stream meets and mixes with the salt water of the ocean.

The change from fresh water to salt water occurs over an area that differs for each estuary. The exact size and shape of an estuary are influenced by two major factors. First, the size and shape of an estuary depend upon the amount of fresh water entering the estuary. For a large river, like the Columbia, the estuary extends many miles inland. The estuaries of small streams may be only a few hundred feet long because much less fresh water is involved.

The second factor that changes the size and shape of estuaries is the geologic history of the area where they are located. Geologic movement of the earth's crust has elevated and lowered coastal areas. These changes cause the average sea level to change. The changing sea level alters the size and shape of estuaries by altering the water depth and extent of submerged coastal areas.

The scouring action of glaciers has formed some estuaries that are very deep and have nearly vertical rocky walls. Puget Sound in Washington State and many of the estuaries in British Columbia and southeast Alaska are examples of this type of estuary.

Most of Oregon's estuaries are shallow bodies of water with narrow exits into the sea. They are known as the drowned river valley type of estuary. The drainage basins of the rivers having this type of estuary were formed when the sea level was much lower than it is today. The sea level was lower because the polar ice caps were larger then and more of the world's water was trapped in these ice caps. Changes in climate thousands of years ago began melting the ice caps and caused the sea level to rise to the level we see today. The rising sea level flooded valleys of the coastal drainage basins, forming the drowned river valley type of estuary.

† Underlined words can be found in the Glossary.

To assist ship navigation into some estuaries, a row of large boulders or concrete slabs is placed along each side of the mouth of the estuary. The boulders or slabs may extend several hundred feet into the sea. These structures, called jetties, extend above the surface of the sea and help to protect the mouth of the estuary from large waves. Even with the construction of jetties, it is very difficult and dangerous to navigate ships into and out of estuaries. Seamen call the area at the mouth of estuaries the bar. Many vessels have been lost "crossing the bar."

Not all estuaries have restricted mouths like those found in Oregon. Some estuaries have complicated, fan-shaped mouth systems called deltas. The Mississippi River delta is an example of an estuary with a delta. A comparison of the mouth of the Mississippi River with the mouth of the Columbia River is shown in figure 2. Deltas are created by millions of tons of sediment from erosion in the basins drained by large rivers.

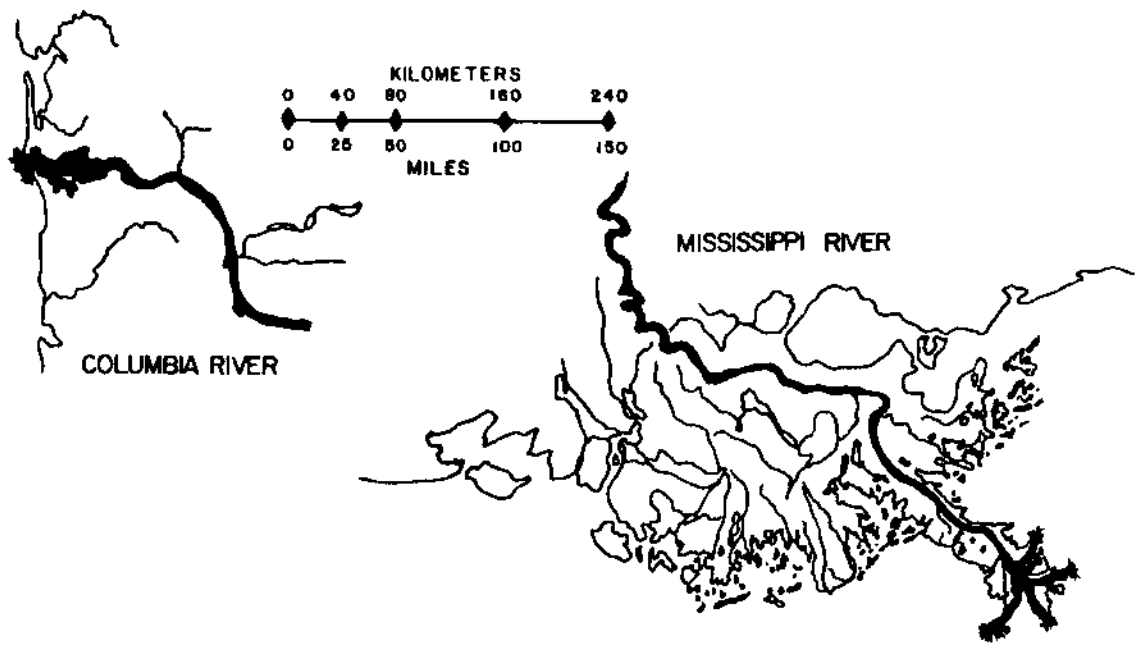


Figure 2. A comparison of an estuary with a restricted mouth, represented by the Columbia River, and an estuary with a river delta, represented by the Mississippi River.

In Oregon many of the drowned river valley estuaries are formed by very small rivers, such as the Elk, Sixes, and Pistol rivers in southern Oregon. In the summer these small rivers may have very little freshwater flow. At this time such an estuary may get blocked off partially or completely by sand deposited by ocean waves. When that occurs we say it has a closed bar. Then as the winter rains fall, the increased runoff reopens the mouth of the estuary and it is said to have an open bar.

Summary

An estuary is an area at the mouth of a river or stream where the fresh water meets and mixes with the salt water from the ocean. The shape of an estuary is influenced by two major factors: first, by the amount of fresh water entering the estuary and second, by the geologic history of the coastal area where the estuary is located.

Short-Answer Questions

1. What is fog?
2. Why is the east side of the Cascade mountain range drier than the west side?
3. Briefly describe the water cycle.
4. What two major factors influence the size and shape of estuaries?
5. What do scientists think was the primary cause of the prehistorical great change in sea level?
6. What general types of estuaries are discussed in this section?
7. What is a delta?
8. What is an estuary?

2

Physical Factors in Estuaries

In this chapter you will explore some of the important physical phenomena in the estuary. These include

- *the physical processes and materials of the ocean and the river*
- *the causes and the main characteristics of tides*
- *the reason the mouth of the estuary is sandy whereas the upper part is muddy*
- *the different ways fresh water and salt water can mix in an estuary*

Tides--A Contribution from the Ocean

The physical properties of estuaries are a result of the interplay between the physical processes of the river and those of the ocean (figure 3).

Figure 3. Physical contributions of the river and the ocean to the estuary.

The two features of a river that have the greatest influence on the physical properties of the estuary are its suspended sediments and its freshwater input. Those features of the ocean that most influence the estuary are the salt water, the tides, and the sand the ocean transports.

The oceans are huge bodies of water that cover almost three-fourths of the earth's surface. Because the earth and the oceans are so large, it took people hundreds of years to understand the forces responsible for the tides. We now know that the oceans, as large as they may be, are affected by the physical forces of gravitation and centrifugal force.

The moon's gravitational force does not have a noticeable effect on the solid parts of the earth, such as the continents. But the oceans are a liquid, and the moon's gravitation is strong enough to pull the surface of the ocean into a huge bulge called a tidal bulge. On the opposite side of the earth from the moon is a second tidal bulge resulting from the centrifugal force of the earth's motion.

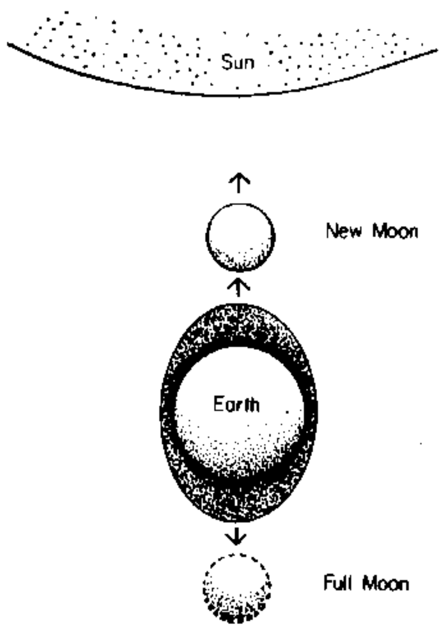
When a tidal bulge is located in the middle of the ocean, it is difficult to detect. But as the earth rotates, a land mass passes through a bulge and the bulge can be detected. Land masses of the earth rotate through these bulges because the earth makes one complete rotation on its axis every 24 hours. We detect the bulges as rhythmic, local changes in sea level which are known as tides.

The rotation of the earth causes the Oregon coast to be affected by two tidal bulges every 24 hours and 50 minutes. When the coast is located in the middle of a bulge, it is high tide. When the coast is located in the area between the two tidal bulges, it is low tide. The average difference in height between the high and low tides is the mean tide range. At Coos Bay the mean tide range is about 1.7 meters (5.6 feet). Since the Oregon coast rotates through the two bulges every 24 hours and 50 minutes, there are two high tides and two low tides every 24 hours and 50 minutes. The changes in tide level which occur during that period are called a tide cycle.

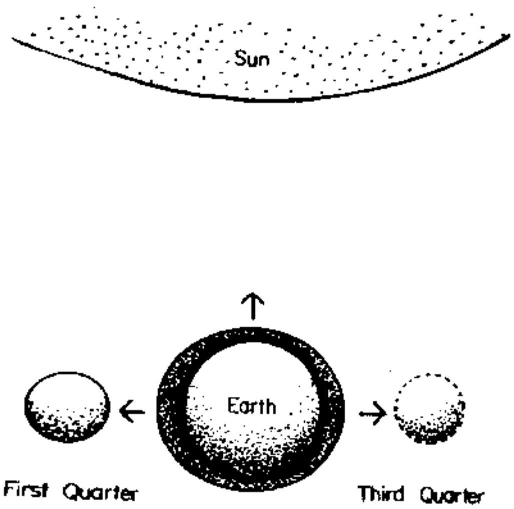
The height of the tides is influenced by many secondary factors. Some influences--for example, the extremely high tides that occur during major storms such as hurricanes--affect the tides for only a few hours. Other influences are due to secondary factors that are essentially permanent. Three such factors modifying tide heights are the effect of the sun's gravitational force, the shape of the ocean basin, and the shape of the coastline in the area where the tide is measured. The shapes of the ocean basin and the coastline are important because in some areas they amplify the height of the bulges, resulting in a daily average sea level difference in excess of 13 meters (42.9 feet).

When the moon is new or full, the sun and the moon form a straight line with the earth. At those times the gravitational forces of the moon and sun combine to make one of the bulges larger, and thus the height difference between high and low tides is greater than the average tide height. Spring tides describe the tides that occur at new or full moons. Spring tides in Coos Bay may have an average tide level difference of 2.2 meters (7.4 feet) or more. The term "spring tide" has nothing to do with the season of the year but is just a name given those tides. Figure 4 shows the relative positions of the earth, sun, and moon during spring tides.

When the moon is in an intermediate state--that is, when it is in its first or third quarter--the moon and the sun are 90° from each other. Because the gravitational forces of the sun and moon are not in line with each other, the sun's gravitational force reduces the height of the tidal bulges. Consequently, the height difference between the high and low tides during quarter moons is smaller than the average tide height. These tides are called neap tides. Figure 4 shows the relative positions of the earth, sun, and moon during neap tides.



a. Spring tide conditions



b. Neap tide conditions

Figure 4. The approximate positions of the earth, sun, and moon during spring and neap tides.

The moon circles the earth once every 27.5 days. During this time the sun and moon are aligned with each other twice and are 90° to each other twice. This causes two sets of neap tides and two sets of spring tides every 27.5 days. Figure 5 shows the height of typical tides at Seattle, Washington, over an eleven-day period.

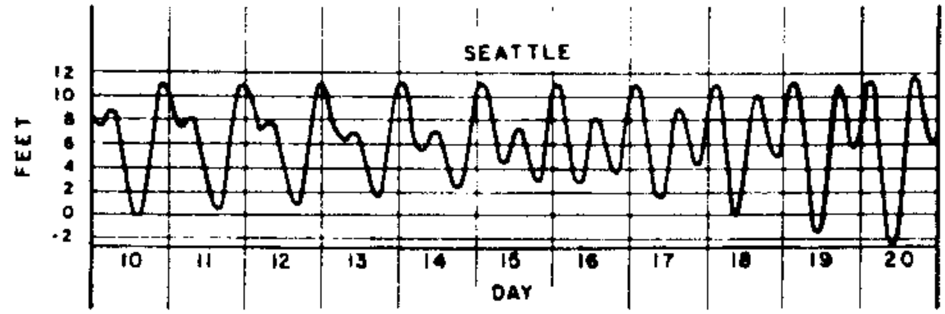


Figure 5. The height of typical tides at Seattle, Washington, over an eleven-day period.

The tides are responsible for the movement of ocean water into and out of the estuary. Twice each day millions of liters of ocean water flood into the estuary and mix with the water from the river. At high tide the maximum amount of water is present in the estuary. The flooding tide brings salt water, sediment, ocean animals, plankton, and nutrients with it. Twice each day millions of liters of diluted ocean water ebb out of the estuary and into the ocean. The ebbing tide carries estuarine animals and plankton, ocean animals and plankton, nutrients, sediment, and materials carried in by the river. Of course, any pollutants entering the river, the ocean, or the estuary are also carried by the flooding and ebbing tides.

Summary

The tides link the ocean with the estuary and are responsible for the transportation of animals, plankton, sediment, and various materials within the estuary. One tidal cycle occurs approximately every 24 hours and 50 minutes. The tides are caused by the passage of the coastlines of the world through two ocean tidal bulges created by the gravitational attraction of the moon and the centrifugal force of the earth. The height of the tides is influenced by three primary factors. The main ones are the shape of the ocean basin and the shape of the coastline. The third factor is the position of the sun relative to the earth and the moon. Spring tides are tides with greater than average tidal differences between high and low tides. They occur when the earth, sun, and moon are in a line. Neap tides are tides with less than average tidal differences between high and low tides. They occur when the sun, earth, and moon form a 90° angle.

Sediments--Materials Transported by Both the River and the Ocean

One of the materials transported by water into the estuary is sediment. Sediment may be made up of large particles, such as coarse sand, or very fine particles, such as silt and clay. Table 1 lists the particle sizes for various types of sediment.

Table 1. Particle sizes for various types of sediments.

Sediment Type	Particle Size
Gravel and larger	Greater than 2.0 mm
Very coarse sand	2.0-1.0 mm
Coarse sand	1.0-0.5 mm
Medium sand	0.5-0.25 mm
Fine sand	0.25-0.10 mm
Very fine sand	0.10-0.05 mm
Silt	0.05-0.002 mm
Clay	Less than 0.002 mm

The sources of sedimentary materials in rivers and streams include weathered and broken down rock, earth slides from various causes, and erosion caused by the loss of vegetative cover along streams and rivers. We are all familiar with the fact that fast-moving water will transport larger particles than will slow-moving water. Anyone who has hosed off a driveway or sidewalk has seen that principle in action. Swift-moving mountain streams have rocky beds because the smaller materials have been moved downstream. As the bed of the river nears the coast, most rivers level off and become wider. They also meander or form channels that loop back and forth across the valley floor. All of this means that the water slows down, and as it slows, smaller and smaller particles drop to the bottom. The river acts as a sediment sorter with the larger particles left upstream. The sorted sediments form a sediment gradient.

A fine example of this can be seen on the Umpqua River between Reedsport and Elkton. Here, about 20 miles from the ocean, the Umpqua Sand and Gravel Company regularly dredges gravel from the river bottom. A few miles downstream, closer to the ocean, the same company dredges sand from the river bed. As long as the company doesn't dredge more material than the river supplies, there will be a continual supply brought by the river from further upstream. Figure 6 is a sketch of a dredge loading a barge of gravel.

