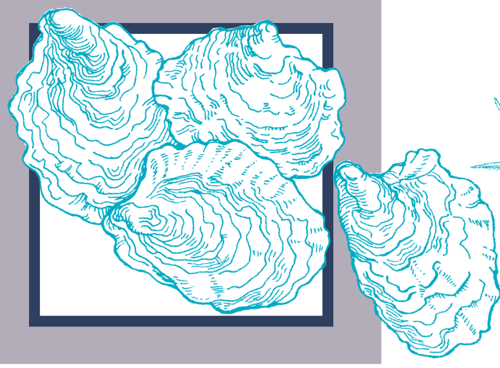
NATIVE SHELLFISH & INTRODUCED SPECIES IN

OREGON ESTUARIES

"Transport of entire coastal planktonic assemblages across oceanic barriers to similar habitats renders bays, estuaries, and inland waters among the most threatened ecosystems in the world".

—James T. Carlton and Jonathan B. Geller
"Ecological Roulette: The Global Transport of Nonindigenous Marine Organisms,"
Science, Vol. 261, 2 July 1993



For nearly 400 miles, U.S. Highway 101 and its bridges afford travelers expansive views of the commerce and industry, docks and wharves, ship and boat traffic, creeks and sloughs, tidal flats and salt marshes, and sandy beaches and rocky shores that now characterize Oregon's estuaries. Obscured from the casual observer's gaze, however, are the many mysteries, complex interrelationships, and even life-and-death struggles unfolding in the hidden fringes and murky depths of these productive and dynamic waters where rivers meet and mix with the Pacific Ocean. Here live estuary-dwelling shellfish of great economic or recreational value, such as Pacific oysters, Dungeness crabs, and about a half-dozen species of bay clams. Making a living in the same territory are two species of burrowing shrimp that are of some economic and recreational value as live bait, but are even more important because of their interactions with native eelgrass and cultured oysters. Uninvited guests, including European green crabs, are unwelcome invaders from other parts of the world that pose potentially severe threats to estuaries here and elsewhere.

OYSTERS MEAN BUSINESS IN PACIFIC NORTHWEST ESTUARIES

The Pacific Northwest oyster industry began in Puget Sound in the mid-1850s, then spread to estuaries in southwestern Washington. Oyster harvests eventually reached 200,000 bushels a year in Puget Sound alone, and by 1895 populations of native oysters were depleted. When transplanted Eastern oysters didn't take well to western estuaries, oyster growers looked elsewhere for hardier stock, which they found in the fast-growing Pacific oyster from Japan, introduced here in the 1920s.

Although Pacific oysters do not naturally reproduce in Oregon, they are the basis for oyster aquaculture in several Oregon estuaries, including Coos Bay, Yaquina Bay, Netarts Bay, and Tillamook Bay. Originally, oyster growers imported oyster seed or "spat" from Japan, but now Pacific Northwest hatcheries supply all the spat required.

Methods for growing oysters vary and depend on local growing conditions, state laws and regulations, and growers' market requirements. Although growers pick the most appropriate methods for local conditions, many also experiment with other methods to improve production or accommodate changing conditions. The most common methods used in the Pacific Northwest are bottom or ground culture, stake culture, rack culture, longline culture, rack-and-bag culture, and floating culture.

In addition to picking the right method for any particular part of an estuary, oyster growers face other concerns in selecting the best sites. They want adequate circulation of nutrient-bearing waters for their oyster beds, but must avoid areas with prolonged heavy currents that can move bottom-cultured oysters or damage structures used in other methods. Oyster beds also need protection from heavy waves and currents associated with large seasonal storms. Additionally, oysters require safe havens from predators.

