Crop Profile for Bivalve (Oysters, Manila Clams, Geoduck Clams and Mussels) Aquaculture in Washington

Production Facts

In 2005, Washington produced 77M pounds of oyster meat, 8.5M pounds of Manila clam meat, 2.1M pounds of mussel meat and 0.85M pounds of Geoduck clam meat, for a total of 88.5M pounds.

In 2005, meat production values in Washington were $72M for oysters, $17M for Manila clams, $2.44M for mussels and $5.31M for Geoduck clams, for a total value of $96.9M.

In a 2008 grower survey, 55% of respondents indicated they were small family businesses and farming less than 260 acres of tidelands on average.

Production Regions

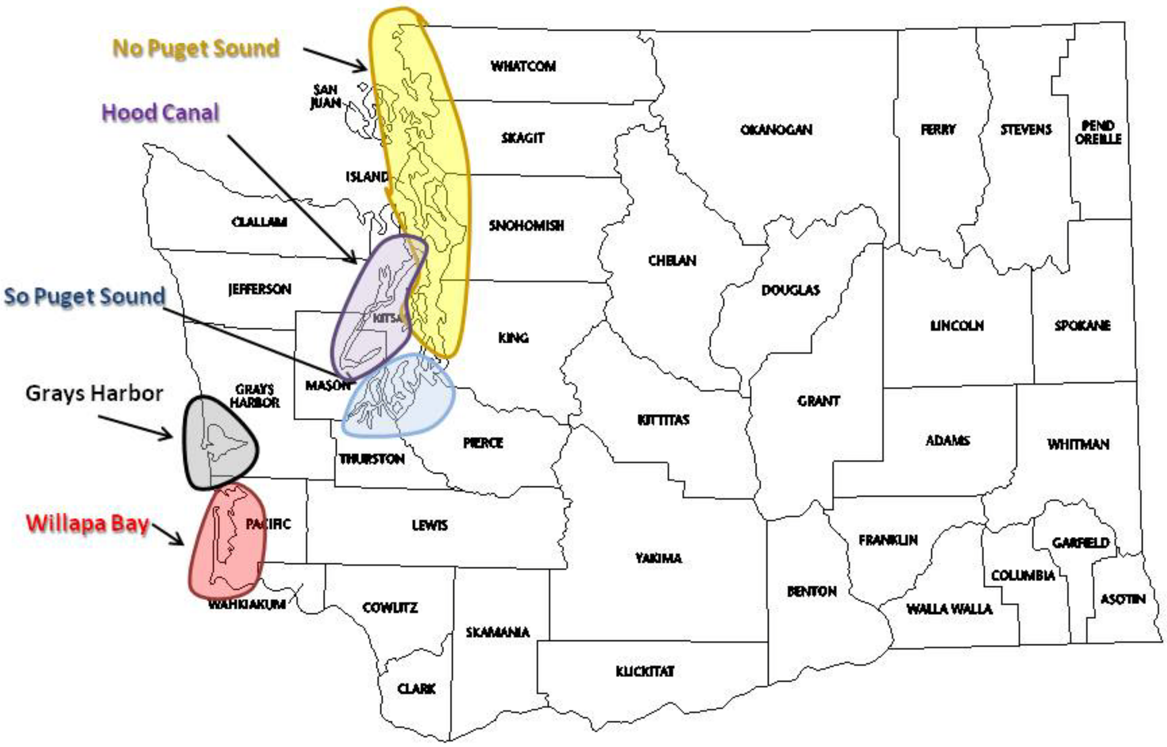
Major production regions are Willapa Bay (Manila clams and oysters), Grays Harbor (Manila clams, oysters), North Puget Sound (oysters, Manila clams, Geoduck clams and mussels), South Puget Sound (oysters, mussels, Manila clams and Geoduck clams) and Hood Canal (oysters, Manila and Geoduck clams).

The bulk of the oyster production comes from Willapa Bay, Grays Harbor, Southern Puget Sound and Hood Canal. Geoduck clams are predominantly farmed in Southern Puget Sound with a few exceptions. Manila clams are farmed predominantly in Hood Canal and Southern Puget Sound with smaller but increasing production in Willapa Bay, on the coast, and Samish Bay, in Northern Puget Sound. Mussel production is located in Totten Inlet in Southern Puget Sound and Penn Cove in Northern Puget Sound.

These five production regions show landscape-scale differences in geomorphology, weather patterns and water quality, all of which result in different pest problems, cultivation techniques and market strategies.

The Crop Profile/PMSP database, including this document, is supported by USDA NIFA.