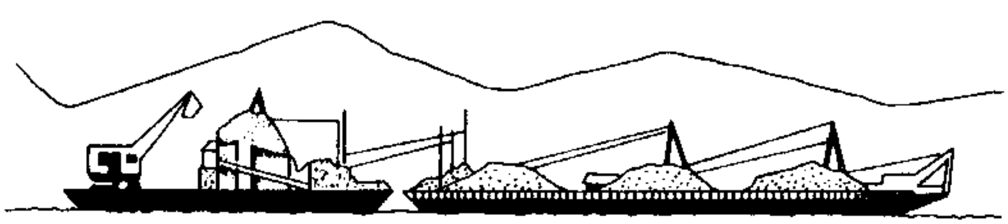


Figure 6. A dredge loading a barge with gravel removed from the Umpqua River near Reedsport.

In most cases, by the time the river reaches the estuary, the water has slowed so much that only the finest sediments remain suspended in the water. The river water stops completely when it meets the incoming and ebb high tides. This allows very fine particles to fall to the bottom. The upper end of the estuary therefore has very fine sediments on the bottom.

At the mouth of the estuary the conditions are totally different. During the winter and spring, vicious storms erode the beaches and move the sand along the coast in the direction of the main ocean currents. This sand is then again deposited on shore. Remember that the bar is dangerous because of the rapid currents and heavy wave action. This rapidly moving water is laden with sand, and so the flooding tides carry the sand into the estuary. This causes the mouth of the estuary to be sandy.

If you were to start at the mouth of the Coos Bay Estuary and travel into it taking bottom samples every mile or so, you'd find a sediment gradient starting with coarse sand, and then becoming fine sand, sandy mud, coarse mud, and finally, silt and clay.

Other materials brought in by the water are <u>nutrients</u>. When rock and soil become broken down so much that they become silts and clays, the chemical components start to dissolve into the water as molecules. Some of the chemical components are nitrates and phosphates which become available to growing plants. Other sources of nutrients are agricultural fertilizers in the water draining from farmlands and organic materials that have broken down.

Summary

Both the river and the ocean carry sediments into the estuary. Since the most rapidly moving water carries the largest particles, the bottom of the estuary forms a sediment gradient with the largest particles at the mouth and the finest particles at the head of the estuary. When chemicals such as nitrates and phosphates dissolve from silts and clays into the water, they become available for plant growth.

Fresh Water--A Contribution from the River

<u>Salinity</u> is a measure of the amount of salts dissolved in water. In the ocean most of the salts are sodium chloride or magnesium chloride. Seawater contains about 35 grams of salts per 1000 grams (one kilogram) of water, or 35 parts per thousand. Usually, it is abbreviated as 35 ppt or 35 $^{0}/oo$.

Several different methods can be used to measure salinity. All the methods are based on the fact that water with salt dissolved in it has different physical properties than fresh water has. For one thing, salt water is denser than fresh water. That is, a given volume of salt water weighs more than the same volume of fresh water if both samples are at the same temperature.

A hydrometer, which is a weighted glass graduated float, can be used to measure the density of water samples. Different densities at a specific temperature can then be converted to salinity. Figure 7 is a sketch of a hydrometer being used to measure the salinity of a sample in a graduated cylinder.

Another difference in physical properties is that salt water conducts electricity better than does fresh water. A salinometer measures salinity by measuring the electrical conductivity of the salts dissolved in a solution. Figure 8 is a drawing of the control panel of a salinometer.

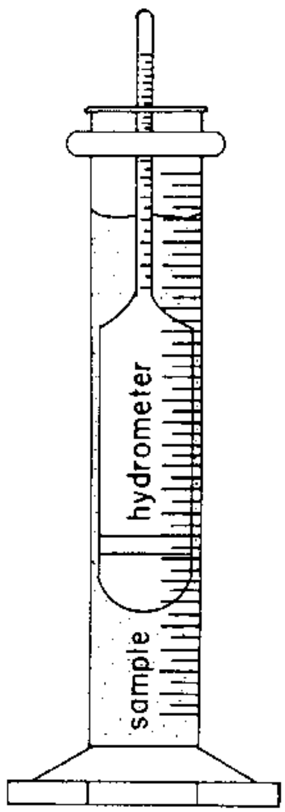


Figure 7. A hydrometer in a graduated cylinder containing a water sample.

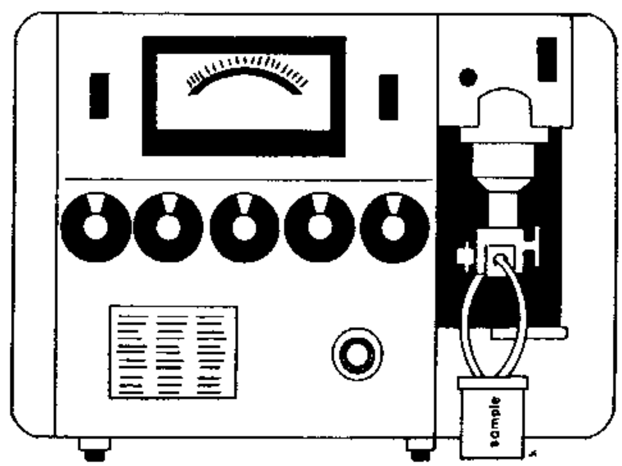


Figure 8. The control panel of a salinometer.

Figure 9 is a drawing of a refractometer. Salt water bends or refracts light more than fresh water does. Consequently, by measuring the degree to which a solution bends light, we can determine the salinity of the solution. A refractometer can be used to measure the salinity of just a drop of water.

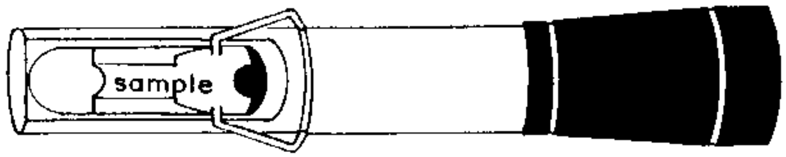


Figure 9. A refractometer.

Although the ocean has a salinity of about 35 ppt, most rivers have less than 0.2 ppt. Knowing this, we can also define an estuary as a body of water with a salinity measuring between 35 ppt and 0.2 ppt.

If we consider the river to be a rather constant supply of fresh water going into the estuary, say on a week-by-week basis, then the salinity is going to vary hour by hour in most of the estuary as the tide level changes. In general, though, we would expect the area near the estuary mouth almost always to be nearly as salty as the ocean and the area at the upper end almost always to be fresh water. From our discussion of sediments, we recognize this to be a gradient, a salinity gradient in this case.

There are different ways in which mixing can occur in estuaries, and this variety results in different types of salinity gradients. Figure 10 illustrates two types of salinity gradients. In an estuary

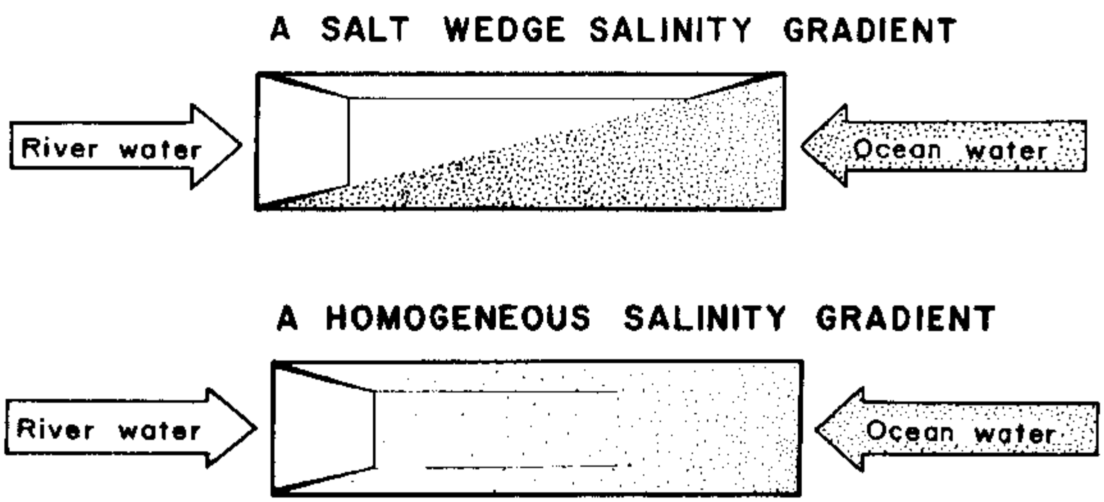


Figure 10. Two types of salinity gradients found in estuaries.

that has a homogeneous salinity gradient, the salinity decreases fairly constantly as you move up the estuary into the river. Also, at any given point in the estuary the salinity is nearly the same from the surface to the bottom. We say the estuary is well mixed. Some estuaries have a salt wedge salinity gradient. In this case the less dense fresh water of the river flows over the top of the denser salt water, and the salinity changes abruptly where the saltwater and freshwater masses meet. In this type of estuary, in most places, the salinity difference is quite large between the surface and the bottom, and there is a very narrow zone where the salinity changes. We say this type of estuary is stratified.

There are many factors that combine to determine the type of salinity gradient an estuary will have. The amount of fresh water from the river is one important factor. Two other factors are the average depth of the estuary and the tide range for the portion of the coastline where the estuary is located. Some estuaries are well mixed during the summer and stratified in the winter. At other times the same estuary may have an intermediate salinity condition that is called partially mixed. The Coos Bay Estuary is usually well mixed with an occasional period of partial mixing during the winter.

Summary

The area where the fresh water from the river meets and mixes with the salt water from the ocean is an estuary. The type of salinity gradient in an estuary helps us to classify the estuary. Therefore, we need to measure the salinity of the water and to determine how much mixing is occurring. The estuary will have a salinity between 35 ppt and 0.2 ppt. We can measure salinity using a hydrometer, a salinometer, or a refractometer. An estuary may have a homogeneous salinity gradient, a salt wedge salinity gradient, or an intermediate condition. An estuary may be well mixed, stratified, or partially mixed. The salinity gradient may change during the year in the same estuary.

Short-Answer Questions

1. What two features of the river have the greatest influence on the estuary? What three features of the ocean?
2. What causes the tidal bulges?
3. How does the sun affect the tides?
4. What is a spring tide? A neap tide?
5. What sediments come into the estuary mainly from the river? Mainly from the ocean?
6. What is the natural source of nitrates and phosphates?
7. What is the sediment gradient in the estuary?
8. What is the salinity of seawater?
9. What three tools can we use to measure salinity?
10. What two main types of salinity gradients were discussed in detail in this chapter?
11. What are the three types of estuaries as defined by their mixtures of fresh water and salt water?

3

Estuarine Habitats

In this chapter we will look at the various habitats in the estuary. We will also

- *look at the characteristics of a salt marsh*
- *learn what detritus is*
- *learn what lives in the holes in mud flats*
- *investigate eelgrass beds*
- *learn the difference bewteen zooplankton and phytoplankton*

In this chapter, we'll look at three estuarine habitats: salt marshes, tideflats (or mud flats), and the channel areas (figure 11).

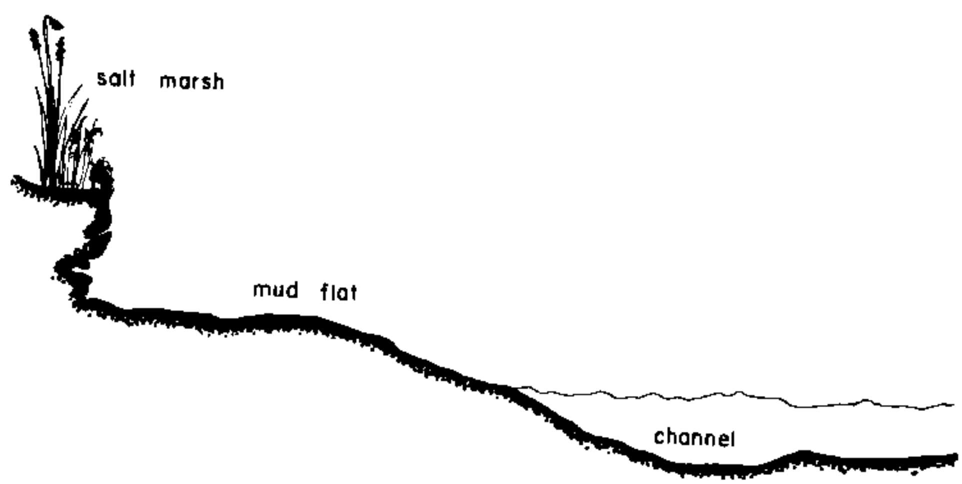


Figure 11. Salt marsh, mud flat, and channel habitats of the estuary.

The areas of highest elevation are the salt marshes. Salt marshes are at least occasionally covered by the tides, and the plants that grow on them are adapted to salt water. Tideflats, or mud flats, are those expanses of sand or mud that are of lower elevation than the salt marshes and that are alternately exposed and submerged by the tides. The channel areas are those parts of an estuary that even at the lowest tides are always covered with water.

Salt Marshes

Salt marshes are defined as wet grasslands growing along the edges of salty bodies of water and composed of plants adapted to salty soils. Such plants are called halophytes. The tide covers the estuary's salt marshes only during spring tides, but this is enough to create the necessary conditions for salt marsh growth.

A salt marsh can be divided into zones, depending on how much time an area is covered by the tide. The zones are characterized by the different plant species typically growing there. The lowest zone of the marsh is covered with water much longer than is the highest zone. The halophytes in the low marsh zone include pickleweed, *Salicornia,* which stores excess salt in its fleshy leaves, and salt grass, *Distichlis,* which has special glands that enable it to rid itself of excess salt as it accumulates (figures 12 and 13). Some species of algae, such as the brown rock alga, *Fucus,* are also found there (figure 14).

In the high marsh zone are found Pacific silverweed, *Potentilla,* and also grasses and sedges, such as *Deschampsia* and *Carex,* which cannot tolerate prolonged submersion by the tides (figure 15).

An estuary is one of the most productive natural areas in the world in terms of primary productivity (table 2).

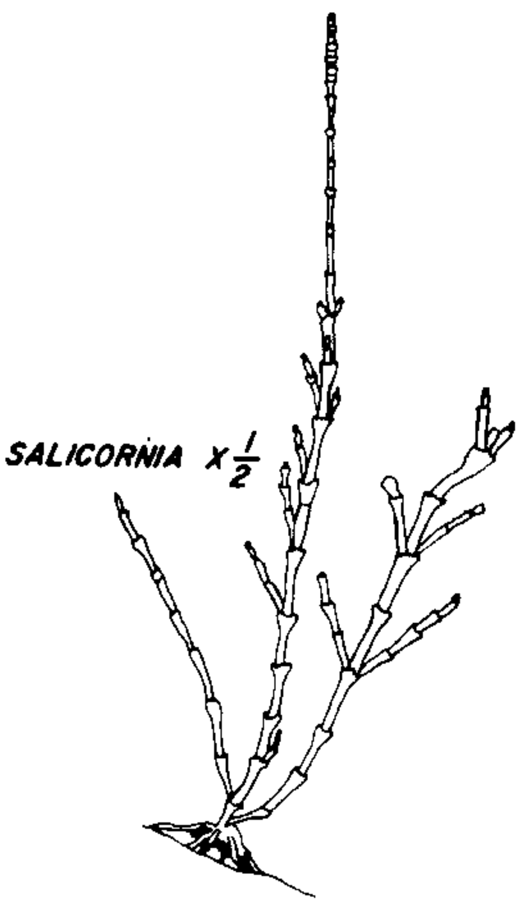


Figure 12. The low salt marsh plant pickleweed, *Salicornia*.