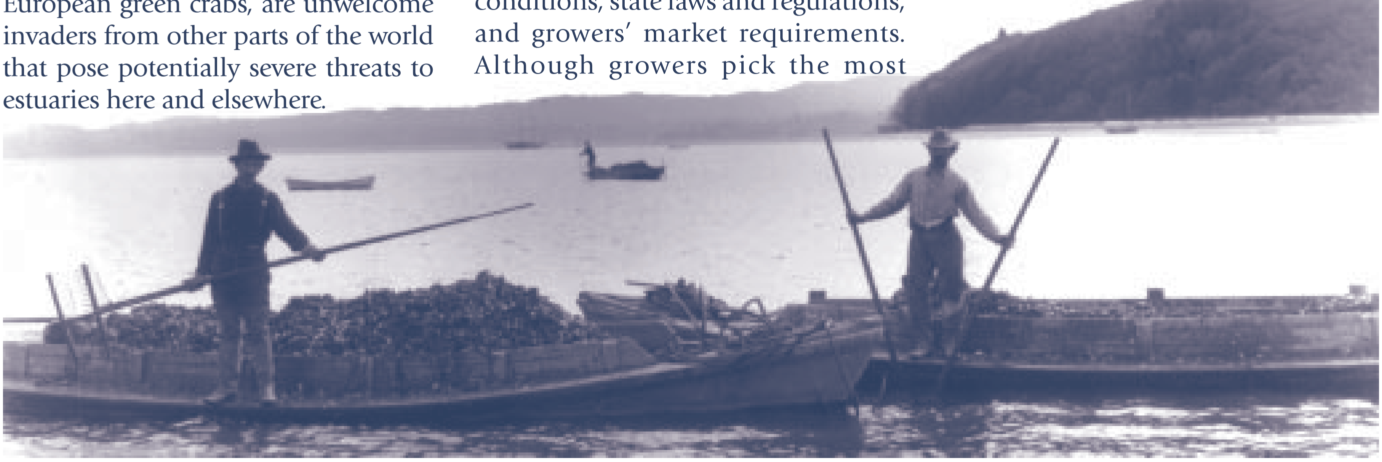


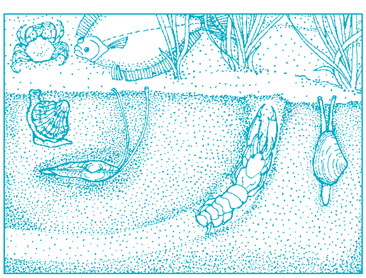
PHOTO OREGON HISTORICAL SOCIETY

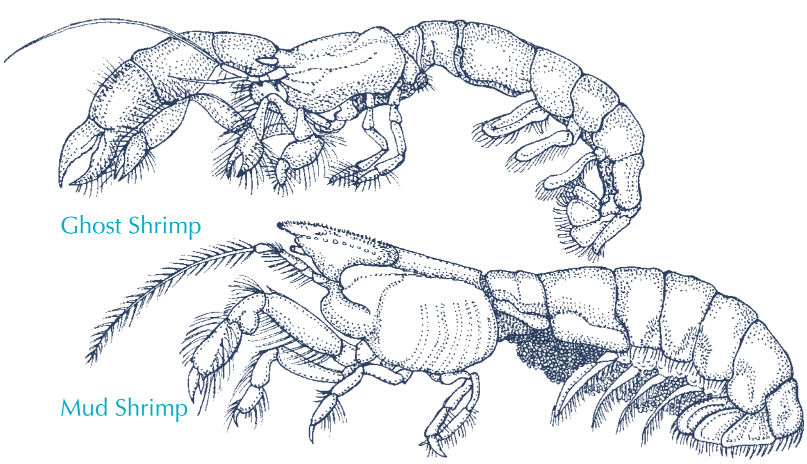
OYSTER BEDS AFFECT ESTUARINE HABITAT IN DIFFERENT WAYS

Research indicates that oyster beds provide habitat with high species diversity. Algae grow on oyster shells, providing food and shelter for snails and small crustaceans. The oyster beds attract and furnish food and refuge for many species of invertebrates, such as amphipods, shrimp, and crabs, as well as small fish, particularly gunnels, blennies, and the juveniles of some larger species. In turn, great blue herons, egrets, loons, brant, and other birds and waterfowl are attracted to the abundant forage in the oyster beds.

Oyster cultivation, however, can also have adverse effects on eelgrass meadows. In some estuarine habitats, for example, bottom culture has been shown to deplete eelgrass beds by direct physical disturbance and by competition for space. Stake culture can also lead to an increased presence of algae, such as sea lettuce, which can have a negative effect on eelgrass. Rack culture causes shading and may result in sedimentation or erosion, all of which are detrimental to eelgrass. Experiments with rack culture in the South Slough of Coos Bay showed that the racks caused a scouring action of the water beneath them, which displaced sediments and left a patch of dead eelgrass around each rack.

Research indicates that all types of oyster cultivation adversely affect eelgrass in some ways, but that doesn't mean oysters and eelgrass can't co-exist in Oregon's estuaries. One study in Tillamook Bay concluded, "The fact that eelgrass is negatively affected by oyster cultivation should not be a blanket condemnation of oyster aquaculture in general."





TWO SHRIMP SPECIES BURROW IN ESTUARY BOTTOM SEDIMENTS

Two species of burrowing shrimp—ghost shrimp and mud shrimp—inhabit Pacific Northwest estuaries. Both dig burrows 10 to 20 inches deep, but the smaller ghost shrimp are a greater nuisance to oyster growers, because they actively disturb the soft sand and mud. Growers, however, consider both species to be pests.

Ghost shrimp and mud shrimp are common in the intertidal and shallow subtidal regions of Oregon's estuaries, where they construct burrows and tunnel complexes in the bottom sediments. These burrowing activities, known as bioturbation, soften the mud and sand and resuspend fine sediments in the water column. The unconsolidated, liquefied bottom sediments are like quicksand, causing bottom-cultured oysters to sink of their own weight and to suffocate. In stake, rack, and longline cultures, the shrimps' burrowing activities can undermine and topple growing structures and make the bottom too soft to bear the weight of oyster-bed workers during harvest and other essential activities. Even where bottom sediments are stable enough to serve as a foundation for oysters and cultivation supports, the fine sediments disturbed by shrimp can clog oysters' gills and interfere with their filter-feeding habits, resulting in slow growth or even death.