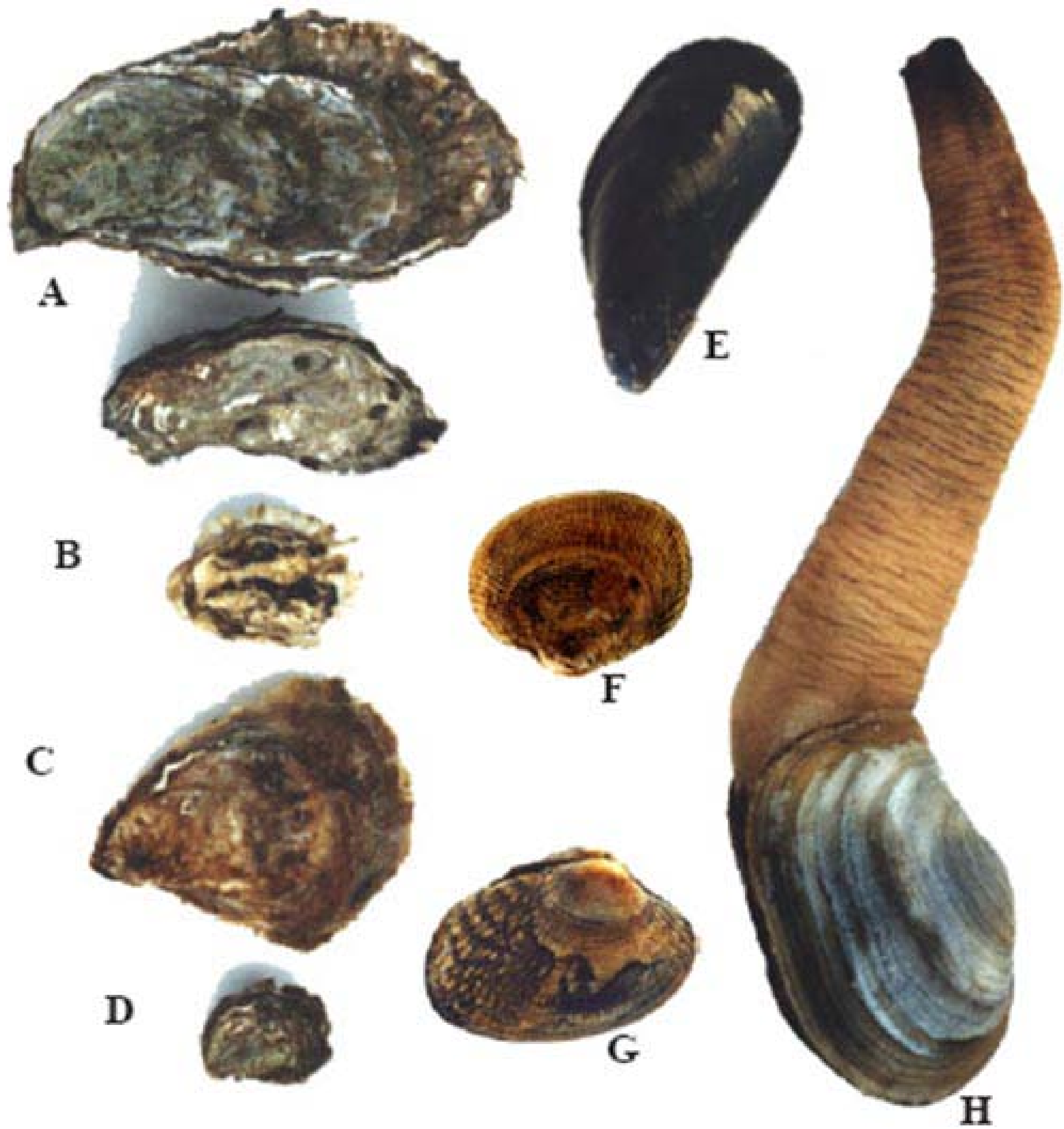
Washington State Bivalve Production Map



General Information

Bivalves (Phylum: Mollusca; Class: Bivalvia) have two-part shells (valves) that are symmetrical along the hinge line. These organisms feed by siphoning and filtering food particles and associated nutrients from water. They grow best in areas having nutrient-rich waters, good tidal action for oxygenation and increased food availability, and acceptable ranges of temperature and salinity.

Although this class has 30,000 species, including scallops, clams, oysters and mussels, this profile will be limited to the dominant bivalve crops of the Pacific Northwest: oysters, clams (including Geoducks) and mussels.



Typical commercial molluscs of Washington State: A) Pacific oyster, B) Kumamoto oyster, C) Belon or Eastern flat oyster, D) Olympia oyster, E) mussel, F) Manila clam, G) Littleneck clam, H) Geoduck

Washington's commercial bivalve industry began in the mid 1800's. The driving force was demand for the native Olympia oyster (*Ostrea lurida*) from gold miners in California. Other native species included the littleneck clam (*Protothaca staminea*), the mussel (*Mytius* *trosulus*), and the Geoduck clam (*Panopea abrupta*). Intensive oyster cultivation began with the passage of the Bush and Callow Acts in 1895 which provided for the sale of tidelands to private owners specifically for the purpose of culturing molluscs. The Olympia oyster was originally harvested for this and later markets but native stocks declined due to water quality problems from pulp mill effluent and overharvesting. Eastern oysters (*Crassostrea virginica*) were introduced in the early 1900's with some initial success, but eventually most of the crops failed; Eastern's are still successfully cultured in small amounts. Pacific oysters (*Crassostrea gigas*), a larger and hardier species, were introduced from Japan beginning in the 1920s. Pacific's now dominate oyster culture despite subsequent improvements in water quality which have allowed Olympia oysters to rebound. Pacific oysters with an extra set of chromosomes (triploid) have more consistent meat quality and grow faster than normal diploid oysters, and are now commonly cultured. Triploids cannot reproduce or genetically recombine with wild diploid stock. The Kumamoto oyster (*C. sikamea*), Belon or Eastern flat oyster (*O. edulis*), the Gulf or Eastern oyster (*C. virginica*), and manila clams (*Tapes philippinarum*) are introduced species. Mediterranean mussels (*Mytilus galloprovincialis*) are also farmed and there is debate as to whether they are introduced or indigenous to Puget Sound.

Bivalves are marketed as fresh, smoked or frozen, but are most often sold as fresh, both in the shell and shucked. If the oyster is sold in the shell, the most valuable form is a single oyster. Oyster clusters are typically shucked with the meats graded for size and packed in varying volume containers. Shell size, shape and appearance as well as meat quality are critical variables for marketing fresh, live oysters. Smaller live single oysters fill a growing "raw bar" market while larger singles are sold for barbequing and a variety of cooked preparations. One large processor has a line dedicated to liquid nitrogen freezing of single oysters with the top shell removed. Manila and Geoduck clams and mussels are marketed predominantly in a live, fresh form. The marketing chain varies across the region. Most of the larger growers sell directly to domestic and international wholesalers and seafood distributers. Some growers sell to other producers or retailers who then resell product. Growers may also sell directly to restaurants or to the public through retail outlets and the Internet.