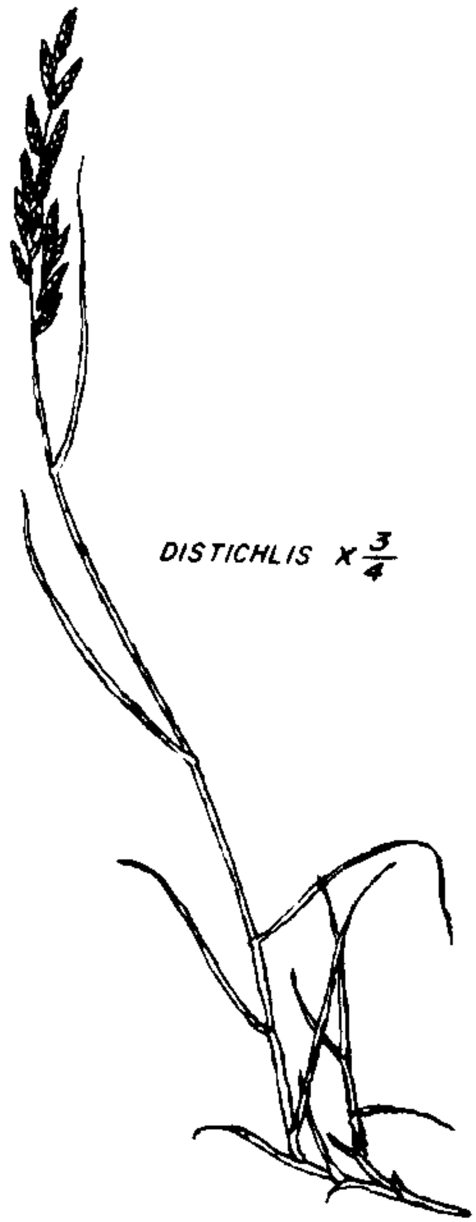


Figure 13. The low salt marsh plant salt grass, *Distichlis*.

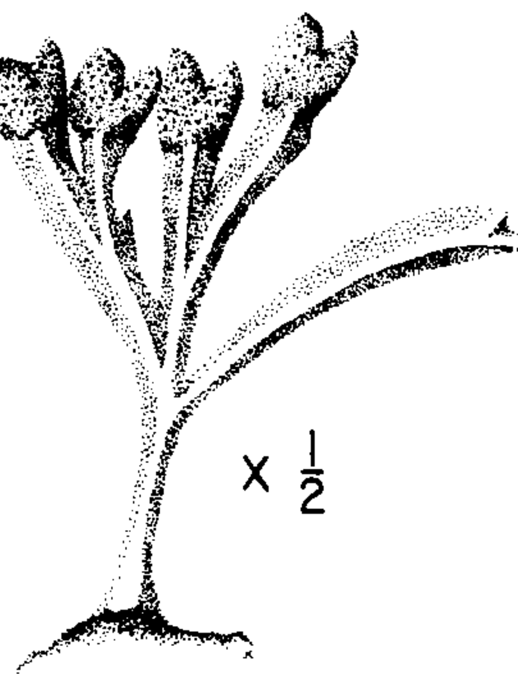


Figure 14. The brown rock alga, *Fucus*, often found in the low salt marsh.

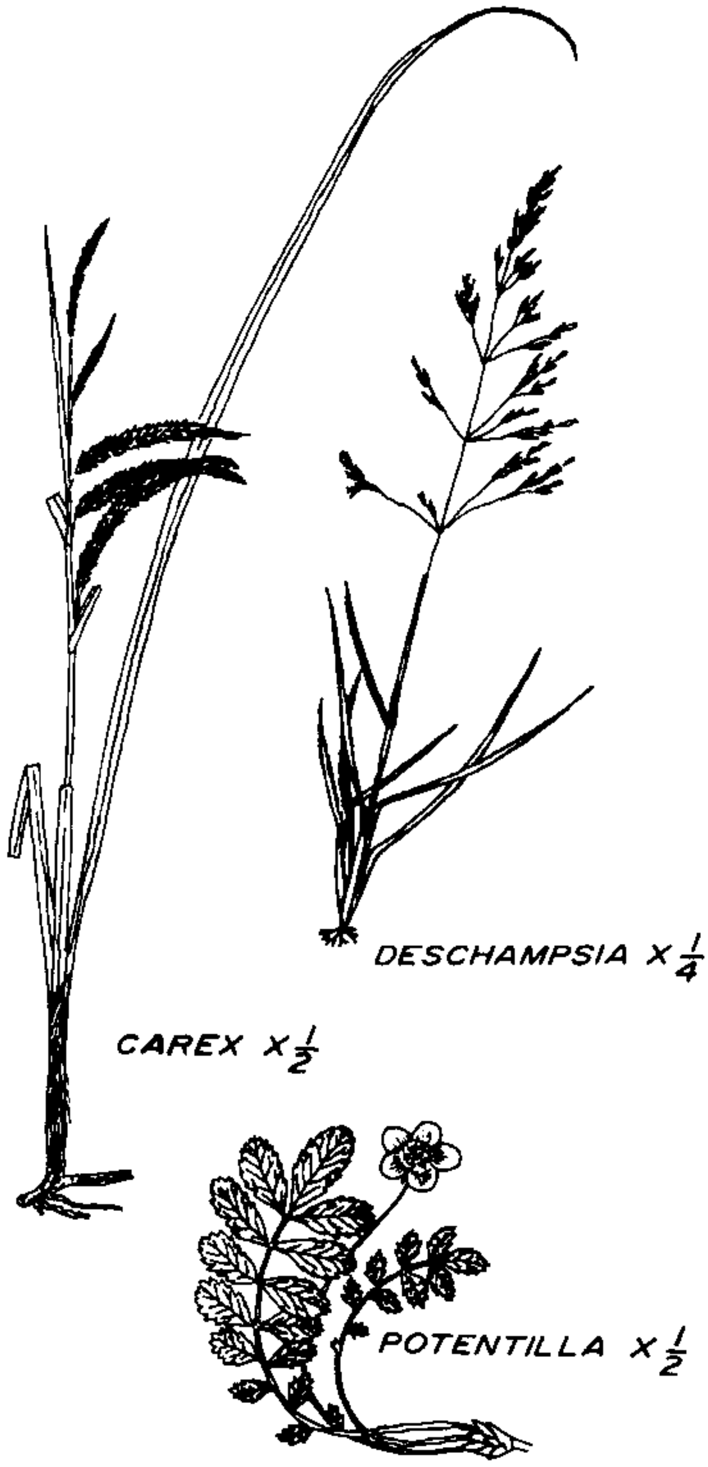


Figure 15. High salt marsh plants: Pacific silverweed, *Potentilla*; a rush, *Carex*; and tufted hair grass, *Deschampsia*.

Primary productivity is the number of grams of plant material produced per square meter of area per day by the process of photosynthesis.

Table 2. Mean annual primary production of major regions of the earth

Region	Grams Dried Weight/ Meter^2/Year
Oceanic attached algae and estuaries................	2000
Swamp and marsh....................	2000
Tropical forest....................	2000
Temperate forest..................	1300
Boreal forest......................	800
Savanna............................	700
Agricultural land.................	650
Woodland and shrubland............	600
Lake and stream...................	500
Temperate grassland...............	500
Continental shelf.................	350
Tundra and alpine.................	140
Open ocean........................	125
Desert Scrub......................	70
Extreme desert, rock, and ice......	3

Photosynthesis by plants is the basis for almost all life on earth. Only plants can use the energy of the sun to produce organic materials from inorganic materials. To do this, plants use carbon dioxide, water, and the energy of the sun to form sugars. Sugars are composed of carbon and hydrogen. Oxygen is a waste product from this reaction. Photosynthesis is responsible for the level of oxygen found in the air. There would be no oxygen-breathing animals on earth if it weren't for the oxygen from photosynthesis.

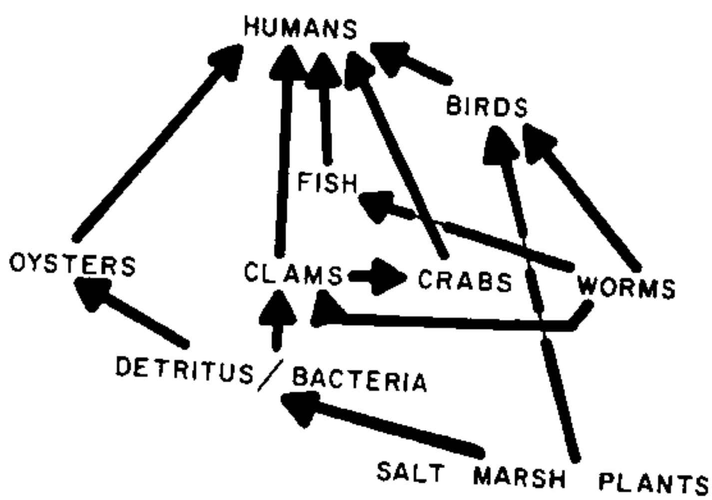


Figure 16. A salt marsh-based food web.

Salt marshes form the base of a large food web (figure 16). Some of the plants in the marsh are eaten by animals, but most of the vegetation enters the food web as detritus. Detritus is the term given to dead bits and pieces of organic material such as the dead and decaying salt marsh plants. The flooding and ebbing tides transport the detritus from the marsh into the estuary where it further decomposes and forms the base of the food web. Some of the detritus is further broken down into chemical nutrients and is used by other plants of the estuary.

Bacteria grow on the detritus, and the bacteria, in turn, provide an important source of food for small animals such as worms and clams. These small animals are eaten by larger ones such as birds, fish, and

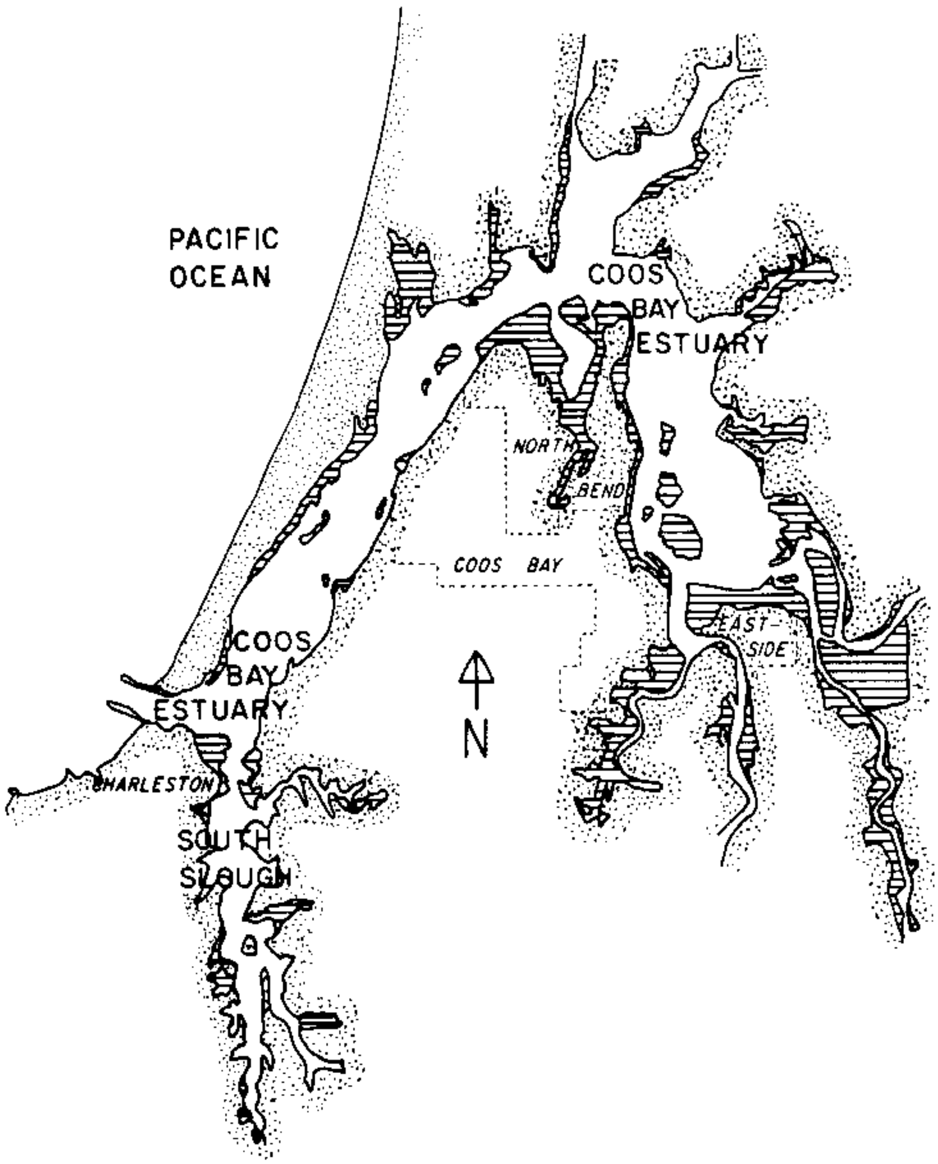


Figure 17. The approximate locations of lost or altered salt marshes and mud flats of the Coos Bay Estuary as of 1983.

people. We can see that even though the salt marshes occupy only a small part of our estuaries, they have a significant influence on the whole estuarine system, particularly by directly or indirectly providing food for many of the animals that live there. Reduction of the amount of salt marsh in an estuary by such processes as filling in a marsh for building sites or dredging out channels in the marsh for boat moorage has an effect not only on the immediate area, but on the estuary as a whole because the base of a large food web is being reduced. The salt marshes also help keep the water quality of the estuary high by trapping pollutants and converting them into harmless substances. Of course, this is true as long as the amount of pollution is not too great. If the salt marsh becomes overwhelmed, the natural system breaks down and water quality suffers. Since the settlement of the Coos Bay area by pioneers in 1851, 90 percent of the salt marshes in the Coos Bay Estuary have been lost through filling, dredging, or diking (figure 17).

Summary

Salt marshes are highly productive. Most of the plant material produced in salt marshes enters the estuarine food web as detritus which supports bacterial growth and, when further broken down, serves as a source of nutrients for other estuarine plants. Tidal movements carry the detritus and nutrients to other parts of the estuary. The loss of marshlands ultimately affects the whole estuary by reducing the base of a large food web and removing a habitat that helps maintain good water quality.

Mud Flats

Tideflats are usually called mud flats because most tideflats are composed of mud. But the sandy areas near the mouth of the estuary can properly be called sand flats. For our purposes, however, we will also call these areas mud flats.

At low tide, large expanses of mud flats can be seen in the Coos Bay Estuary. At first glance, or even with a good long look, it appears as though not a lot is living there. However, a careful examination will show that many different plants and animals are present.

Digging down into the mud, you will find that just below the yellow-brown surface the mud is black and smells something like rotten eggs. Such color and smell indicate the absence of molecular oxygen. We call this layer anaerobic, meaning it is without molecular oxygen. Surprisingly, though, there are organisms that can live in this black mud; in fact, some can live only there. The animals that burrow into the estuary bottom are sometimes called infauna. Some of the animals have ways of getting oxygen from the water overlying the mud flat. For example, clams have long, elastic siphons which they extend up to the surface. Figure 18 is a diagram of two animals of the mud flats.