Burrowing activities of these shrimp can reduce species diversity among bottom-dwelling invertebrate and sea-grass communities. Root mats and rhizomes of eelgrass beds, however, can inhibit the colonization of ghost shrimp. Mud shrimp, on the other hand, do invade established eelgrass beds, but apparently not in significant-enough numbers to pose a threat to eelgrass. Although burrowing shrimp do not co-exist well with oysters or eelgrass, once either shrimp species colonizes any part of an estuary, that area becomes unsuitable habitat for either oysters or eelgrass.

GHOST SHRIMP AND MUD SHRIMP ARE SIMILAR BUT DIFFERENT

One recent study pointed out that the two species of burrowing shrimp "have different life histories, habitat preferences, burrowing and feeding habits, and different effects upon oysters and other benthic organisms." Nevertheless, as the study concluded, "current efforts to control these species treat them as if they were one species and do not use knowledge of their ecologies to develop targeted control tactics."

Inasmuch as the two species have different economic effects on the oyster industry, they require different management and control strategies. Existing information on the density of burrowing shrimp populations and their damage to oyster beds is inadequate, as are the means of predicting the growth of shrimp populations. Although the range and distribution of the two species overlap, their habitat requirements differ, and so should the efforts to deal with them.

Pinkish-tan in color, ghost shrimp occupy estuaries from Alaska to Baja California, Mexico. They prefer sandy bottom sediments, where they dig unlined burrows. They deposit feces and excavated materials at burrow entrances, forming small mounds on tidal-flat surfaces.

Bluish-gray mud shrimp are found from southeast Alaska to central California, where they seek out the fine-grain, muddy bottom sediments of estuaries. As they dig their burrows, they secrete a mucouslike material that binds sediment particles to line burrow walls and create relatively permanent tunnels and complexes.

Ghost shrimp grow more slowly and are smaller than mud shrimp of the same age. Both species live about four to five years, with ghost shrimp and mud shrimp typically attaining average lengths of about 2 and 3 1/2 inches, respectively.

Expanding populations of burrowing shrimp are thriving in major West Coast oyster producing estuaries, including Oregon's Coos Bay, Yaquina Bay, and Tillamook Bay. Although supporting scientific evidence is lacking, oyster growers on some estuaries have reported dramatic increases in burrowing-shrimp populations since the 1950s. They have also reported expanded distribution within the estuaries, particularly noting that ghost shrimp are now found nearer the tributary mouths than ever before. Reasons for such population expansions are unknown, but several possibilities exist. Speculation ranges from declining populations of shrimp predators to channel dredging, soil erosion, the effects of El Niño, and possible changes in salinity levels in some estuaries.

Many species of fish and shellfish feed voraciously on burrowing shrimp, accounting for as much as 70 percent of some fishes' diets. Juveniles of such species as Pacific herring, cutthroat trout, chinook salmon, and chum salmon feed extensively on shrimp larvae and postlarvae. Adult and subadult Dungeness crab eat the adult shrimp, as do many fish, including staghorn sculpin, starry flounder, leopard shark, green sturgeon, white sturgeon, and striped bass, among others. Declining populations of most of these predators could account for increasing numbers of larval, juvenile, and adult burrowing shrimp.

Channel dredging in estuaries stirs up bottom sediments, increases turbidity, and decreases sunlight penetration—all to the detriment of eelgrass beds. In addition to directly damaging eelgrass, the same activities might entice invasion by burrowing shrimp and favor their establishment.

Soil erosion in upland areas, caused by road building and some logging and agricultural practices, may also contribute to the shrimp population increases. Properties of sediments transported to the estuaries from upland areas might create habitat conditions conducive to burrowing-shrimp colonization.

Some experts have suggested that climatic and oceanic patterns associated with El Niño events may be responsible in several ways for changing populations of burrowing shrimp. Warmer water temperatures might accelerate the onset of sexual maturation, enhance growth rates, and increase abundance of burrowing shrimp.

Although scientists tell us that burrowing shrimp are intolerant of low salinity, two possibilities might explain the expansion of their distribution in some estuaries. First, burrowing shrimp, particularly ghost shrimp, may adapt to lower salinity levels and colonize areas heretofore unfit for them. Second, flood control and other practices that alter freshwater input, flow, circulation, distribution, and properties of estuarine waters may lead to salinity levels more favorable to burrowing shrimp in areas they once found uninhabitable.