Cultural Practices

Growers farm bivalves on tidelands they own or lease from other private owners or the Washington State Department of Natural Resources, an agency that manages state-owned tidelands. Most are grown at the intertidal level, the area along beaches that is alternately exposed and submerged by the tides. Alternatively, some culture takes place at the sub tidal level, defined as areas that are always submerged.

Bivalve farmers depend on a consistent supply of larvae or juveniles, whether that supply comes from hatcheries or from natural spawning. When larvae originate from natural sources, growers refer to this as “natural set”. Some production areas can rely on natural set of oysters, clams or mussels, while others must rely partially or entirely on hatchery-supplied larvae. Willapa Bay and Hood Canal are locations where there are frequently natural sets of Pacific oysters and Manila clams. All commercially farmed Geoducks and Mediterranean mussels are sourced from hatcheries.

There are four main hatcheries which supply larvae and seed to West Coast growers. Two of the hatcheries belong to the largest producers generating larvae and seed for their farms and for others to purchase. These same companies have nursery operations in Kona, Hawaii and one of them has another nursery in Humboldt Bay, California. In many locations production of Pacific oyster, Manila clam, Mediterranean mussels and Geoduck seed is largely or wholly dependent on hatcheries.

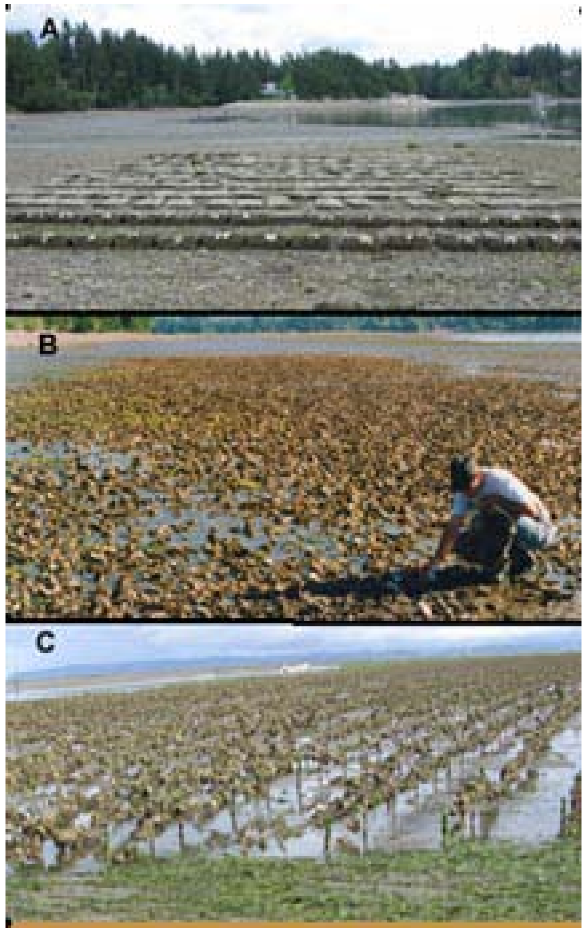
Oysters*:* For shucked oyster meat production, oyster larvae are set on old oyster shells that are placed in plastic mesh bags. These bags, which are typically 8 inches in diameter and 3 to 4 feet long, are placed in tanks of heated seawater and larvae from the hatchery are introduced to attach to the shells. The small, developing oysters are called “spat” and their substrate are termed cultch, but growers may also refer to it as “seed” in the way terrestrial farmers refer to planting material.

Oyster seed: several small oysters growing on a single recycled oyster shell

Bags of cultch ready for planting

Batches of oyster larvae are produced by hatcheries for setting throughout the spring and summer. Rearing a single batch of larvae through metamorphosis takes typically 2 to 4 weeks depending on water temperature, nutrient levels, pH, etc. The seeded cultch is then typically held for 1 to 6 months before planting to allow the young oysters to grow to a suitable size.

In areas with natural sets, cultch is placed in bays either loose or in bags at critical times to collect larvae. Natural spawning and settlement generally occurs from June through early September. This approach is not without risks. During the last 60 years, at intermittent intervals and for periods from one to five years in a row, natural set has declined to levels that will not sustain commercial production. The reasons for these interruptions are not entirely understood, but include very low pH, low levels of dissolved oxygen, increased levels of carbon dioxide, changes in phytoplankton composition and abundance, and bacterial pathogens. Natural set has been particularly low during the last four years in Willapa Bay and Hood Canal. Growers that traditionally relied on natural set have been forced to purchase seed from hatcheries. However, some hatcheries have also suffered reduced production which will in turn lead to lower on-farm production over the next few years.



A) Bottom culture of oysters in bags and trays, B) scattered bottom culture, and C) off-bottom long-line culture

For the production of single oyster seed, larvae are set on microscopic shell chips and reared to varying sizes in nursery systems to get them to appropriate sizes for further growth on the farms. Land-based and floating upwell systems are the most common nurseries. Some growers will plant single oyster seed at high densities at higher tidal elevations to harden shells prior to transplanting to lower elevations with predator (crab) exposure.

Several methods of cultivation are commonly used. Methods chosen are determined largely by the growing conditions of the tidelands, economic situation, labor availability, market type and size, and experience of the company or individual grower. Clustered oysters for the shucked meat market are typically cultured on the bottom or, on softer bottom the mother shells (with spat attached) are entwined in ropes that are suspended horizontally between short pipes (e.g. long lines). Single oysters are cultured directly on the bottom or secured in bags, trays, or cages.