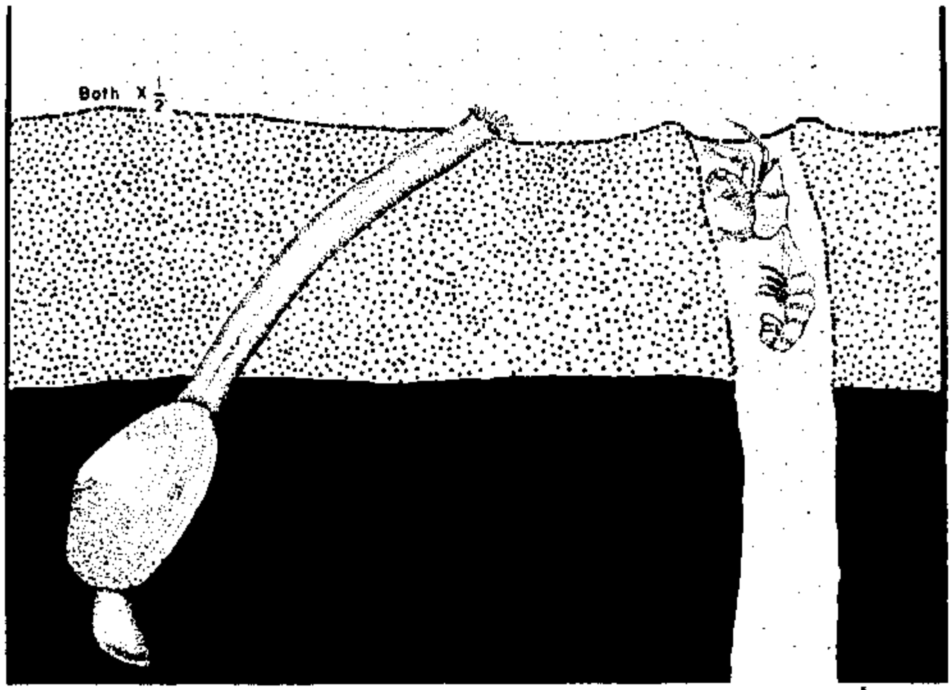


Figure 18. A soft-shell clam, *Mya,* and a mud shrimp, *Upogebia,* burrowed into the black, anaerobic layer of a mud flat.

Organisms in the black sediment that do not need molecular oxygen are called anaerobes. The most common type of anaerobe in the mud is bacteria. These bacteria produce a gas, hydrogen sulfide (H_2S), which is responsible for the rotten egg smell. Some of the hydrogen sulfide reacts with the iron salts in the sediment, producing iron sulfide (FeS), which is black and which gives the mud its characteristic color. When molecular oxygen is available, it reacts with the iron sulfide to produce mainly hematite (Fe_2O_3), which is a yellow-brown color. Because of the presence of hematite in the upper layers of the sediment, the surface of the mud flat is a yellow-brown color. Also produced is a small amount of magnetite (Fe_3O_4). If a magnet is used to stir the mud flat sediments, bits of magnetite will be attracted to it, confirming the presence of that mineral.

Why would an animal ever adapt to living in a hole in a stinking, oxygen-poor environment? There are several advantages to living in the mud. For one thing, animals burrowed into the mud are not as exposed to predators as are animals in a less sheltered environment. For another, they're not subjected to the drying effects of the sun at low tide. And for another, the salinity of the mud is more constant than that of the overlying water. Some animals that always stay in the mud, like mud shrimp, feed by filtering food from water currents they create in their burrows. Clams feed by filtering food from the water passing through their siphons. Some animals--for example, many of the worms living in the mud--are deposit feeders and digest the bacterial and organic coatings from the sediment particles passing through their digestive system. Figure 19 is a drawing of a lugworm, *Abarenicola,* which is a common mud flat worm, and a bent-nose clam, *Macoma nasuta.*

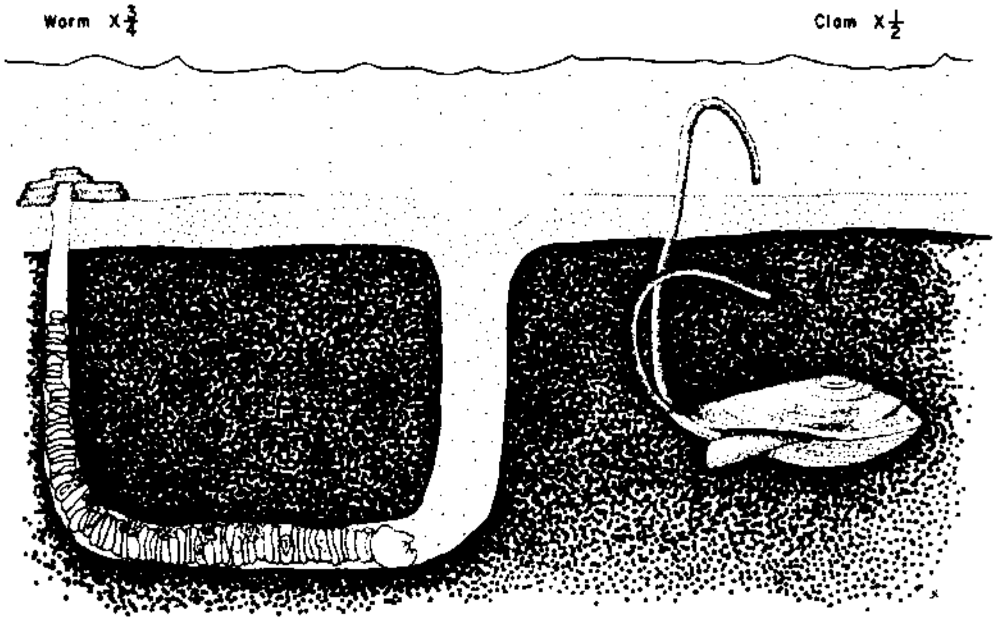


Figure 19. A lug worm, *Abarenicola* (a common mud flat worm), and a bent-nose clam, *Macoma nasuta.*

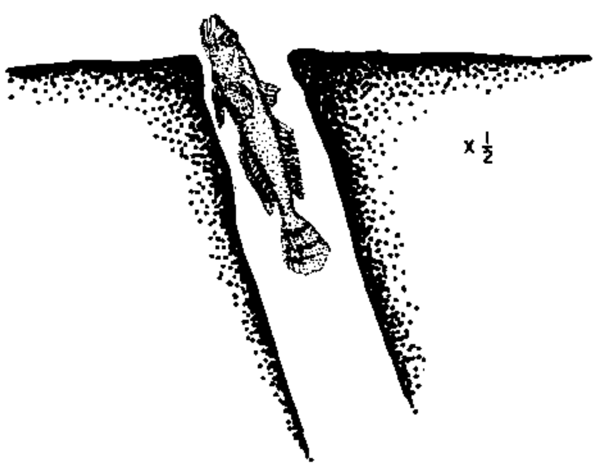


Figure 20. An arrow goby, *Clevelandia ios.*

Still other burrow-dwelling animals, like the arrow goby, *Clevelandia ios* (figure 20), leave their burrows at high tide and forage over the mud flat.

The animals of the higher levels of the food web also have various feeding strategies. At low tides wading birds such as egrets and great blue herons feed on the fish in pools of water left by the receding tide. Shorebirds can be seen probing the sediment with their bills. The length of a shorebird's bill determines how deep the bird can probe (figure 21). This, in turn, not only determines what the bird will have in its diet, but allows it to feed in the same area with a minimum of competition from other species. As the tide floods over the mud flats, predatory fish such as shiner seaperch, *Cymatogaster aggregata,* and English sole, *Parophrys vetulus,* forage over the submerged mud flats. They feed on the burrowing animals that have come up to the surface of the mud flats to feed. Foraging fish also feed on the tips of the clam siphons sticking above the surface of the mud.

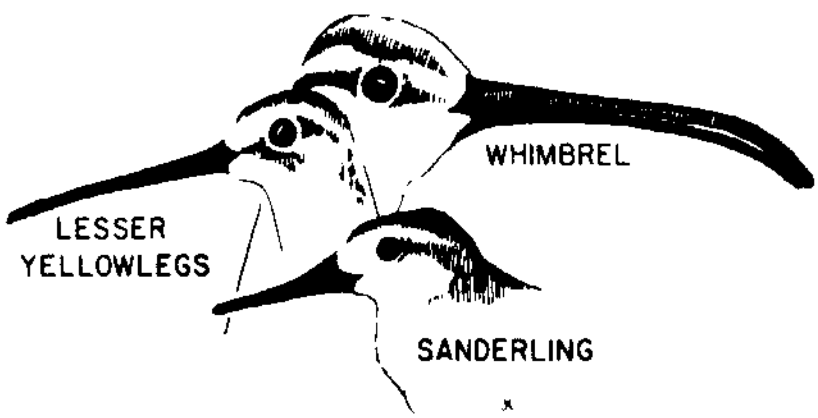
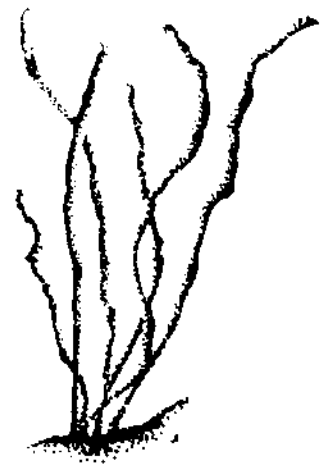


Figure 21. A comparison of the bill length of three species of wading birds.

There are three major sources of plant productivity on the mud flats. First, some species of algae grow during the spring and summer and cover the mud flats in thick, green mats that look like a lawn from a distance. There are several species of green algae in the genera *Enteromorpha* and *Ulva* (sea lettuce) that do this (figures 22 and 23).

Figure 22. Sea lettuce, *Ulva,* a green alga that grows on the mud flats and rocky surfaces in the estuary.

Figure 23. The tube-like green alga, *Enteromorpha,* that grows on the estuary mud flats.



ENTEROMORPHA $X\frac{1}{2}$

A second major source of primary productivity in the estuary is completely invisible to the unaided eye. This is the diatom plankton that coat the surface of the mud flats and almost everything else as well. Organisms such as diatoms that live on the bottom of the estuary are called benthic. Diatoms are spectacular when seen under the microscope because they have highly sculptured and ornate silica shells enclosing gold-brown structures. Figure 24 shows benthic diatoms of several different genera.

The third major source of primary productivity is the eelgrass beds. Eelgrass, *Zostera,* is one of the few flowering plants in the world that can live completely submerged in salt water. The flowers of this plant in many respects look similar to wheat or oat heads (figure 25). Eelgrass is found low on the mud flats along the channels. The pollen is spread by water currents. Eelgrass gets its name because it has long, thin, grasslike leaves that grow to two meters (6.6 feet) in length and wave back and forth in an eel-like manner with the currents.

Eelgrass is itself a valuable food source and is fed upon by some species of ducks and geese (such as widgeon and black brant) that are common in Oregon's estuaries during the spring and fall. Algae and diatoms grow on its leaves, and small animals graze on these miniature gardens. Animals and plants that grow on eelgrass leaves include stalked jellyfish, red algae in the genus *Parphyra,* and three types of crustaceans--isopods, caprellid amphipods, and gammarid amphipods

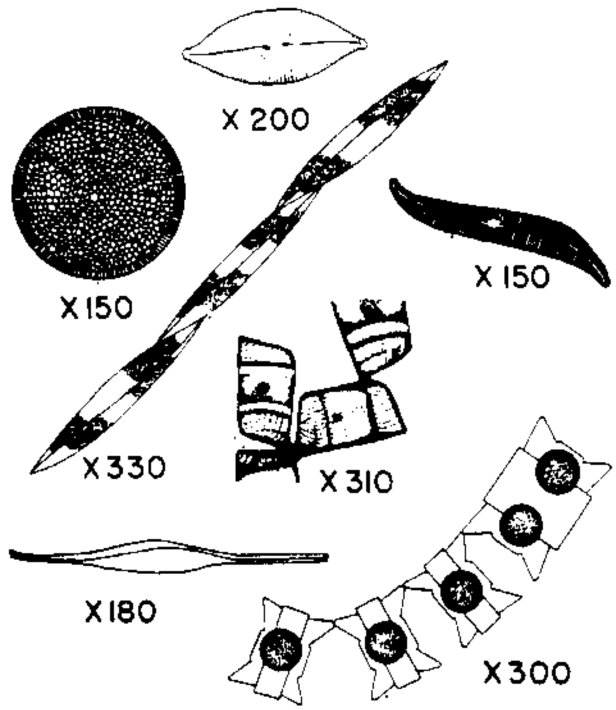


Figure 24. Representative benthic diatoms found in estuaries.

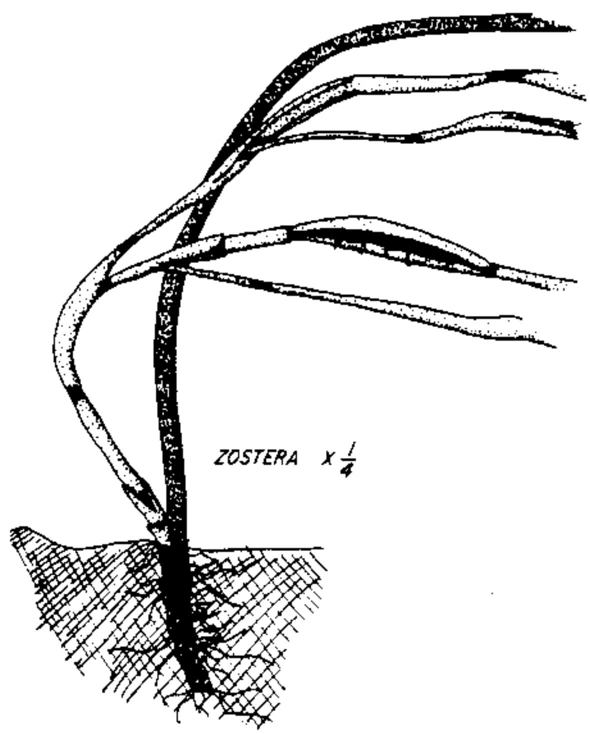


Figure 25. An eelgrass plant, *Zostera*, showing the grasslike flower of the plant.

(figure 26). Of course, much of the eelgrass ultimately becomes detritus and joins the detrital food web.