A search continues for new or better ways to control or eradicate burrowing shrimp in specific areas. Although application of the chemical pesticide carbaryl (tradename, Sevin) is the most effective way to rid areas of burrowing shrimp, its use is illegal in Oregon, because it's not selective and has proven lethal to many species of bottom-dwelling vertebrates and invertebrates, including Dungeness crabs.

Meanwhile, scientists recommend more and better monitoring, mapping, and inventorying projects, which may help resource managers and oyster growers determine the best courses of action for dealing with expanding burrowing-shrimp populations and possibly lead to improved methods for controlling the troublesome shellfish. Monitoring the effects of oyster culture on eelgrass beds, for example, should be expanded to three or four years to include complete oyster-planting/harvest cycles. Studies should investigate such direct effects on eelgrass as physical disturbance, shading, and competition for space, as well as any incidental mortality of associated species caused by oyster harvest.

Eelgrass inventory and mapping projects, such as those undertaken at the Tillamook Bay National Estuary Project and South Slough National Estuarine Research Reserve, can be useful to assist agencies with the management of estuaries and granting or denying new oyster lease sites. In addition, eelgrass enhancement and restoration programs can contribute to the overall health of estuaries and possibly reduce conflicts between oyster cultivation and eelgrass beds.

Such programs can serve resource managers and oyster growers in several ways. They can identify areas lost to invasion and colonization by shrimp. They can help in any future programs designed to control or eradicate the shrimp in specific areas. And they may allow oyster growers to move to suitable areas not infested by burrowing shrimp and thereby prevent the need for growers to plant oysters in existing eelgrass beds.

BURROWING SHRIMP AREN'T ALL BAD

Burrowing shrimp are native species in most West Coast estuaries, and they contribute to intertidal and shallow-subtidal ecosystems in several ways. In various stages of their life cycles, they are important components of estuarine food webs, providing forage for many species of birds, fish, and other shellfish. Their burrows also provide temporary refuge for small fishes and crustaceans, such as gobies, shore crabs, and juvenile Dungeness crabs.

Any such abundant and easily harvestable forage species is also recreationally and economically important to communities along the entire Oregon coast and beyond. Anglers routinely head for the tidal flats at low tide to gather burrowing shrimp for bait, using "shrimp guns" made of polyvinyl chloride (PVC) pipe. Bait dealers use shrimp guns and gasoline-powered water jets to harvest burrowing shrimp by the thousands, which they sell up and down the Oregon coast and ship to the Willamette Valley, lower Columbia River, and even San Francisco Bay.

From 1986 to 1995, commercial-bait harvest of mud shrimp ranged from 25,000 to 56,000 pounds a year. Ghost shrimp harvests for the same period ranged from 52,000 to 100,000 pounds a year. The retail price of $1.25 a dozen for these popular bait shrimp works out to about $3.00 or more a pound, comparable to prices paid for some commercial food fishes.

INTRODUCED SPECIES CAN WREAK HAVOC ON ESTUARIES

From the Great Lakes, where a tiny European mussel has caused billions of dollars worth of damage and threatens freshwater and brackish-water ecosystems of North America, to San Francisco Bay, where a similar-sized Asian clam has crowded out native species and eliminated summertime phytoplankton blooms, to the Black Sea, where an American jellyfish wiped out the Northern anchovy fishery, introduced species are creating mayhem in aquatic ecosystems worldwide.

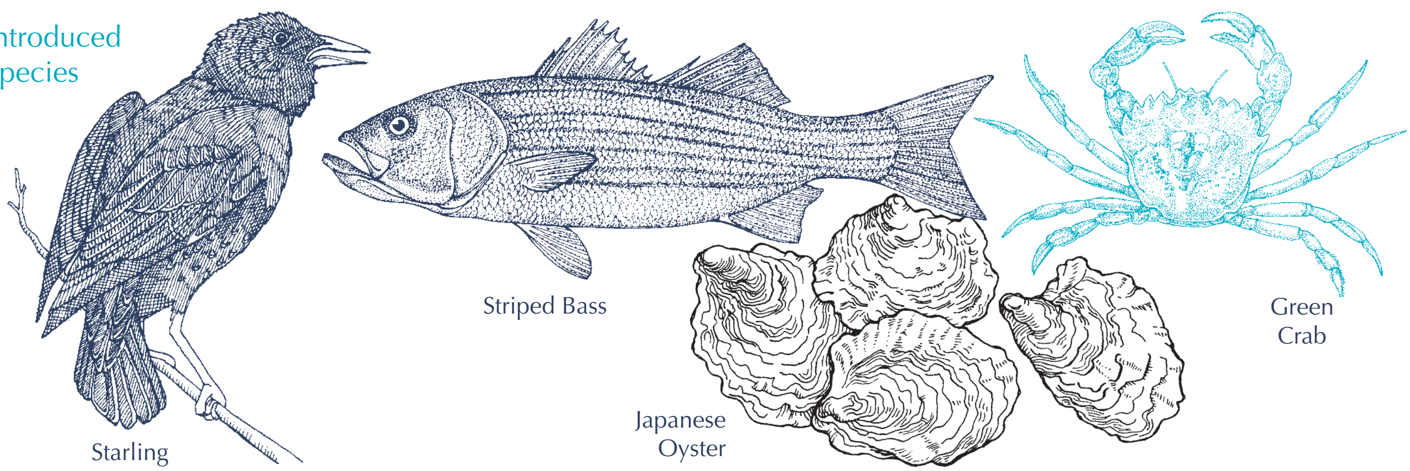
Exotic plants and animals go by various names—such as invasive, nonnative, nonindigenous, and introduced species—and they find their way to foreign lands and waters by any of a number of means. Federal and state resource managers have intentionally introduced many species, and private citizens have illegally or inadvertently done so. Other organisms have hitchhiked aboard cars, trucks, recreational vehicles, and seagoing boats and ships. Some have expanded their range with the aid of birds, winds, and waterways. Most have proved to be unwelcome visitors.