Growers sometimes culture cluster seed for one or two years on nursery beds and then move the seed to fattening beds to improve meat yield prior to harvest. Depending on the market they are destined for, food availability and quality, nutrient levels, and temperature, maturing oysters can reach market size in one to four years.

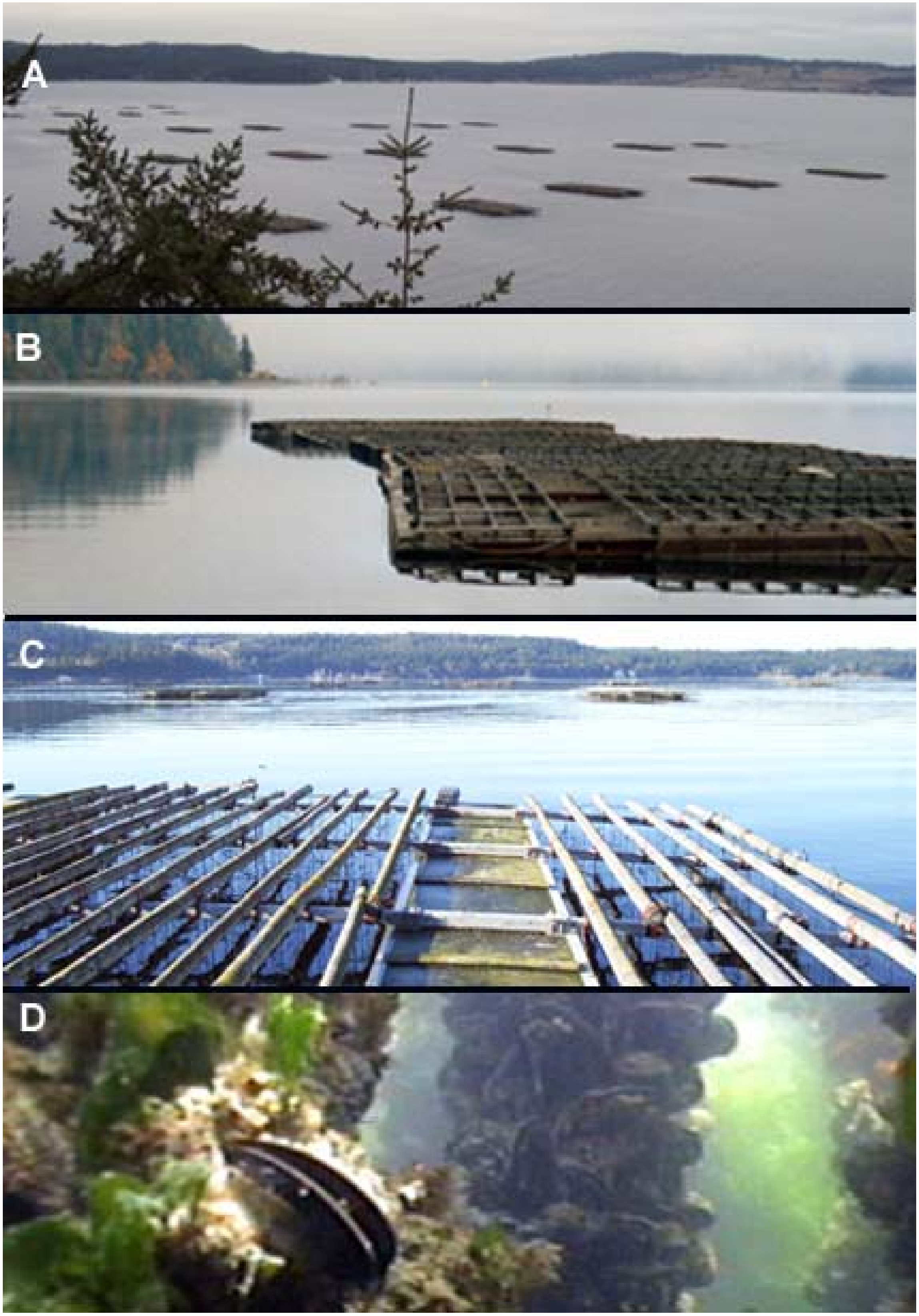
Manila Clams*:* Like oysters, Manila clams are both planted and arise on beds via natural set. Tiny, hatchery-raised clams are scattered by hand, planted in bags, or sometimes covered with mesh netting to protect them from predators. Gravel is sometimes added to muddy tidelands to better approximate natural clam ground and reduce predation. In Samish Bay, two growers are growing Manila clams in 4-foot wide rows under predator nets to facilitate mechanical harvest.

Manila clams are planted A) by hand to grow freely in the substrate, or B) in bags, or C) under netting to protect them from predators

Geoduck clams*: Geoduck* seed are supplied by hatcheries and planted by hand individually into PVC sections, plastic mesh tubes, or under raised netting or rigid mesh tunnels. Recent studies have shown that biodegradable tubes can also be used. Mesh netting is placed either over each individual tube or over groups of tubes to protect small Geoducks from predation. Netting and tubes are removed after one to two years as the developing Geoducks burrow deeper into the substrate. They attain harvestable size (one to two lbs.) after a total of five or six years, depending on planting density, food and nutrient levels, and temperature. Geoducks are grown at lower intertidal or even sub tidal elevations. By harvest, the clam resides as much as a meter deep in the sand, with its long siphon extended to the surface.