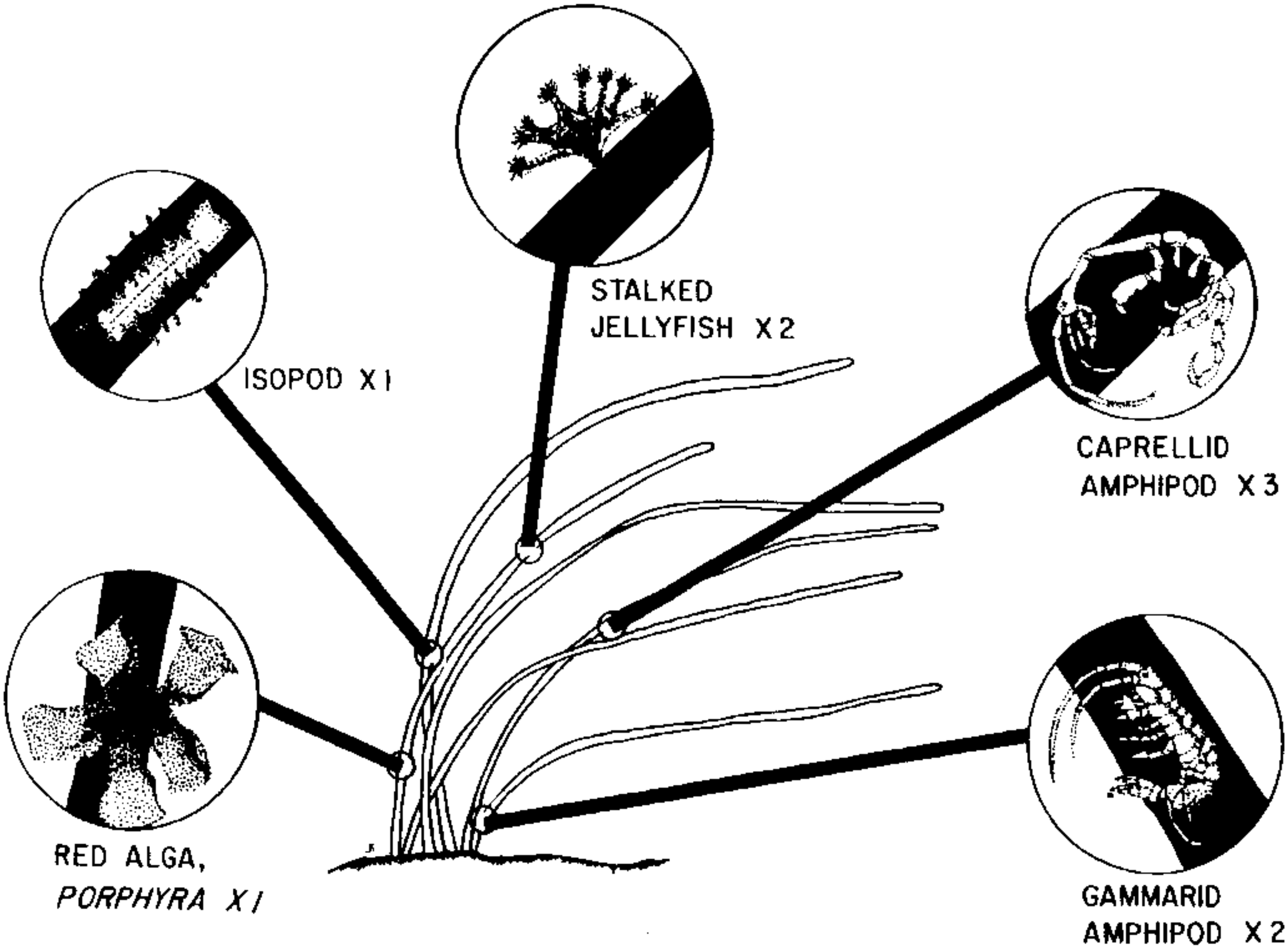


Figure 26. The leaves of eelgrass, *Zostera*, provide a surface for several species of plants and animals to grow on.

Eelgrass makes important contributions to the estuary in addition to its role in the detritus food web. It is the first rooted plant to take hold in the shallow water. The roots and long leaves trap fine particulate materials to produce an ideal, food-rich, protected eelgrass bed. This environment enhances the growth of worms and other bottom dwellers. It also promotes the settling of clam larvae and enhances the animal productivity of the area. Finally, the eelgrass acts as a "nutrient pump" by taking up nutrients for growth and then releasing them as it dies back at the end of the growing season (figure 27).

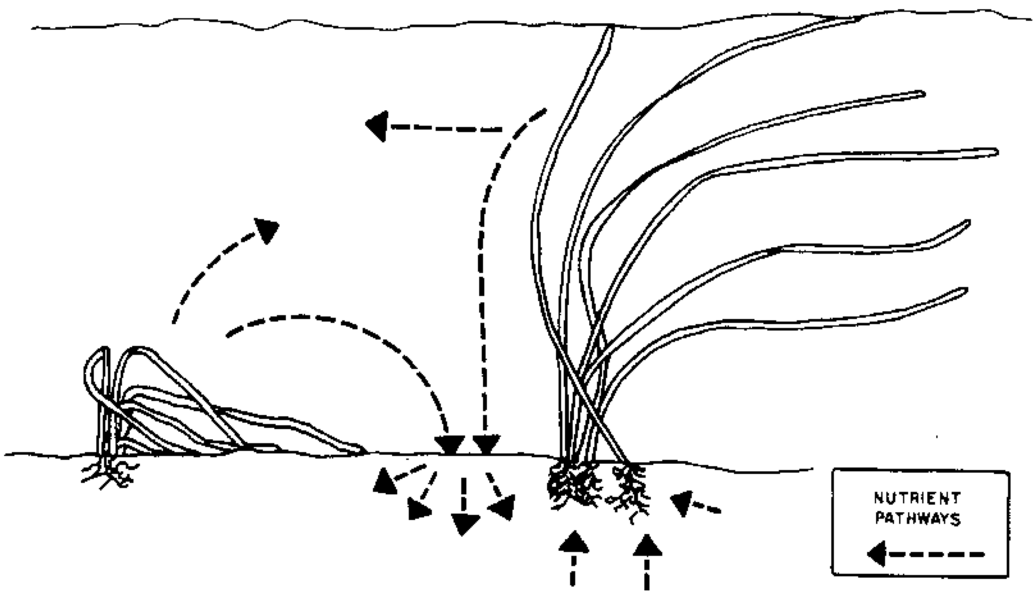


Figure 27. The nutrient pathways powered by the eelgrass "nutrient pump."

Summary

Although mud flats appear to be almost devoid of life, they are, in fact, a productive and dynamic part of the estuary. Because of the relatively harsh conditions at the surface of the mud, most animals live burrowed into it. The deeper sediment of mud flats exhibits a black color and peculiar smell indicative of anaerobic conditions. But the reduction in predation and the rather stable environmental conditions found there make it advantageous to live in the mud. Furthermore, the animals living in the sediment have developed different feeding habits to cope with their environment. The major sources of plant productivity on the mud flats are seasonal green algae, benthic diatoms, and eelgrass.

The Channel

The channel is that area of the estuary where water is always present, even at extremely low tides. Unlike mud flat organisms, the animals and plants that live in the channel never have to cope with the problems of being exposed to air. The fact that the amount of water in the estuary alternately equals the size of the whole estuary at high tide and shrinks to the size of the channel areas at low tide makes the channel an important habitat.

Many of the animals and plants in the channel are microscopic. Most of them float freely in the water and are called plankton. Plant plankton are called phytoplankton, and animal plankton are called zooplankton. Plankton are very inefficient and weak swimmers or move only by the aid of water currents. Plankton can be sampled by towing a net behind a boat or by standing on a dock or bridge and letting the current pass through the net.

The majority of the phytoplankton in the estuary are the diatom and dinoflagellate algae (figure 28). These plants can double their populations every one to two weeks under optimum conditions. The famous "red tide" is the result of an explosive increase in certain dinoflagellate species. Phytoplankton are food for many estuarine animals, and thus they form the base of another food web. Phytoplankton are eaten by benthic filter feeders such as clams and worms, by fish, by the zooplankton, and by other estuarine animals.

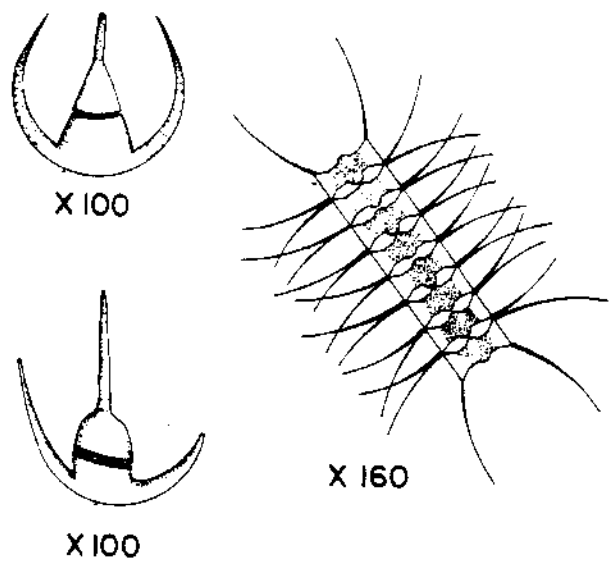


Figure 28. Representative diatoms and dinoflagellates common to the channel habitats of the estuary.

Permanent zooplankton are animals that live all of their lives as plankton. The most common of the permanent zooplankton are minute crustaceans such as copepods. Comb jellies, such as *Pleurobrachia* and jellyfish such as *Aequorea* are other members of the permanent zooplankton (figures 29, 30, and 31).

Temporary zooplankton are animals that spend only part of their lives as plankton. The most common types of temporary zooplankton are the juvenile stages, or larvae, of invertebrate animals such as worms

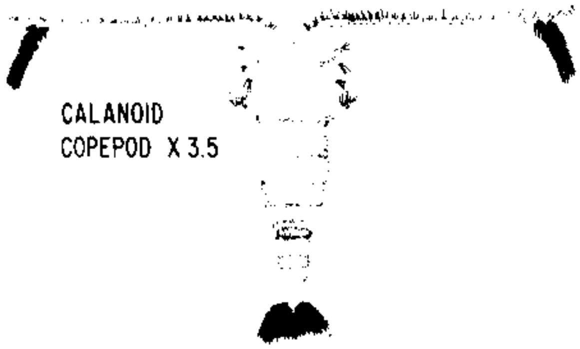


Figure 29. A copepod.

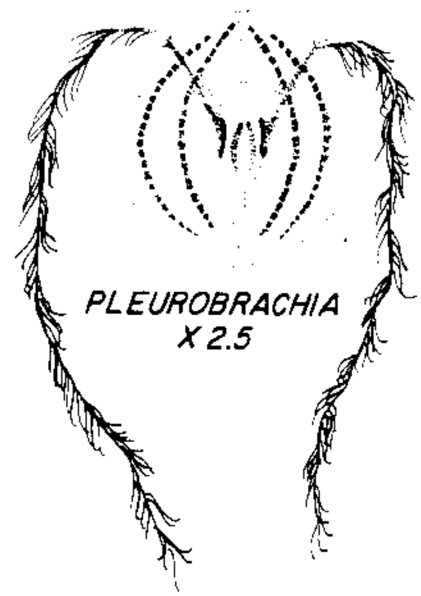


Figure 30. A comb jelly, *Pleurobrachia*.

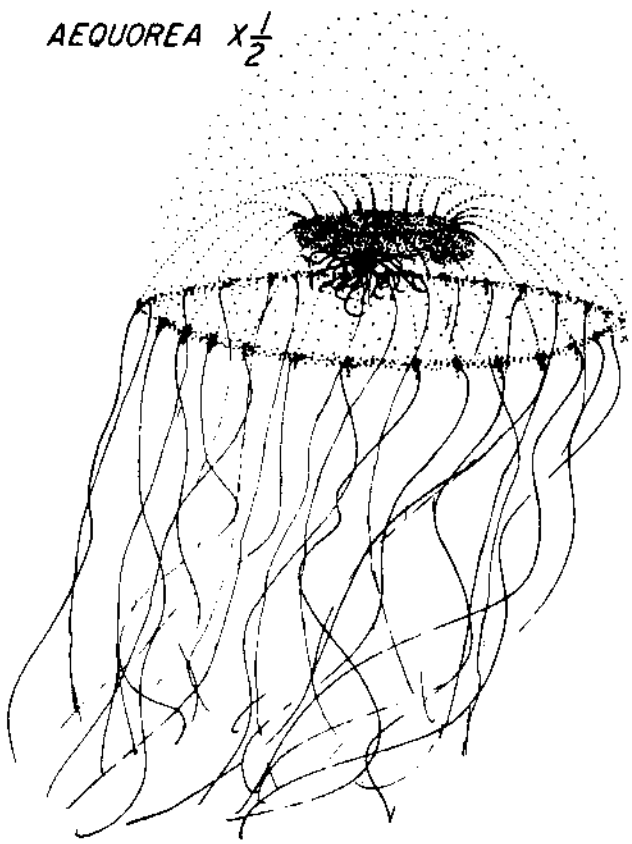


Figure 31. A jellyfish, *Aequorea*.

and clams. Many of the benthic animals release their young into the water, or the eggs are fertilized and hatched as they float around. The larvae feed and grow and may pass through several developmental stages before becoming adults. The larvae rarely resemble the adult form. Figure 32 shows a polychaete worm larva, a clam larva, and a

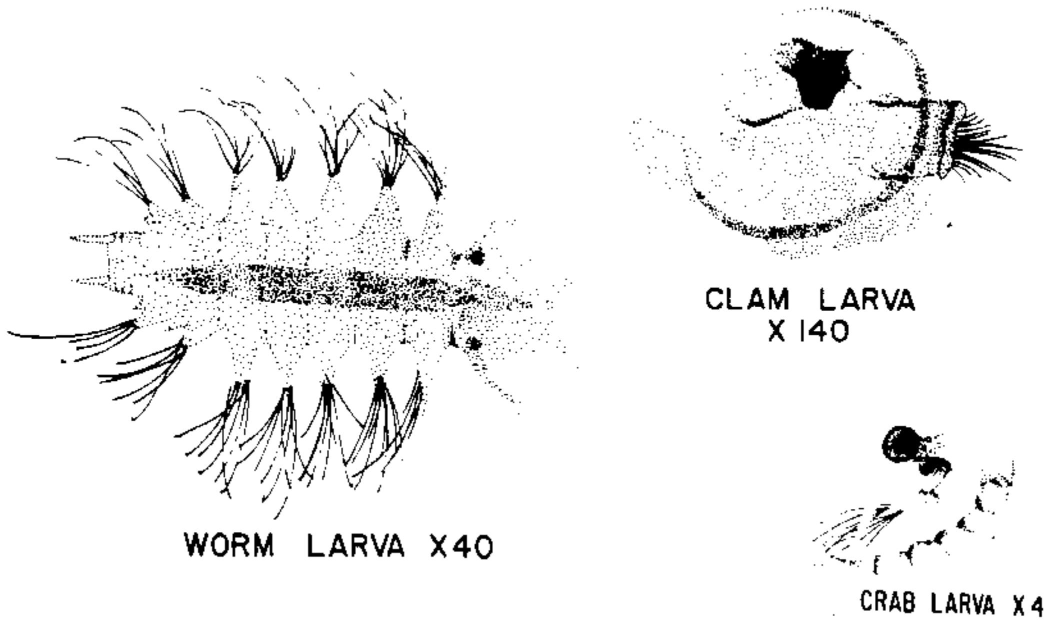


Figure 32. A polychaete worm larva, a clam larva, and a crab larva as commonly found when sampling the temporary animal plankton.

crab larva as seen under the microscope. Some larval fish are also members of the temporary zooplankton (figure 33).

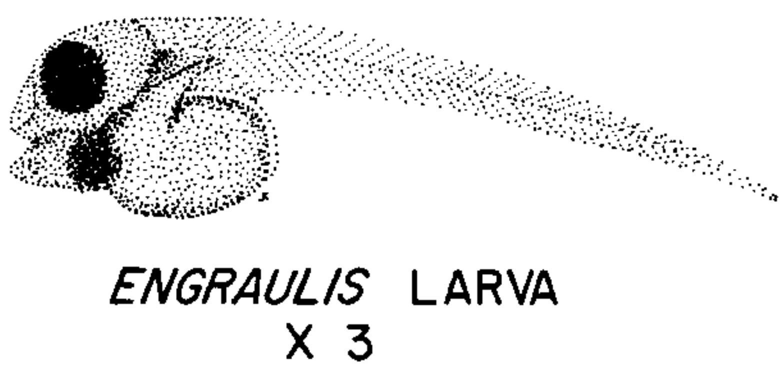


Figure 33. The larva of the anchovy, *Engraulis*, is an example of a fish larva found in the temporary plankton.

Fish are nektons, strong swimmers that can propel themselves efficiently through the water. Many different kinds of fish--for example, staghorn sculpin, *Leptocottus armatus,* and starry flounder, *Platichthys stellatus*--are found in the estuary, where they are permanent residents. As we've noted in the section on mud flats, some fish, like the arrow goby, live in burrows made by other animals at low tide, but most fish retreat into the channels and then move back over the mud flats at high tide to feed.