On America's West Coast, San Francisco Bay is a veritable stew pot of introduced species, where more than 250 nonnative plants and animals have taken up residence. In the Sacramento-San Joaquin Delta, alone, at least 130 nonindigenous species—including 10 mammals, 3 birds, 1 amphibian, 16 invertebrates, 30 fishes, and 70 plants—have been established within the last 130 years.

The subject of intentional introduction of nonnative species is controversial, with some managers and interest groups favoring the judicial use of nonindigenous species to enhance commercial and recreational opportunities, while others steadfastly oppose any attempt to introduce nonnative species. Arguments can be made to support these opposing perspectives. What angler, for example, laments the introduction of the striped bass to West Coast waters? On the other hand, who wouldn't gladly send the English starling back to Great Britain? Consider, too, that in the absence of abundant native oysters, many people on the West Coast enjoy and profit from the introduction of the Japanese Pacific oyster.

The vast majority of species introductions, however, have been unintentional and their spread hopelessly uncontrolled. During the past three or four centuries, ships and boats have distributed thousands of species of marine organisms in several principal ways. For example, marine borers—gribbles, shipworms, and such—bore into the hulls of wooden ships and boats and in this way travel to foreign ports. Barnacles, seaweeds, and other fouling organisms travel on the hull surfaces of ships and boats. Organisms that live on rocks and other materials used as dry ballast can colonize new areas when the ballast is dumped overboard at any port of call. Nowadays, ships' ballast water, which can transport many different types of living organisms, is the main conveyance for introducing invasive species into Pacific Northwest estuaries.

Introduced Species



BALLAST WATER IS A WITCH'S BREW OF UNWANTED ORGANISMS

Depending on where it's pumped aboard, ballast water is either fresh or brackish. It's carried in compartments or tanks inside a ship and is used to adjust the vessel's trim. A ship might carry hundreds, thousands, even millions of gallons of ballast water, the largest vessels being capable of holding 50 million gallons or more. All this water, full of living organisms from ports around the world and around the nation, gets dumped into our Great Lakes, rivers, and estuaries when these ships reach their destinations. On departure, they take on more ballast water, laden with living organisms, which they carry to other parts of the world. In U.S. ports alone, ships discharge ballast water at a rate of 2.4 million gallons an hour.

Implications for Oregon's estuaries are dire, especially for those engaged in maritime commerce. But even the small, nonnavigable estuaries are endangered, because many organisms are able to travel up and down the coast in their larval forms, carried by oceanic currents. Even invasive species introduced to the East Coast by ships engaged in trade with Europe can eventually find their way to Oregon's estuaries. At least one already has.

The European green crab—long established on America's East Coast, where it has preyed upon or competed with many important native species, including soft-shell clams—was discovered in San Francisco Bay in 1989. By 1993 green crabs had made their way north to Bodega Bay, and they've been in Humboldt Bay since 1995. The European green crab was first discovered in Coos Bay in 1996. Only a few green crabs, measuring two to three inches each, have turned up in the bay so far, and the current population here is thought to be small. Nevertheless, one female found in the lower bay carried fertile eggs.

Although the meat of the green crab is edible, the crab is too small to be of commercial or recreational value, but can devastate native populations of important fish and shellfish. It's an aggressive crab that feeds on just about anything, including salt-marsh grasses, insects, small fish, mussels, clams, oysters, and other crabs. It prefers the protected waters of bays and estuaries to the heavy waves of open coastal areas, but it can tolerate a wide range of temperatures and salinities, making it an extremely adaptable invasive organism.

This unwelcome invader is already established as far south as Monterey Bay, California, and could eventually reach bays and estuaries as far north as southeast Alaska. On June 1, 1998, scientists discovered an inch-long molt, or shed shell, of a green crab in Washington's Willapa Bay, one of the nation's largest oyster-producing estuaries.