A) Baby Geoducks are B) seeded into tubes where they grow for one to two years, and then grow to C) harvestable size in ca. three or four more years

***Mussels**:* Hatchery-produced *M. galloprovincialis* seed are grown initially in shore-based upwells and later on frames of window screen for six to 12 weeks. *M. trosulus* seed is collected from natural sets. The seed is manually or mechanically stocked onto the mussel lines. The lines are suspended from rafts or large buoys where the mussels complete development. Most often mussels are grown using rafts or large buoys that support ropes or lantern nets/bags that hold the product. Mussel rafts are restricted to deeper areas, such as the bays and inlets of South Puget Sound. Attempts to grow mussels on intertidal long-lines have not been as successful as long-line oyster culture. In certain locations (e.g., Penn Cove) *M. trossulus* is cultured from natural set.


A
B
C
D

A) Flotilla of mussel rafts in Penn Cove; B) Single raft in service and C) under construction
D) Mussels growing on ropes suspended from raft

Growing and Harvesting

***Oysters**:* Fattening beds are sometimes harrowed in the spring to lift partially sunken oysters and break large clusters into smaller ones, allowing for production of more “single” oysters. Oysters can grow too large for market- based on both raw and shucked forms. Growers in Willapa Bay and Grays Harbor monitor temperature and pest conditions closely because once chemical applications are made they can’t harvest for another year. If temperatures are warm, oysters may grow too large in a year’s time to then successfully market. Bottom cultured oysters are often hand-picked at low tide and collected into large cages or bins which are then lifted onto barges at high tide. Sometimes small mechanical drag-dredges are skimmed across bed surfaces to harvest bottom cultured oysters. Long-line oysters are harvested by hand at low tide or via barges and boats while water covers the oyster ground. Harvest occurs year-round with a significant surge during Thanksgiving, Christmas, New Year and Chinese New Year. Triploid oysters are popular for summer harvest due to improved yield and meat quality. Harvest of diploid oysters is lower during spawning season, when quality is somewhat reduced.

Workers in Willapa Bay pick oysters into bins for later loading into barges at high tide

***Manila Clams**:* Manila clams grow to harvestable levels in two to five years. They are harvested year round, primarily using hand rakes, although specialized mechanical harvesters have been developed and are at different stages of implementation. Generally, small clams are separated out and put back to continue growing. Bagged clams occasionally sink, especially in softer substrates, so are periodically lifted and reset. Bags of clams are harvested intact and sorted for size and quality in-house.

Hand harvest of Manila clams

Geoduck clams*:* Like Manila clams, Geoducks are harvested year round. These clams burrow deeper in the sand after their first year and continue growing for a period of three to five more years. Intertidal plantings are harvested by passing a high volume of low pressurized water through the sediment to liquefy it, then extracting the mature clams by hand. Geoducks which are cultured intertidally are harvested during low tide events or by scuba or surface air-supplied divers at high tide. Sub tidal Geoducks must be harvested by divers.

Mussels*:* Mussels are also harvested year round after one to two years of growth using barges equipped with hydraulic platforms or booms.

All bivalves: The Washington State Department of Health implements the National Shellfish Sanitation Program under the supervision of the U.S. Food and Drug Administration. They classify growing areas as Approved, Conditionally Approved, Restricted or Prohibited based o n water quality and shoreline sanitary surveys. They also monitor naturally occurring harmful bacteria (*Vibrio parahaemolyticus*) and biotoxins. Harvest activities are restricted or curtailed, and in some cases products can be recalled, if threshold levels are exceeded. In Conditionally Approved areas, and after major flood events, bivalves cannot be harvested until the growing area is purged for intervals specified by the state. In the summer months, the risk to human health associated with bacterial contamination (*Vibrio parahaemolyticus*) is reduced by shortening the interval to cool the product down. Strict federal and state regulations also guide the length and conditions under which bivalves are stored prior to shipment. Bivalves are cleaned, sorted, and otherwise processed, then placed under refrigeration prior to and during shipping.

Pest categories are listed in the order of importance with invertebrate pests being the most damaging to the industry.

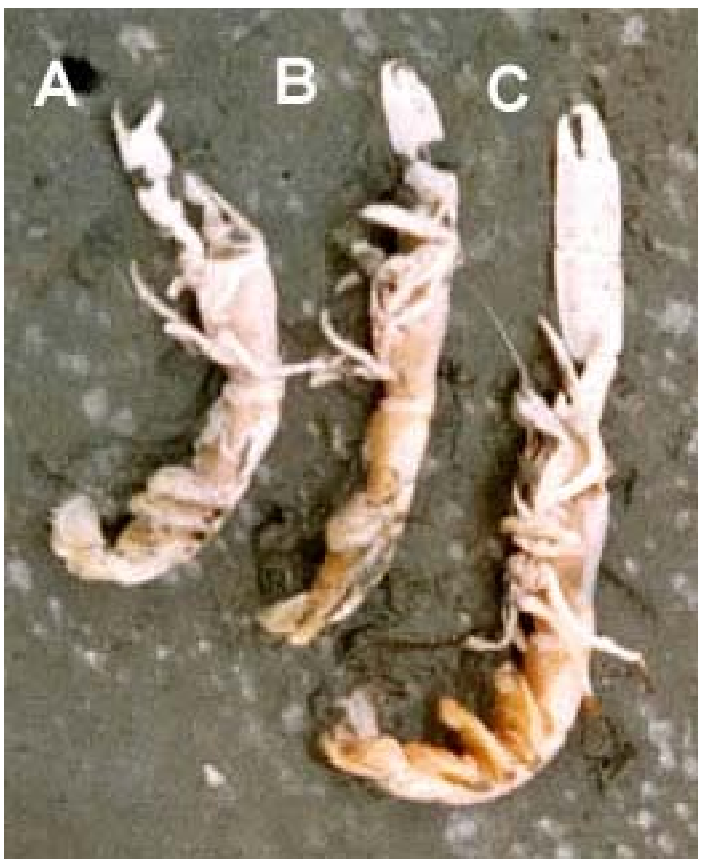
Invertebrate Pests

Burrowing shrimp

Ghost shrimp (*Neotrypaea californiensis*)

Mud shrimp (*Upogebia pugettensis*)

Giant sand shrimp (*Neotrypaea gigantis*)



A) Mud shrimp, B) Ghost shrimp, and C) Giant sand shrimp

Burrowing shrimp are indigenous and quite common in intertidal sediments of estuaries from Northern California to Southern British Columbia. Larval stages are found in ocean waters and, through current patterns and tide action, are highly mobile both within and among estuaries.