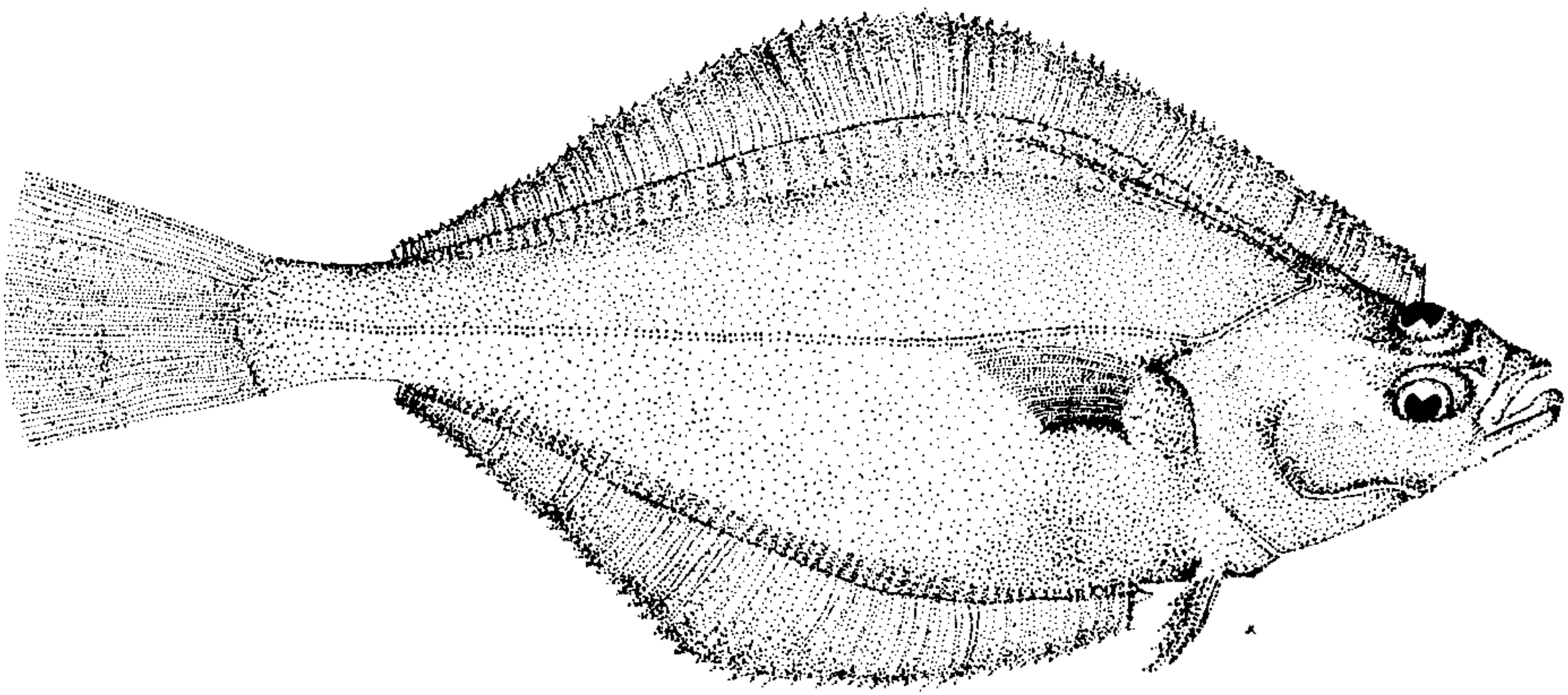
Other fish species move into estuaries from the ocean to spawn. Those that spawn in the estuary use it as a nursery to take advantage of the sheltered conditions and large amount of food available. Some of them are commercially valuable species such as English sole, *Parophrys vetulus,* Pacific herring, *Clupea harengus pallasi,* and northern anchovy, *Engraulis mordax* (figures 34, 35, and 36).

The larvae of the Dungeness crab, *Cancer magister,* also use the estuary as a nursery.

Coho salmon, *Oncorhynchus kisutch,* use the estuary mainly to get from their spawning areas in the rivers and streams to the ocean, where they spend most of their adult life. Chinook salmon, *Oncorhynchus tschawytscha,* use the estuary for feeding and adjusting to the salt water before migrating to sea. Species which have adults that migrate from the sea to fresh water to spawn are called anadromous. Other anadromous fish include shad, *Alosa,* and steelhead trout, *Salmo gairdneri.* Steelhead are rainbow trout that have become anadromous.

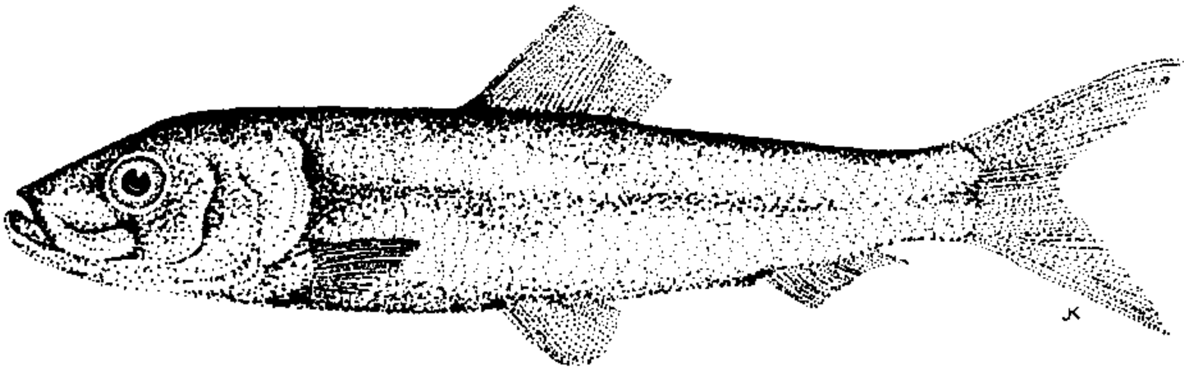
The life cycles of the five species of Pacific salmon are slightly different from one another. The amount of time spent in the river and in the ocean is the major difference. Coho, also called silver salmon, is one of the salmon species native to Oregon's rivers. The following description of a salmon's life cycle refers to this species, but the general stages apply as well to the other four species that occur in the Pacific Ocean (figure 37).

Adult salmon return to spawn in the gravel of rivers and streams. The fertilized eggs hatch, and the immature fish, called alevins, are nourished by their attached yolk sacs. They live in the gravel for two or three weeks. They then leave the gravel, become free-swimming, completely absorb the egg sac, and develop characteristic vertical dark stripes across their backs. At this stage they are called parr and the vertical stripes are called parr marks. More often, however, they are called fingerlings. The fingerlings live in fresh water for one or two years, lose their parr marks, and then swim downstream toward the estuary. There they undergo physiological changes called smolting that allow them to adjust to the changing salinities of the estuary and eventually to the salinity of the ocean. The young salmon enter the sea as smolts to begin to grow to maturity.



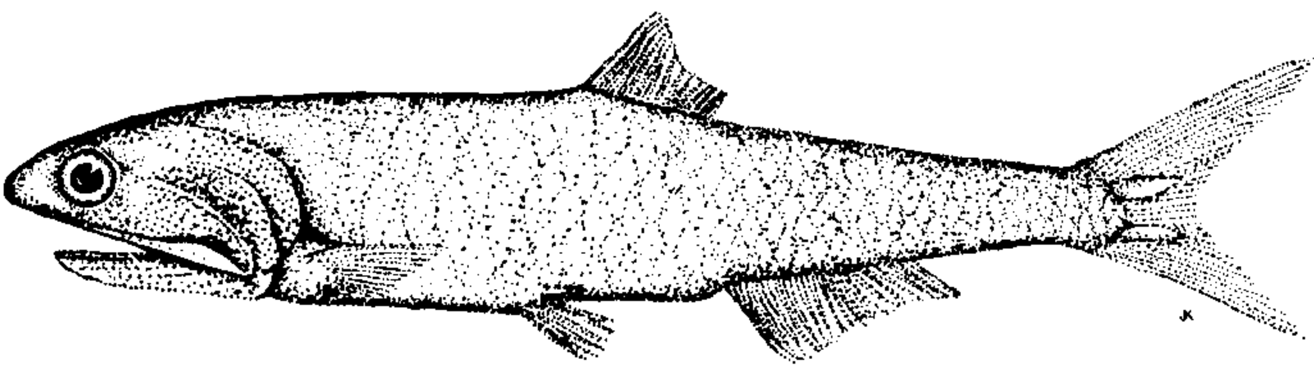
ENGLISH SOLE, *PAROPHRYS* X$\frac{1}{2}$

Figure 34. The English sole, *Parophrys vetulus*.



PACIFIC HERRING, *CLUPEA* X 1/2

Figure 35. The Pacific herring, *Clupea harengus pallasi*.



ANCHOVY, *ENGRAULIS* X1

Figure 36. Northern anchovy, *Engraulis mordax*.

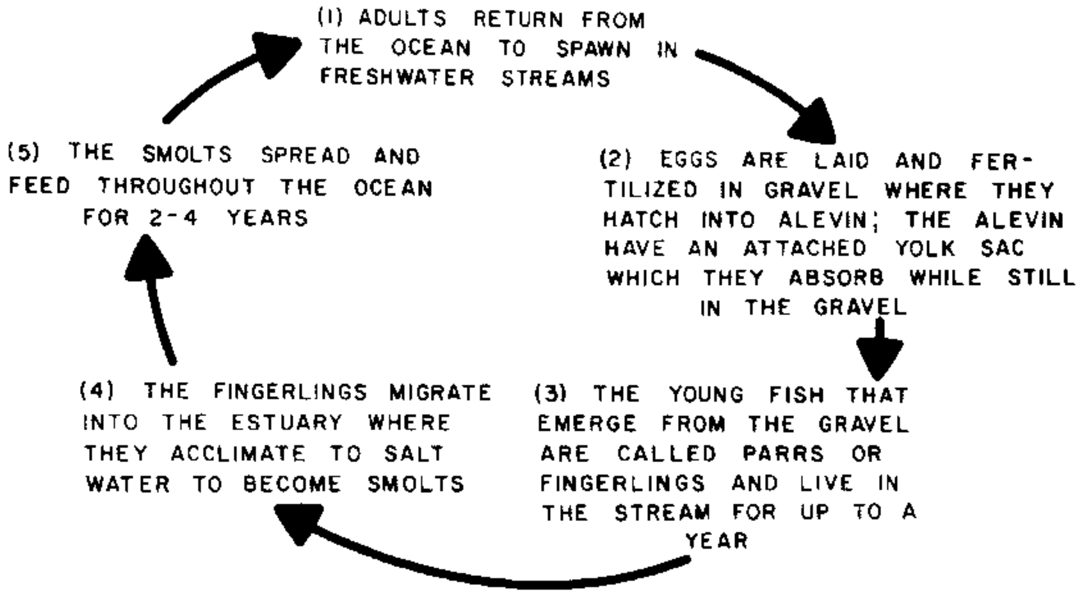


Figure 37. The life cycle of the coho salmon. This cycle is typical of most species of Pacific Northwest salmon.

The adult coho salmon spend one to three years in the ocean, and then they return to fresh water. Salmon have a remarkable homing sense that allows the surviving adults to return to the same stream from which they were hatched.

Only certain areas of streams are suitable for spawning. Successful spawning and hatching require water that is clean, well oxygenated, and low in silt. Furthermore, the spawning area must contain gravel of a certain size.

Natural events can damage a salmon stream. Landslides and mudslides can smother the spawning gravel. Ash from the eruption of Mt. St. Helens covered the gravel of streams in many areas. In years when rainfall is low, the level of the stream may be insufficient to allow salmon to swim far enough upstream to spawn. The greatest impediments to spawning, though, are improper road building and logging practices, which fill streams with sediment, and the construction of dams without providing for the passage of fish past the dam.

Summary

The phytoplankton and zooplankton are the most numerous organisms, besides bacteria, living in the channel waters. The phytoplankton form the base of one estuarine food web. Most of the phytoplankton are diatoms and dinoflagellates. The zooplankton can be divided into permanent zooplankton and the temporary zooplankton. The temporary zooplankton include the larvae of species such as worms and clams. Animals that are efficient swimmers and that are not dependent upon water currents to move them about are called nektons. Several fish species move into the estuary to spawn, and for them the estuary is a nursery area. Other species, such as salmon, use the estuary to get from their spawning areas in the rivers and streams to the ocean where they spend most of their adult life. Species having adults that live in the ocean and that migrate into fresh water to spawn are called anadromous fish.

Short-Answer Questions

1. Name two types of tideflats.
2. What is a halophyte?
3. How do we recognize different zones in the marsh?
4. What causes these zones to form?
5. What is detritus?
6. Diagram a simple estuarine food web.
7. Why are the lower layers of the mud flat black?
8. List three advantages an organism gains by living burrowed into the mud flat.
9. Name two feeding strategies used by burrowed mud flat animals.
10. What are three major sources of primary productivity on the mud flat?
11. What are plankton?
12. What are nekton?
13. What are the two general types of plankton?
14. Name two general types of plant plankton.
15. Name two general types of animal plankton.
16. Why are estuaries often called nursery grounds?
17. What is an anadromous species?
18. What are the three habitats of the estuary?

4

How Estuaries Are Used

In this chapter you will have the opportunity to explore the many ways people use and affect the estuary. We will look at

- *two new uses of estuaries*
- *the various activities that go on in developed estuaries*
- *the way these activities affect the estuary*
- *the importance of keeping the waters of the estuary as clean as we can*
- *the events at Great South Bay that teach us about balancing the uses of estuaries*

You have already read about some of the ways in which people affect the estuary and its inhabitants. People are part of the food web; the estuary provides us with food. People eat shellfish such as clams and crabs, catch fish, and hunt ducks in the estuary. They use the estuary to commercially grow and harvest oysters and fish. They also alter the shape, size, and habitats of the estuary to better suit it to their needs.

Aquaculture

In recent years new commercial uses of the estuary have been developed. These industries require that the estuary be kept in a productive state and that high water quality be maintained. More than ever they demand that we understand our estuaries and use them wisely.

Aquaculture is a relatively new commercial use of the estuary. Aquaculture refers to the raising and harvesting of aquatic plants or animals for human use. In the Pacific Northwest, salmon and oysters are the major aquaculture products.

For thousands of years, Native Americans of the Pacific Northwest gathered and ate the oysters that grew naturally in many of Oregon's estuaries. In the 1860s sailing schooners dredged Puget Sound, Washington, and Yaquina Bay, Oregon, for oysters which were taken to San Francisco to be sold. Soon oysters were almost gone from these bays because of environmental changes, many of which were brought about by people. Today a few native oysters survive, but by far the most numerous species that makes up the majority of the commercial harvest is one native to Japan, *Ostrea gigas*.

Adult oysters feed by filtering phytoplankton and other particles from the water. Thus, the quality of the water is important for oyster growth. If the water is turbid, light cannot penetrate and phytoplankton growth will be slow, limiting the oysters' food supply. Large quantities of sediment or other particles falling on the oysters will smother and eventually kill them. Dredging, harbor development, and the dumping of pollutants in the estuary can be damaging to oyster farming by causing excess turbidity, by smothering oyster beds, or by reducing the amount of oxygen in the water. Bacteria from untreated farm and human wastes can contaminate oysters, making them unsafe to eat. Certain areas of the estuary suitable for oyster growth are often set aside, and severe alteration of the estuary is prohibited there. Estuary use plans, drawn up by local and state governments, can help ensure that these areas remain available for aquaculture activities. Every citizen can participate in these decisions by attending meetings and writing letters.