The European green crab is not the only introduced species in Oregon estuaries and certainly won't be the last. One of the world's foremost experts on introduced species is Dr. James T. Carlton, director of the Maritime Studies Program at Williams College in Mystic Seaport, Connecticut. He and a team of researchers sampled the ballast water of 160 ships calling on the Port of Coos Bay. His tests showed a tremendous number of living organisms representing more than 400 different species arriving alive in ballast water that was ultimately pumped into the bay. Some of these organisms are already established in the bay. Scientists have documented at least 32 introduced species residing in the South Slough of Coos Bay, 14 of which were introduced by ships.

Rather than enhance the diversity of the estuarine communities they invade, nonindigenous species often have the opposite effect. The nonnatives may crowd out more desirable native species and become the dominant organisms in an area, thus reducing biodiversity. A case in point is the small Asian clam that, in only a few years, has colonized many parts of San Francisco Bay. The clam, which grows to a maximum size of about one inch, was not even present in San Francisco Bay in 1985. Within a year of its introduction by ballast water, however, it inhabited the bay's mud floor in densities ranging from 300 to 3,000 individuals per square foot. By 1990 it was present in colonies of more than 6,000 clams to the square foot. It now dominates many parts of the bay bottom and has few natural enemies.

WARDING OFF INVASION REQUIRES CHANGES

Among the various ways of protecting Oregon's coastal waters against ballast-water introductions, Dr. Carlton and other scientists favor high-seas ballast-water exchange. Ship owners have been reluctant to adopt the policy, asserting that their ships might become unstable in heavy seas. Shipbuilders have also failed to make design changes that would ensure stability during high-seas ballast-water exchanges. If the U.S. is to protect its coastal waters from further introductions of invasive species, it will have to take action—the sooner the better, but even then it will be too late for estuaries already infested. As Dr. Carlton points out, the ships being built today with current technology are likely to continue dumping ballast water in estuaries, and those ships are designed and built to last for at least 25 years.

OREGON'S POPULAR BAY CLAMS

Although more than a half-dozen species of clams grow to harvestable sizes in Oregon's estuaries, five are popular recreational species, several of which are also taken commercially in some bays. Those that show up most often in clamdiggers' buckets are soft-shell, littleneck, cockle, butter, and gaper clams. They provide food and untold hours of recreation for thousands of coastal residents and visitors.

Soft-shell clams are among the most widespread in America. They were introduced to the West Coast in the 19th century and have found their way into all of Oregon's estuaries. They live in the mudflats and gravelly mud fringes of the upper and middle portions of bays, where they're found from 6 to 18 inches beneath the surface, often in dense colonies. These medium-size clams, which average 3 to 4 inches long but can grow to 6 inches, are food for many predators, including crabs, ducks, swans, and raccoons.

Littleneck clams inhabit the sandy gravel of rocky intertidal areas along open ocean beaches, but they also reside in the sandflats and gravelly sand of the lower reaches of larger estuaries, such as Coos Bay and Tillamook Bay. They're usually from 1 1/2 to 2 1/2 inches across when harvested and are highly prized as steamer clams. They're short-necked clams that live 1 to 4 inches below the surface, sometimes in large colonies, and are often found in the company of cockles.

The *cockle,* which grows to a maximum length of 6 inches but probably averages 2 to 3 inches, prefers the sandflats of the lower bay, where it lives 1 to 3 inches beneath the surface. Recreational harvesters usually use rakes to collect these shallow-dwelling clams. Cockles do not tolerate low salinity levels and are susceptible to seasonal die-offs during extended periods of flooding

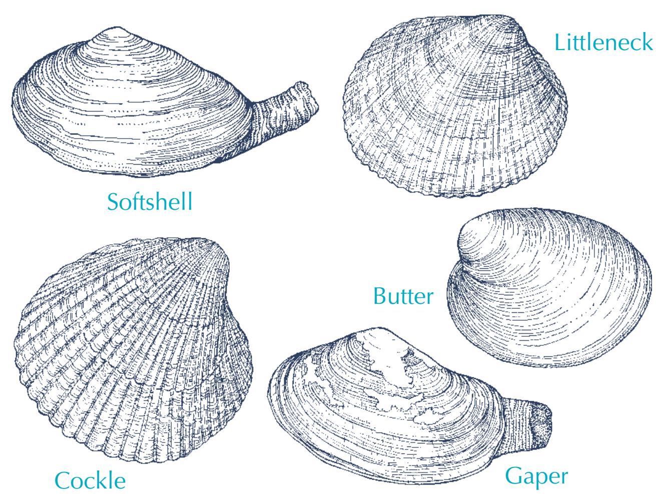
Butter clams grow to about 5 inches but probably average 3 to 4 inches in length. They have hard, thick shells and prefer the gravelly sand and mud of the middle and lower bays, where they're usually found from 6 to 12 inches beneath the surface. Because such habitat is fairly limited in Oregon's estuaries, butter clams aren't so plentiful or widely distributed as other bay clams.