Although these organisms compete with other estuarine fauna for food (plankton), their main effect on bivalves is indirect. They reside beneath the substrate surface, where they displace and mix sediment particles as they feed in a process called bioturbation. Disruption of the normally hard and sandy tide flat bottom structure results in formation of a soft mud layer. Tide flat bottom dwellers, like bivalves, literally sink in the resulting mud and suffocate. At densities of 30 or more shrimp burrows per square meter, both large oysters and smaller oyster-seeded shell will sink and die within a few months. The time to death is longer at lower pest densities but yield of multi-year crops will be severely impacted if burrow densities exceed 10 per square meter.

Burrowing shrimp are a considerable problem at almost all farms in Willapa Bay / Grays Harbor, with ghost shrimp by far the most abundant and destructive pest species. Burrowing shrimp have historically been less abundant in the Puget Sound growing regions, although growers report that recent increases in ghost shrimp densities now impact production. Lacking an effective control, beds on the Skokomish flats in the Hood Canal are so infested they have been abandoned for oyster culture. Mud shrimp have declined in numbers in the past decade due to the non-native parasitic bopyrid isopod, *Orthione griffenis.* Now only isolated bivalve growing areas have mud shrimp populations. Areas that still support high densities of mud shrimp, however, are problematic. The giant sand shrimp is relatively uncommon in Willapa Bay but its distribution is not well known across production regions. All three species of burrowing shrimp have the same economic effect to growers and control mechanisms are sought for the broad category of burrowing shrimp.

Cultural Controls

Long-line cultivation techniques are sometimes used to reduce oyster mortality due to soft sediments. However, oysters that fall from the line on severely infested beds will still sink, as will the lines themselves. When mussels are grown using intertidal long-line cultivation, they too are susceptible to sinking. In Willapa Bay, attempts to grow high value single oysters in shrimp-infested areas by placing them in mesh bags and specially designed baskets hanging from the long lines have met with some success. Where they have been exposed to extreme winds there have been problems with them being blown or ripped from the ropes.

Most Willapa Bay growers have found stake culture to be an ineffective management tactic for burrowing shrimp. Tidal currents and storms dislodge stakes or stakes sink or tip over in the soft sediment. As with long-lines, oysters that fall off will sink and suffocate in severely infested beds. Stake culture is also impractical on a large scale from a labor standpoint.

Currently, no pre- or post- harvest practices are available that substantially aid in burrowing shrimp suppression. Beds are sometimes harrowed prior to oyster planting, which may slightly suppress burrowing shrimp, but the economic impact has not been measured.

Biological Controls

Burrowing shrimp are indigenous species with large ranges of distribution on the west coast. The entire estuarine ecosystem might suffer if this range suddenly became substantially smaller. The introduction of foreign biological control agents with unknown and unpredictable potential is discouraged. However, the accidental introduction of a foreign parasite (*Orthione griffenis)*, likely through ballast water in the early 1980s, appears to be responsible for a precipitous decline in mud shrimp. Levels of infection are typically less than 5% for bopyrids in their native waters, but *O. griffenis* currently parasitizes up to 80% of mud shrimp in most Pacific Northwest estuaries, which could potentially nearly eradicate that species.

Chemical Controls

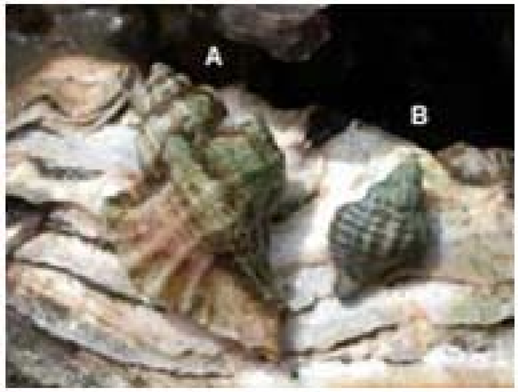
Carbaryl (Sevin 80SP) is applied at 8 lb a.i./acre in Willapa Bay and Grays Harbor on beds with shrimp densities greater than a threshold of 10 burrows per square meter. Applications are made during the extreme early morning low tides in July or August, usually by helicopter. Carbaryl is applied according to several Best Management Practices that are legally formalized on the 24C label (WA900013). These include a limitation of 800 acres, a maximum wind speed threshold of 10 mph, a 200 ft buffer around targeted beds, and a seasonal window of application. A treated bed usually remains farmable for several years after a single application. Carbaryl is the only material registered for use against burrowing shrimp.

Applications later in the season would capture more juvenile ghost shrimp (which settle out of the water column in late summer or autumn) but such timing might impact migrating salmon and are not allowed under the 24C registration.

Oyster drills

Japanese oyster drill (*Ocinebrellus inornatus*)

Eastern oyster drill (*Urosalpinx cinerea*)



Two varieties of oyster drills

These non-native parasitic snails perforate the shell of oysters and eat the meat. Mortality is higher among smaller, younger, more vulnerable oysters and clams. While their impact has not been precisely measured, damage levels vary from low to high among farms and bed locations. Bottom culture systems are the most vulnerable because drills only move along the bottom.