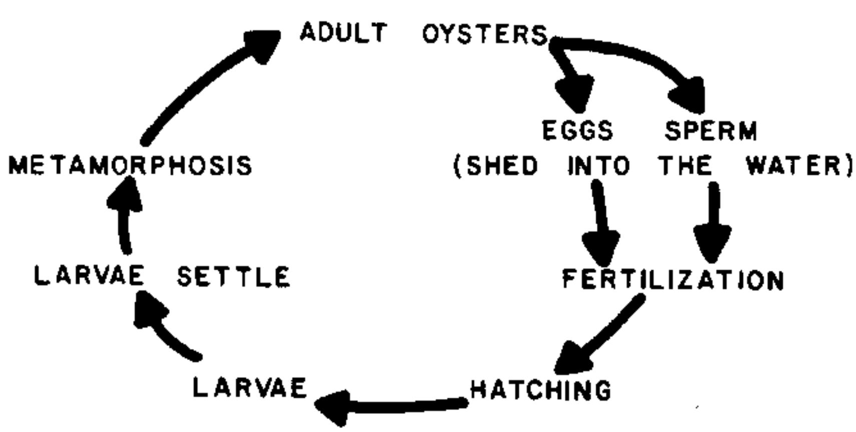
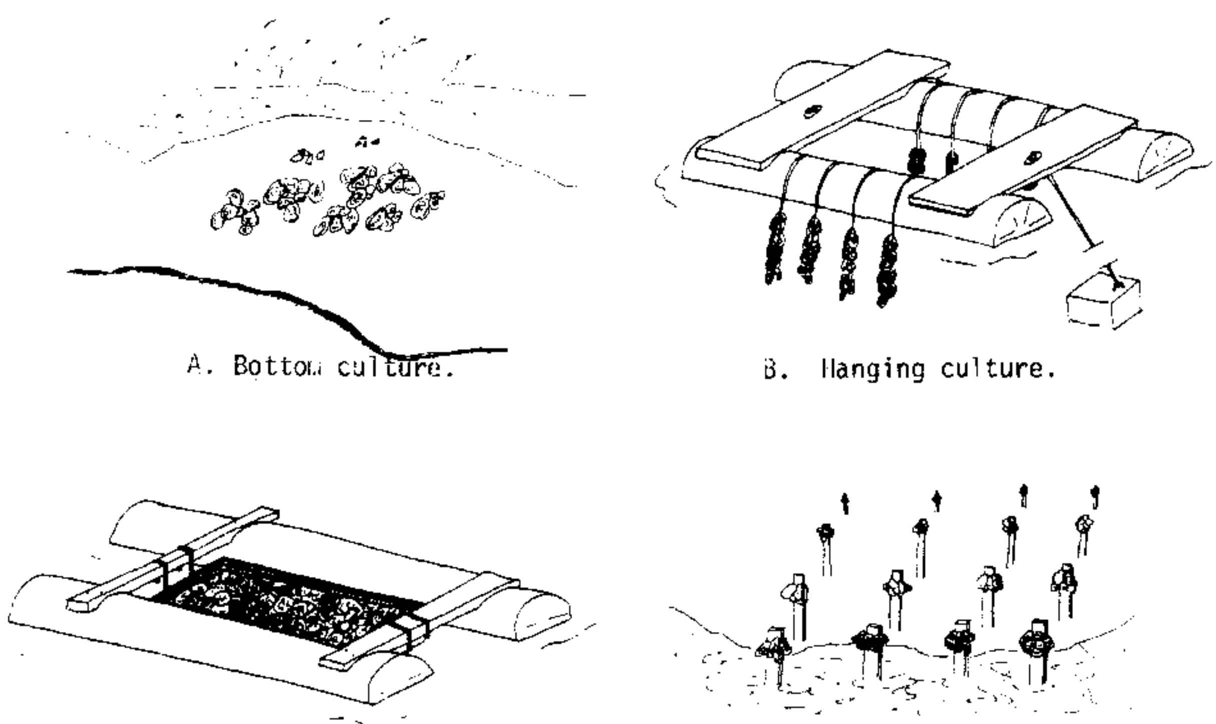


Figure 38. The life cycle of the Japanese oyster, *Ostrea gigas*.

Figure 38 diagrams the life cycle of the Japanese oyster. In the spring, when water temperatures reach about 20° C (68° F), adult oysters spawn, releasing eggs and sperm into the water. A female produces thousands of eggs (250,000 to 6,000,000, depending on her size). The fertilized egg develops into a larva which spends two to four weeks as a member of the temporary zooplankton. During this time it feeds on phytoplankton. Most of the larvae become food for the filter feeding animals of the estuary or are swept away into unsuitable areas where they die. The few surviving larvae settle out of the water onto a solid surface, often an old oyster shell. A special gland produces a drop of cement that sticks the larva to the surface. The larva then undergoes a change in shape and structure and assumes the adult form. The larvae are said to undergo metamorphis. The young, attached oyster is known as a spat.

In the commercial culturing of oysters, the spat are collected on old oyster shells that are placed in the water the adults have spawned in. Oregon's estuaries are too cold for the successful spawning of the commercial oyster. In Oregon either the spat have to be imported from Washington State, or brood stock oysters are spawned in tanks with water at the appropriate temperature. The spat, firmly attached to the old oyster shell, are then placed in the estuary, where they develop and grow. As you might expect, all commercially grown oysters are private property and cannot be gathered for personal use.

There are four major ways to cultivate oysters: bottom culture, hanging culture, tray culture, and stake culture (figure 39).



A. Bottom culture.

B. Hanging culture.

C. Tray culture.

D. Stake culture.

Figure 39. The four major methods of commercially culturing oysters.

The easiest method of farming oysters is the bottom culture method. The shells with the attached spat are simply placed on the mud flats and left to grow. This method is not used very much in the South Slough because the mud is soft and the spat would quickly get buried. Bottom cultures are harvested mechanically by dredges or by hand gathering.

In deeper waters, but away from navigation channels, the hanging culture method is sometimes used. The old oyster shells are attached to ropes and hung from floating rafts. Since the oysters are always covered with water and thus can feed at all tide levels, they grow rapidly. The hanging culture method is used extensively in Japan.

The tray culture method is similar to the hanging culture method except the spat are placed in flat trays that are then suspended from floating supports. The advantage of this method is the ease with which mature cultures can be harvested.

The stake culture method is used by most of the oyster farmers in the South Slough and was actually developed there. Oyster shells with the spat are strung on wires and tied to wooden stakes about one meter (3.3 feet) long. One end of the stake is stuck into the mud, supporting the oysters up off the bottom where they can feed during flooding and ebbing tides and not be suffocated by accumulating sediments.

After two or three years, the oysters can be harvested and sold. Some are simply sold in the shell. Most are prepared for market by removing the oyster meat from the shell, a process called shucking. The meat is then canned or placed in jars. The empty shells are sometimes ground up and used as grit for poultry or as a lime supplement for application on cropland.

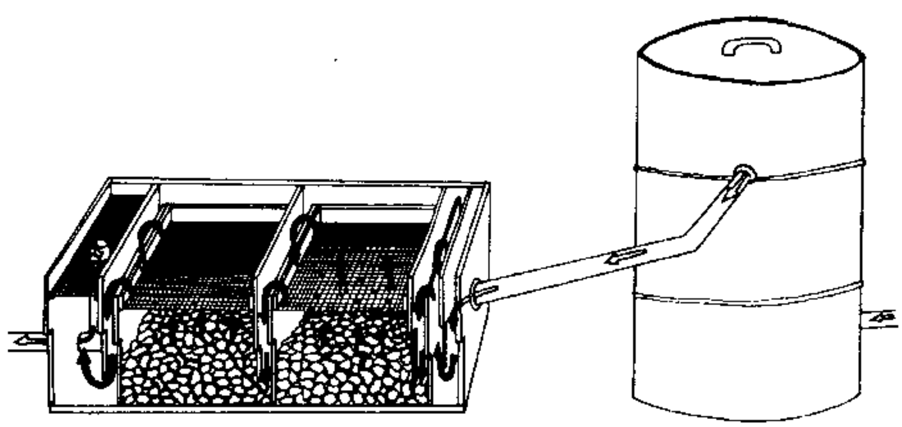
Salmon ranching or aquaculture is being tried as one way to improve the availability of salmon for commercial harvesting. The aquaculture industry uses the remarkable homing instinct of the salmon. The adult salmon are trapped as they return to spawn. The eggs and sperm are extracted and mixed together to fertilize the eggs. The juveniles are raised in artificial ponds in which a special chemical has been added. On reaching a predetermined size, the smolts are released into the estuary. As they return as adults, a trough leading back into the hatchery is kept filled with constantly running water to which the special chemical has been added. The smolts home in on the source of the chemical and end up back in the hatchery, where they are either harvested for market or used for their eggs and sperm.

Hatcheries release large numbers of smolts, and the effect of this influx of fish on the food webs of the estuary and the ocean is not known. Certainly, hatchery and native fish, which mix together in the estuary and in the ocean, compete for the same food. Some of the hatchery adults do not return to the hatchery but stray into the rivers and spawn with the native fish. The mixing of native and hatchery fish can affect the genetic traits of the native populations.

However, because salmon aquaculture is a relatively new phenomenon, the influence of hatchery fish on the natural life cycle of the salmon has not yet been determined.

Unfortunately, salmon populations can be drastically affected by many activities other than those occurring in the estuary. Logging and road building activities can greatly increase erosion along streams, thus clogging the spawning beds with sediment. Logging debris, if not cleaned up, can also slide into the streams, blocking the migration routes of the adults and keeping them from the spawning beds above the blockage. The removal of trees and shrubs from the edges of streams (called riparian vegetation) exposes the water to the sun, thereby raising the stream temperatures too high to allow survival of the juvenile salmon. Irrigation lowers the stream flow and can restrict the passage of salmon moving upstream. The construction of hydroelectric dams has also greatly reduced the native salmon populations, mainly by blocking the migration of adults and thereby removing hundreds of miles of streams above the dam from production.

The state of Oregon has initiated a Salmon and Trout Enhancement Program (STEP Program) in an attempt to improve the successful natural spawning of these species. One way this is being done is to improve the condition of severely damaged streams by replanting lost riparian vegetation, by removing materials blocking the migration paths of the fish, and by reducing the impact of excessive erosion whenever possible. In some streams nothing can reasonably be done to improve the stream itself. In these cases, streambank land owners have



(THE ARROWS INDICATE WATER MOVEMENT)

Figure 40. A cutaway drawing of a hatch box commonly used to hatch coho salmon eggs. The arrows indicate the flow of water through the filtering barrel (right) and hatch box (left). When in use the box is covered with a lid.

volunteered the use of their property to allow other volunteers to place and maintain small hatch boxes. In these boxes, several thousand fertilized salmon eggs are hatched and held until the juveniles can be placed into the nearby stream to complete their life cycle and add their numbers to the natural abundance of our rivers, streams, and estuaries.

Figure 40 is a diagram of a hatch box commonly used to hatch coho salmon. The arrows indicate the path of the water which usually comes from the nearby stream. The water first passes through a barrel filled with gravel to filter it. The filtered water then flows into the box, which contains two screens upon which the fertilized eggs are placed. The screens have a mesh size that supports the eggs but still allows the alevins to get through them. The gravel beneath the screens serves to further filter the water and to provide a place for the alevins to hide until they have absorbed their attached yolk sac. When the hatch box is in use, a lid is kept on it to keep out predators and light. Light is harmful to the eggs. The screen around the overflow pipe keeps fish from accidently being lost from the box.

Summary

Oyster farming and salmon ranching are two relatively new ways we are using our estuaries. We call these commercial ventures aquaculture. Aquaculture demands that we maintain the productivity and water quality of the estuarine areas being used. The oysters grown commercially in the Pacific Northwest are Japanese oysters. Oysters are grown in bottom culture, hanging culture, tray culture, or stake culture. It takes two to three years before an oyster bed is ready for harvesting. Because these beds are private property, taking oysters from a bed can result in a fine. Salmon ranching is a method that attempts to use the homing abilities of salmon to permit them to be raised in hatcheries, released into the estuary and the ocean, and then harvested back in the hatchery as adults. These fish are private property only while in the hatchery and so can legally be caught along with the wild fish. Much remains to be understood about the impact salmon ranching may have on native stocks. The state of Oregon's Salmon and Trout Enhancement Program (STEP Program) is a volunteer-based, statewide effort to improve the natural runs of our native fish stocks.

Human Activities in the Estuary

One major use of the estuary is as a place to locate commercial, industrial, and shipping facilities (figure 41). Such use includes the storage and transportation of raw materials. Often little rock is present because it is buried below the sediment carried into the estuary. This dearth of rock necessitates filling in parts of the estuary in order to build roads and other facilities. The estuary must be dredged out frequently to maintain the water depths needed by

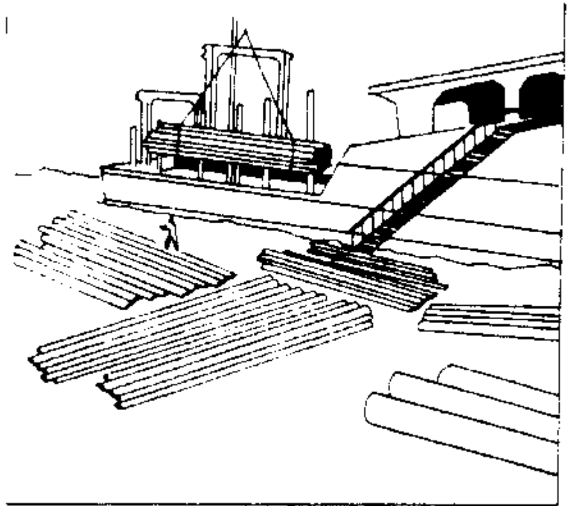


Figure 41. Loading of logs onto ships bound for foreign ports is one of the jobs performed by the longshoremen of Coos Bay.

large, ocean-going ships. Docks and other structures need to be placed on pilings to keep the ship-loading facilities above the rising and falling tides. In places where wave action is intense, the bank must be covered with rock or cement slabs to prevent erosion. Lumber mills often use the estuary as a place to store logs by lashing them into large rafts and mooring them to pilings driven into the mud flats and channels until they can be floated to the mills for processing. Log rafts are also lashed to pilings as they await shipping to a distant port.

The salt marshes have traditionally been used for agricultural purposes. Farming requires diking the salt marshes and installing tide gates, which keep the tides out but allow fresh water to drain from behind the dike during low tides. Such diking causes a further loss of salt marsh habitat.

While people affect the estuary in many different ways, filling and dredging activities produce the most obvious changes. The filling reduces the amount of estuarine habitat present because it raises the level of the filled area above the tides. Dredging deepens the estuary, disturbs the bottom, and greatly reduces the number of animals able to live there. Dredging can also change the salinity gradient of an estuary by allowing greater volumes of salt water to penetrate further into the estuary.

Docks, pilings, and other solid structures may destroy the homes of some plants and animals, but at the same time, they provide new areas for some animals to colonize. Figure 42 diagrams some of the kinds of animals and plants that colonize pilings in the estuary.

Often the logs that are stored in the estuary alter the mud flats beneath them by compacting the sediment as they rise and fall with the tides onto the mud. Natural organic chemicals leach into the water from the log rafts; bacteria use the wood as a source of food, and the rafts shade the mud flats, thereby reducing the oxygen content of the water and the primary productivity of the estuary.

Leaking machinery and waste water pumped out of ships into the estuary introduce oil and other chemicals into the water. And new species of plants and animals are introduced into estuaries by being transported on the bottom of visiting ships. These introduced species may benefit the estuary or compete unfavorably against native populations.