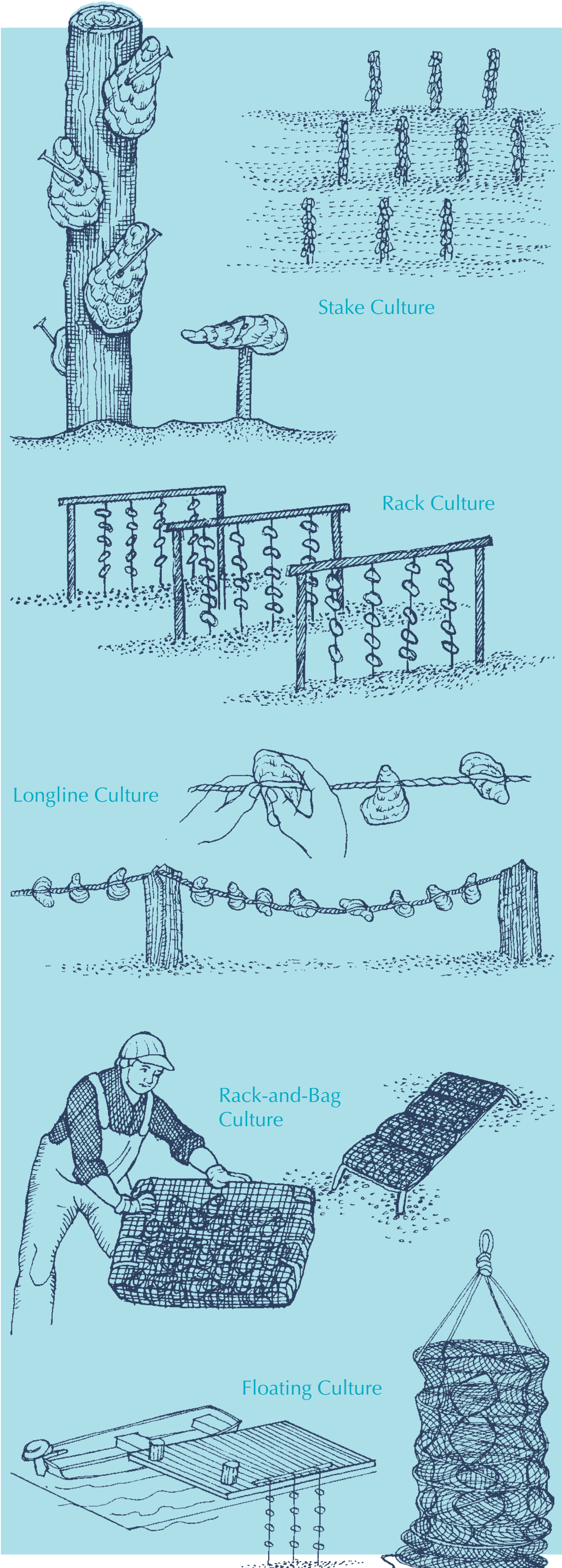
Gaper clams are the largest of Oregon's bay clams, with shells commonly 4 to 5 inches long and weight often exceeding two pounds. Gapers of three pounds or more are not uncommon, and they can reach five pounds. They live in the sandy mud of intertidal and subtidal flats, where they're found from 12 to 20 inches or more beneath the surface. These big clams are among the most popular species found in Oregon's medium-size and large estuaries.

Harvesting Oregon's bay clams is great family fun with no license or permit required. The necessary tools—shovel, rake, and bucket—are inexpensive or readily available in most households. And clams of one or more species are abundant in Oregon's estuaries, where their requirements are simple: suitable habitat, abundant food, and good water quality.

OREGON'S CLAMDIGGING BAYS

BAY	CLAMS PRESENT				
	SOFT-SHELL	LITTLE-NECK	COCKLE	BUTTER	GAPER
NEHALEM	•				
TILLAMOOK	•	•	•	•	•
NETARTS	•	•	•	•	•
NESTUCCA	•				
SILETZ	•				
YAQUINA	•	•	•	•	•
ALSEA	•		•		
SIUSLAW	•		•		•
UMPQUA	•				•
COOS	•	•	•	•	•
COQUILLE	•				





METHODS FOR GROWING OYSTERS IN ESTUARIES

Of all the methods for growing oysters, *bottom culture* most closely approximates oyster beds in their natural state, except that in the aquaculture operation, oysters are spread out in a single layer instead of growing in a mound, attached to one another. Bottom-cultured oysters grow on the surface of the sandflats and sandy mudflats of the estuary in the least expensive and most widely practiced method of oyster propagation.

In *stake culture* the "cultch"—oyster seed that has settled on and attached itself to nonliving oyster shells—is fastened to the tops or sides of stakes usually set about two feet apart in rows about eight feet apart and parallel to the water's edge. Growers drive the stakes into bottom sediments in the intertidal zone, where all oysters are underwater during high tide. Stake culture is possible in some areas where bottom sediments are too soft for bottom culture, but this method is more labor-intensive and expensive.