Cultural Controls

Control is most often accomplished by hand removal of drills and egg cases after higher priority labor-intensive tasks have been completed. This is typically done when the drills congregate to mate.

Biological Controls

No potential biological controls have been identified.

Chemical Controls

No chemicals are currently registered for use against oyster drills.

Bamboo worm (*Clymenella torquata*)

Bamboo worm in burrows

The bamboo worm is an invasive tube-dwelling polychaete (Capitellida: Maldanidae), native to the Northwest Atlantic. It's currently restricted to a few farms in Samish and Similk Bay Washington, where it severely impacts oyster culture by softening the ground, causing oysters to sink and suffocate.

Cultural Controls

Some control has been achieved by draining infested areas thoroughly at low tide and rototilling.

Biological Controls

No potential biological controls have been identified.

Chemical Controls

No chemicals are currently registered for use against bamboo worm.

Moon snail (*Polinices lewisii*)

Moon snail inside former egg case aka sand collar

Moon snails are large, predatory gastropods that drill holes through the shells of bivalves. Their presence is often indicated by the characteristic egg case which holds hundreds of fertilized eggs. Snails hatch and are dispersed when the floating case bursts and sinks to the bottom. *P. lewisii*, named for Meriwether Lewis, is indigenous to the west coast. It is mostly a problem in Hood Canal and South Puget Sound, where they impact cultured oysters, Manila and Geoduck clams. It is managed by hand removal which makes management expensive.

<u>Cultural Controls</u>

Bags, nets, tubes to exclude snails and hand removal are the primary cultural controls used by growers.

<u>Biological Controls</u>

No potential biological controls have been identified.

<u>Chemical Controls</u>

No chemicals are currently registered for use.

Crabs

Dungeness crab (*Cancer magister*)

Rock crab (*Cancer productus*)

Green crab (*Carcinus maenas*)

Graceful crab (*Cancer gracilis*)

A) Dungeness crab (width ca. 15 cm); B) Graceful crab (width ca. 5 cm), and associated feeding damage to C) Manila clams and D) Geoduck clams

Green crab (width ca. 9 cm)

Dungeness and rock crabs are native species and have economic, as well as ecological importance in estuaries of the Pacific Northwest, especially Dungeness, which supports a sizeable fishery. Nevertheless, they impact the production of all commercially grown bivalves, especially those cultured on the bottom. Young, uncovered clams and cultchless oyster seed are particularly vulnerable. While not commercially valuable, the Graceful crab also preys on young clams and oysters.

Green crabs are invasive predators, originally from Europe but now well established in California. In Tomales Bay, California, they are a problem for farmers growing clams in bags as the crab larvae may recruit into the bags. Protected from predators, they grow and feed on the clams in the bags. They invaded estuaries and inlets of the Pacific Northwest during the warm El Niño event of 1997-98. The result was establishment of a monitoring program by the Washington State Department of Fish and Wildlife. The program was severely reduced in 2002 then disbanded in 2005 due to a lack of funds and after conclusions that the relatively cool Pacific Northwest waters could not support sustainable populations. However, recent trapping by the Pacific States Marine Fisheries Commission and by Fisheries and Oceans Canada indicate that small populations are recruiting new larvae at selected sites on the coast and islands of British Columbia, principally in marginal areas where larger native crabs are not present. A few crabs were also captured in Willapa Bay in 2005-2006 but not 2007. Given future warming events, these small populations could become more dense, numerous, and potentially detrimental to bivalve production.

Cultural Controls

Bags, nets, and tubes are the primary cultural controls used by growers.

Biological Controls

No potential biological controls have been identified.

Chemical Controls

No chemicals are currently registered.

Weeds

Cordgrass

Smooth cordgrass (*Spartina alterniflora*)

Common cordgrass (*Spartina angelica*)

Thick infestations of smooth cordgrass (right) and cut areas (left) in 2007

Spartina is native to the American Southeast. It was probably accidentally introduced to Willapa Bay in the late 1800s but remained at tolerable levels until the early 1990s. *S. alterniflora* expanded into hundreds of acres of formerly bare mudflats in all coastal counties except Whatcom, trapping sediments within its dense root structure and creating huge racks of floating organic debris during annual fall diebacks. *S. angelica* has a somewhat lesser distribution, especially in Pacific County, but nevertheless causes similar problems. Both species have been designated Class A noxious weeds by the Washington State Noxious Weed Board. An eradication program administered by Washington State Department of Agriculture with strong collaborative efforts from U.S. Fish and Wildlife, Washington State Department of Natural Resources, University of Washington, Washington State University, and the Willapa Bay Grays Harbor Oyster Growers Association has made substantial progress in a plan to eradicate *Spartina* by 2012. At the time of this writing, less than 100 acres (of mostly *S. alterniflora)* remain in Willapa Bay and Grays Harbor and ~100 acres (of mostly *S. angelica)* remain in Puget Sound. The eradication program features several integrated control strategies, as outlined below. Growers are acting as scouts for weed appearance and, when found, notifying state agencies for targeted management efforts.

Mechanical Control

Crushing of *Spartina* using large heavy tract vehicles (e.g., the Marshmaster™, Coast Machinery, LLC; Baton Rouge, LA) has been effective in localized areas by state agencies. Seedlings are also pulled by hand at areas of sparse infestation and difficult access. Mowing before seed development can slow infestation rates.