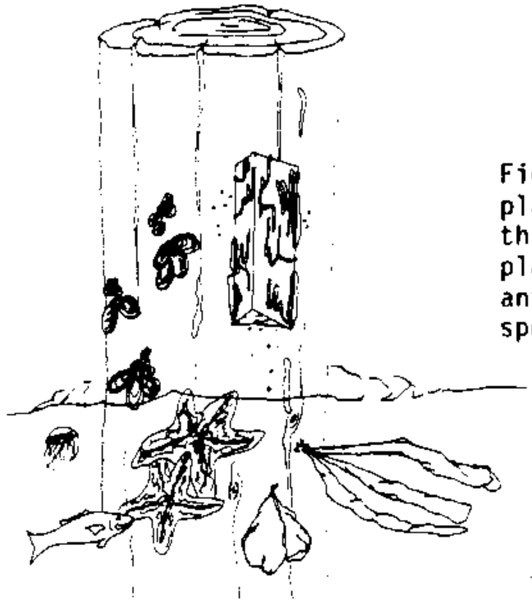


Figure 42. Solid structures placed in the estuary, like this old piling, serve as places upon which plants and animals can grow and create specialized habitats.

Estuarine waters have often been considered a dumping area for waste products. Industrial waste and domestic sewage are commonly pumped into the estuary from shore facilities. This is a significant impact when you consider that one-third of the people in the United States live adjacent to estuaries. Where dumping occurs, solid materials can smother the organisms. Toxic chemicals and raw sewage can accumulate in the water and sediments. Increases in the turbidity of the water can markedly reduce primary productivity. The addition of organic materials can result in the lowering of oxygen to very low levels. The overall effect is to reduce markedly the water quality and the productivity of the estuary.

In order to use the estuary and still continue to benefit from the natural resources found there, we must be careful to balance the uses of the estuary for the benefit of all of us. In recent years, legislation has been enacted to reduce or eliminate the amount of waste and untreated sewage pumped into estuaries. We must continue to develop ways of keeping pollutants out of the water, devise better methods of treating our wastes, and encourage people to treat sewage and industrial wastes before discharging them. Laws have also been passed to control the amount of dredging and filling permitted in estuaries to protect estuarine salt marshes, mud flats, and eelgrass beds.

Summary

People use the estuary in diverse ways. Commercial and industrial activities alter the estuary. Alterations include dredging, filling, and placing various structures in the water. Most alterations cause a loss of habitat and primary productivity in the estuary. Some habitat areas are created when the shoreline is rocked to protect it against erosion and when pilings are placed in the estuary. Waste materials pumped into the estuary also can have negative impacts by reducing primary productivity, reducing the dissolved oxygen in the water, causing the accumulation of toxic materials, and smothering benthic habitats. Dredging is required to maintain efficient ship transportation, and dredged materials are disposed of on upland, estuary, or ocean floor areas. Thus, not only does dredging alter the estuary, but the disposal of dredged materials further affects adjacent land and water. Agricultural use of the estuary results in diking and draining salt marshes. This further reduces the production of the estuary. We must be careful to balance all of the uses of the estuary to be able to continue to benefit from the abundant natural resources it provides.

A Lesson about Interrelationships

For want of a nail, the shoe was lost;
For want of the shoe, the horse was lost;
For want of the horse, the rider was lost;
For want of the rider, the battle was lost;
For want of the battle, the kingdom was lost;
And all from the want of a horseshoe nail.

Benjamin Franklin's famous maxim teaches that small events can lead to disastrous consequences. It also comments on the importance of interrelationships.

There are many examples of interrelatedness in the natural world. Food webs are one way in which the inhabitants and habitats of an ecosystem are linked together. Other ties also exist. The people of Long Island, New York, learned this lesson the hard way.

Along the southern shore of Long Island is an estuary called Great South Bay. Prior to 1965 Great South Bay was used for commercial oyster culturing, and homes were located along its shores. Ducks were one agricultural product raised around the bay. For a while the raising of ducks and oysters could be carried out in harmony.

But by 1965 the duck farms on the edges of Great South Bay were producing over three million ducks. Each day 133 million gallons of duck wastes drained into the bay. Much of the human sewage from the dense housing around the bay also contributed to the excess of nutrients in the water. These excess nutrients allowed the aquatic plants of the bay to greatly increase their growth rate. A disastrous chain of events followed.

Because of the excessive nutrients in the water, a small, green alga, normally present in extremely low densities, became so abundant that visibility in the water was reduced to less than 30 centimeters, or about one foot. The bay's large oyster industry was wiped out because the alga clogged the oyster's gills and suffocated them. But the people of Great South Bay had not yet seen the end of the problem.

Tons of dead aquatic plants sank to the bottom. As they decomposed, oxygen was depleted. Hydrogen sulfide, the foul-smelling gas resulting from the lack of free oxygen, was produced and bubbled to the surface of the bay. The concentration of this gas became so high that the paint on the homes along the shore turned black.

It is hoped that we can learn from examples like this. Rapid and extensive environmental changes can upset the balances between organisms which have taken thousands of years of adaptation to achieve. The result of adaptation is the harmonious working of the whole ecosystem. When we upset these balances, the ecosystem stops working harmoniously and serious consquences result, as the people of Great South Bay learned.

In this booklet we have explored some of the important biological, physical, and economic aspects of estuaries. We have seen how the Coos Bay Estuary is used for many commercial, industrial, and recreational purposes. Many of these activities require altering the estuary in different ways. The Coos Bay Estuary is also being used to help better manage all of our estuaries in the future. The South Slough Sanctuary, operated by the state of Oregon, exists to help find the answers to questions about estuaries and to provide protection for the estuarine habitats found in the South Slough, as well as for the plants and animals living there.

The key to the wise use of the estuary is cooperation among all the different users of the estuary: the people who value its natural beauty and its recreational potential and those who support its economic development. We can have a healthy estuary and still use its resources. We must work in harmony with nature in meeting our needs, for cooperation is ultimately in our best interests.

Summary

The habitats and organisms of the estuary are interrelated. Food webs are one example of a linkage that ties the inhabitants of an ecosystem together. The destruction of a Long Island estuary, Great South Bay, by intensive duck farming is an example of the disastrous consequences that can result when we disturb the balances between the organisms of an ecosystem. The key to the wise use of the estuary is cooperation among all its users.

Short-Answer Questions

1. How does filling and dredging alter the estuary?
2. How can log rafts alter the productivity of the mud flats?
3. What is the purpose of filling parts of the estuary?
4. What are the overall effects on the estuary of our development activities?
5. Why are tide gates in dikes used in agriculture?
6. What is aquaculture?
7. What are the two primary kinds of aquaculture in the Pacific Northwest?
8. What are the four types of oyster cultures?
9. What do we call the oyster larva that attaches itself to old oyster shells for culturing?
10. Briefly describe the process of salmon ranching.
11. What are some of the stream conditions detrimental to salmon?
12. What change first occurred in the waters of Great South Bay that started the chain of events which wiped out the oyster industry there?
13. What general ecological idea does the Great South Bay example demonstrate?
14. What is the key to the wise use of the estuary?
15. Why was the South Slough Sanctuary developed?

Glossary

*adaptation: any characteristic of living organisms which improves their chances of survival in their environment.

*alevin: a newly hatched salmon dependent upon the attached yolk sac for nourishment.

*alga (pl. algae): any of various primitive, chiefly aquatic, one-celled or multicelled seaweeds and diatoms that lack true stems, roots, and leaves.

amphipod: a crustacean having thoracic gills, no carapace, and usually a body form flattened from side to side.

*anadromous: living as an adult in the ocean and migrating into fresh water to spawn.

*anaerobic: living in the absence of molecular oxygen.

*anaerobe: an organism that can live without molecular oxygen being present; typically a bacterium.

*aquaculture: the raising and harvesting of aquatic organisms for human use.

bar: the area at the mouth of an estuary.

benthic: of, relating to, or occurring on the bottom of a body of water.

brackish water: water containing salt.

caprellid: an amphipod crustacean with the second thoracic segment fused to the head, the abdomen greatly reduced in size, and one large leg adapted for seizing prey.

carapace: a hard outer covering of the body of some crustaceans which covers the head and thorax.

centrifugal force: the apparent outward force experienced by a body moving in a circle.

*channel: the area of the estuary that is always covered with water.

closed bar: a condition in which the mouth of an estuary is partially or completely blocked off by sand deposited by ocean water.

*Indicates essential vocabulary words.

comb jelly: a soft-bodied, floating marine organism, similar to a jellyfish, but without stinging cells and moving through the water by means of rows of short, hairlike structures.

copepod: a minute to small crustacean possessing a carapace covering the head and the first one or two thoracic segments.

*crustacean: an organism with a jointed body, a hard external skeleton, a pair of jointed limbs on each thoracic body segment, two pairs of antennae, and gills for breathing.

*delta: the fan-shaped mouth of an estuary formed by the deposition of river sediments.

*deposit feeder: an animal that eats sediment and digests the organic materials from it before excreting the sediment back into the environment.

*detritus: dead bits and pieces of organic material.

*diatom: any of various microscopic, unicellular or colonial golden-brown algae of the class Bacillariophyceae, having cell walls of silica made up of two overlapping, symmetrical parts. Diatoms are an important component of the phytoplankton.

dinoflagellate: a microscopic aquatic organism with an outer covering of cellulose having two furrows in it. One furrow encircles the animal and contains a long, hairlike structure called a flagellum. The other furrow extends the length of the body from which extends a second flagellum. A high concentration of species in the genus *Gonyaulax* creates a condition called red tide.

*drainage basin: all portions of a landscape upon which rain will ultimately drain into the same body of water; also called a watershed.

*dredging: removing sediments and rock to deepen harbors and waterways.

*ecosystem: an ecological system formed by the interaction of organisms and their environment.

*estuarine: of, pertaining to, or found in an estuary.

*estuary: a place where the fresh water of rivers and streams meets and mixes with the salt water of the ocean.

*fill: the material, usually soil or rock, added to a watercourse or wetland to provide a dry, elevated surface.

*filter feeder: an animal that obtains its food by filtering it from water currents.

fingerling: a stage in the life cycle of a salmon after it has hatched and emerged from the spawning gravel and before it has adapted to the ocean; also called a parr.

*food web: two or more interconnected series of organisms in which each member of a series is food for a later member of the series. Food webs are the pathways by which energy is passed through an ecosystem.

*fresh water: water having less that 0.2 grams of salt in each 1000 grams of water.

gammarid: a suborder of amphipods characterized, in part, by having only the first thoracic segment fused to the head.

*gene: a unit of the hereditary material in cells that directs the development and functioning of an organism.

genetic: affecting or affected by genes.

gradient: a regularly increasing or decreasing change in a variable in a specified direction: for example, the change in temperature from the peak of a snow-covered mountain to the desert at its base.

gravitation: a force resulting from the mutual attraction of two objects in space.

*habitat: the place normally occupied by a particular type of organism.

halophyte: a plant that lives in salty soils.

*hatchery stock: fish which result from the artificial breeding of parents selected by hatchery personnel.

*high tide: the part of a tidal cycle when the coast is passing through the middle of a tidal bulge and when the greatest amount of ocean water is in an estuary.

homogeneous salinity gradient: a condition of the mixing of salt water and fresh water in an estuary which is typified by a uniform salinity between the surface and the bottom at any given point. A well-mixed type of estuary is the result of this type of gradient.

hydrometer: a weighted, graduated glass float used to measure the density of liquids. It can be used to measure salinity because salt water is denser than fresh water.

infauna: animals that live burrowed into the sediment.

isopod: a crustacean having abdominal gills, no carapace, and a body usually flattened from top to bottom.

jellyfish: a soft-bodied animal having its body parts diverging from the center of the animal and having tentacles with special offensive and defensive stinging cells.

*jetty: a structure extending into and above a body of water from a shoreline to protect a portion of the shoreline from wave action and currents.

juvenile salmon: a sexually immature salmon.

*larva (pl. larvae): the newly hatched, earliest stage of any of various animals, typically looking and functioning unlike its parents, and which must undergo metamorphosis before assuming the adult characteristics.

*low tide: the part of the tidal cycle when the coast is passing through the area between two tidal bulges. At low tide the least amount of ocean water is in an estuary.

mean tide range: the average height difference between the high and low tides.

metamorphosis: the process of changing from the larval form to the adult form or a more mature form.

*mud flat: a tideflat composed primarily of muds, silts, and clays.

*neap tide: a tide with a less than average difference between high and low tides. A neap tide occurs when the sun is at a 90° angle from the moon, as seen from earth.

nekton: aquatic animals that are strong, active swimmers and so are independent of water currents for efficient movement.

nutrients: organic or inorganic materials required by organisms for growth and repair.

open bar: a condition in which the mouth of an estuary has an essentially unrestricted connection to the sea.

parr: a stage in the life cycle of a salmon after it has hatched and emerged from the gravel and before it has adapted to the ocean; also called a fingerling.

*phytoplankton: plant plankton.

*photosynthesis: the process whereby green plants use the sun's energy to produce sugars from carbon dioxide (CO_2) and water (H_2O); oxygen is given off as a waste product from the process.

*plankton: aquatic plants or animals, usually microscopic, that are dependent upon water currents for movement.

PPT: parts per thousand, symbolized as $^{0}/oo$; usually defined as the number of grams of a material dissolved in each 1000 grams of a solvent, such as water.

*primary productivity: the weight of plant material produced per unit of area per unit of time by the process of photosynthesis; often measured as grams per square meter per year.

refractometer: an instrument used to measure how much a solution bends light. It can be used to measure salinity because salty water bends light more than does fresh water.

riparian vegetation: the vegetation along the banks of streams or lakes.

*salinity: a measure of the amount of salt dissolved in water.

salinometer: an instrument that measures the electrical conductivity of a solution. It can be used to measure salinity because salt water is a better conductor than is fresh water.

*salt marsh: wet grasslands growing along the edges of salty bodies of water and composed of plants adapted to living in salty soils.

salt wedge salinity gradient: a condition of the mixing of salt water and fresh water in an estuary which is typified by low salinity at the surface and high salinity at the bottom with a very narrow zone of rapid change between them. A stratified type of estuary is the result of this type of gradient.

sand flats: tideflats composed primarily of sand.

sea level: the average level of the surface of the sea for all tidal stages measured over a number of years at various tide stations along the west coast of the U.S. and Canada.

*sediment: particulate material that is kept suspended in a fluid only by the motion of the fluid; when the motion of the fluid stops, the material settles to the bottom of the container.

shucking: the process of removing the adult oyster from its shell for food processing.

smolting: the process a fingerling salmon undergoes to develop the physiological capacity for saltwater regulation before migrating to the ocean.

smolt: a sexually immature salmon having recently migrated to the ocean.

spat: the larva of an oyster after it has settled on a solid surface such as an old oyster shell and before it metamorphoses into the adult form.

*spring tide: a tide with a greater than average difference between high and low tides and that occurs when the moon and the sun are aligned with the earth.

stratified estuary: an estuary with a salt wedge salinity gradient.

thoracic: of, in, or near the thorax.

thorax: the body segment of crustaceans that bears the legs.

*tidal bulge: the upward rise of the surface of the ocean caused by the gravitational force of the moon and the centrifugal force of the earth's movement.

*tide cycle: the rhythmic rise and fall of the level of the sea occurring every 24 hours and 50 minutes.

*tideflat: the expanse of sand or mud that is lower in elevation than the salt marshes and that is exposed and submerged by the tides.

*tide: the rhythmic local rise and fall of the level of the sea caused primarily by the gravitational attraction and movements of the earth and moon.

turbid: cloudy, as with sediment; muddy.

upland: land that is higher in elevation and drier than another area.

water cycle: a cycle involving the continual evaporation of fresh water from the oceans and the return of that water to the oceans by the rivers of the world.

*watershed: all portions of a landscape upon which rain will ultimately drain into the same body of water; also called a drainage basin.

well-mixed estuary: an estuary with a homogeneous salinity gradient.