Rack culture calls for cultch to be attached to lines suspended from racks that keep the oysters off the bottom but ensure they are submerged at least during high tides. Racks of various designs are set in intertidal and shallow subtidal areas where workers can walk to them.

In *longline culture*, oysters grow on long lengths of polypropylene rope or wire, strung from posts or lengths of PVC pipe set in the bottom sediments. Oyster-laden lines are then kept several inches above the bottom sediments. All maintenance and harvest are by hand, requiring posts or pipes be set high enough in the intertidal area to permit worker access. In this method, as many as half the oysters might fall from the lines and are then bottom cultured beneath the suspended oysters.

Rack-and-bag culture requires racks made of steel concrete-reinforcing bar stock (rebar), which are positioned on intertidal flats. The grower encloses oyster cultch in a single layer inside a plastic mesh bag, then attaches several bags to each rack. Workers flip the bags about every two weeks, and as oysters grow, they're transferred to bags with larger mesh. Although this method requires considerable labor, loose oysters are confined inside bags that individual workers can handle with relative ease, thus offering some advantages over other labor-intensive methods.

Oysters grown in a *floating culture* are attached to lines suspended from floats, buoys, rafts, or floating docks. The floating devices are deployed in relatively deep water, so this method does not require tidal mudflats or sandflats. Although oysters in floating cultures are susceptible to predation by sea ducks, river otters, and other predators, they aren't prone to harm caused by the burrowing and bottom-dwelling organisms that cause damage in other oyster-growing methods. Because of the depth of water required in floating cultures, the area available for such purposes is limited in characteristically shallow estuaries.


PHOTO OREGON HISTORICAL SOCIETY

GLOSSARY

amphipod *n.* any of small, numerous crustaceans of the group *Amphipoda.*

anadromous *adj.* (of fish) hatching in fresh water, migrating to salt water, and returning as adults to fresh water to spawn.

aquaculture *n.* the cultivation of aquatic plants and animals in controlled or natural freshwater, saltwater, or estuarine environments.

benthic *adj.* of or pertaining to the benthos, a biogeographic region that includes the bottom of a body of water.

bioturbation *n.* the process of burrowing into and disturbing bedded sediments.

brackish *adj.* slightly salt, as some estuarine water, with salt content usually ranging from 0.5 to 1.7 percent.

cultch *n.* nonliving oyster shells serving as points of attachment for oyster seed.

indigenous *adj.* native of or originating in a particular region or country.

planktonic *adj.* of the plankton, the aggregate of passively floating, drifting, and somewhat motile, mainly microscopic organisms occurring in a body of water.

spat *n.* oyster spawn or seed.

trim *n.* the balance and attitude of a boat or ship in the water.

turbidity *n.* the state of being unclear or cloudy because of stirred-up sediments, algal blooms, and the like.

RECOMMENDED READING

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McConnaughey, Bayard H. and Evelyn. *Pacific Coast.* New York: Alfred A. Knopf, 1985.

Ricketts, Edward, e*t al. Between Pacific Tides.* Stanford, California: Stanford University Press 1985.

Schultz, Stewart T. *The Northwest Coast.* Portland, Oregon: Timber Press, 1990.

WEB SITES

National Estuarine Research Reserves:
http://wave.nos.noaa.gov/ocrm/nerr/welcome.html

South Slough National Estuarine Research Reserve:
http://www.southsloughestuary.com

Tillamook Bay National Estuary Project:
http://osu.orst.edu/dept/tbaynep/nephome.html

The Oregon Estuary Plan Book:
http://www.inforain.org/epb/intro.htm

Oregon Department of Fish & Wildlife Home Page:
http://www.dfw.state.or.us

Oregon Department of Fish & Wildlife Research:
http://www.ors.edu/Dept/ODF/index.html

NOAA Web Sites: http://www.websites.noaa.gov

U.S. Environmental Protection Agency:
http://www.epa.gov

Bioregional Information on North American Rainforest Coast: http://www.inforain.org

Sustainable Ecosystems Institute:
http://sei.org/homepage.html

Sea Grant Nonindigenous Species Site:
http://www.ansc.purdue.edu/sgnis/home.htm

Coastnet Links to Other Sites:
http://secchi.hmsc.orst.edu/coastnet/links.html

An antique oysterman's dredge and equipment used to scoop up oysters from the sea bottom.

Funding provided by the National Oceanic & Atmospheric Administration.

SOUTH SLOUGH NATIONAL ESTUARINE RESEARCH RESERVE
Division of State Lands
PO Box 5417, Charleston, OR 97420

Tillamook Bay National Estuary Project
Written by Kenn Oberrecht
Illustrated by Sharon Torvik