Biological control

In 2001 and 2002, the plant hopper *Prokelesia marginata* (Delphacidae: Homoptera), was introduced to small, selected study sites in Willapa Bay that were heavily infested with *S. alterniflora*. Although hopper populations initially remained sparse and declined each winter when cordgrass went dormant, they showed substantial increases at some sites by 2005. Plants in areas of high hopper infestation (>5000 per square meter) were visibly stressed. Hoppers increased in distribution range as well as density. The experiment was greatly curtailed in the fall of 2006 when all study sites, except the one where hopper infestation was highest, were treated with imazapyr as part of the eradication program. The remaining site was similarly treated in 2007. Adjuvants in the formulation suppressed most hoppers, but some persisted on remaining *Spartina* plants. The full potential of *P. marginata* to impact large, dense stands of *Spartina* will never be known, but they may help keep remaining isolated patches in check.

Chemical Controls

Imazapyr (Habitat) is applied at 6 pt/acre to infested areas once per year and is quite effective. Imazapyr has been applied both by air and ground-operated equipment including airboats, large and small tracked vehicles, 4-wheelers, and back-pack sprayers. Aerial applications have decreased in tandem with the decrease in large tracts of *Spartina* in favor of ground spot-treatments. This is a critical use chemical for the industry as it is much more effective than glyphosate.

Glyphosate (Rodeo) is applied at 3% v/v in 100 GPA spray volume. It is less effective than imazapyr. In certain areas it is applied as a check for effective coverage of imazapyr as plants treated with glyphosate will turn brown as they die whereas those treated with imazapyr will not.

Japanese eelgrass (*Zostera japonica*)

Japanese eelgrass

Japanese eelgrass was unintentionally introduced to the west coast many decades ago in shipments of Japanese oyster seed. In recent years it has since spread to most areas in Willapa Bay / Grays Harbor where it forms thick blankets over the higher intertidal areas, affecting water drainage, sediment temperature, and likely nutrient composition. Japanese eelgrass is not protected to the degree that native eelgrass is in Washington State however policy regarding its status is unclear and currently evolving. Recent Army Corp of Engineers permits are clear that protection is only extended to native eelgrass. California has switched to an eradication policy.

Mechanical Controls

Growers are not able to actively control Japanese eelgrass because it's unclear whether it's protected or not.

Biological Controls

No potential biological controls have been identified.

Chemical Controls

No herbicides are currently registered for use against Japanese eelgrass.

Vertebrate Pests

Shorebirds and Waterfowl

Predation by shorebirds is significant, especially Scoter ducks that favor Littleneck and Manila clams. Passive measures include substrate covers and fencing. Hazing is also used with some degree of success. Timing farming activities when birds are most likely to be present has proven effective in scaring them away from sites. As a last alternative, hunting has been utilized when depredation permits can be obtained. At this time, Scoter populations are depressed and, as such, depredation permits are not available. While overall populations are depressed, shellfish growers have observed greater numbers of Scoter ducks on their farms. This may be an opportunistic response since the herring populations the Scoter's rely on as a primary food source are depressed in many areas.

Shiner perch (*Cymatogaster aggregata*)

Shiner perch, as well as other perch species, nibble on long-lined oysters and can cause substantial yield losses. Growers in Grays Harbor seem particularly affected. These losses currently cannot be managed. They also prey on small clam and mussel seed.

Diseases

Bivalve disease epidemics are sporadic by nature and determined by factors that are known, (e.g., upwelling and temperatures in the open ocean) as well as factors under investigation (e.g., ocean acidification). Although they have the ability to decimate production, most diseases are well managed. Management tactics do not involve chemical treatments. Regulations governing product handling, storage, and transportation also prevent disease outbreaks and diseases. Currently, the diseases of most concern often impact hatchery production rather than harvested bivalves. The fact that diseases are listed last in this sequence does not mean they are less important to this industry, simply that they are not as well understood.

Organisms that cause mollusc diseases described here are not the same organisms that cause human diseases (i.e. *Vibrio parahaemolyticus*).

Vibriosis (*Vibrio tubiashii*)

Vibrio is a naturally occurring marine bacterium that originates from ocean sources. This virulent pathogen occurs primarily in bivalve larvae and juveniles, both from hatchery and natural set, periodically causing severe reductions in seed supply of oysters and susceptible clam species. In spite of the economic importance of *V. tubiashii* in the cultivation of bivalves, very little is known about the virulence mechanisms of this pathogen.

Hatchery production was severely affected by this organism in 2006-7 and similar declines were reported during early 2008. While a possible solution for hatcheries may be conversion to sterile, bacteria-free culture facilities, it would be a difficult option for the typical open-sea-water-supply and large-scale batch culture operations. Various water treatments have been assessed, and are proving successful for the smaller research hatchery operated by Oregon State University in Newport, OR. Application of sterile culture or water treatment measures for larger hatcheries is expensive: the hatchery usually has to be shut down entirely and this option requires additional monitoring and testing. Continued declines in larvae and seed production mean the future of the $100 million dollar west coast mollusc industry is at great risk.

Oyster velar virus disease (OVVD)

OVVD affects mid-stage larvae and can occasionally cause significant morbidity and mortality in hatcheries. Control is achieved by sanitation, including destruction of affected groups, followed by tank disinfection. Viral transmission is also prevented by regulating the movement of brood stock, as the virus is likely transmitted from infected brood stock.

MSX (*Haplosporidium nelsoni*)

MSX of oysters is caused by a parasitic protist that can cause high mortality in Eastern oyster, particularly in moderate seawater temperatures and higher salinities. It is also reported occurring in juvenile Pacific oysters in California but has not been reported in cultured juvenile Pacific oysters in Washington. Eradication is not possible, but holding infected oysters in cold, low salinity waters can reduce the infection. Infection intensity and possible prevalence can be reduced by exposing oysters to mean salinities of 10 ppt or less and temperatures above 20˚C for periods of two weeks or longer. Some brood stocks of Eastern oysters show resistance to MSX.

Denman Island Disease *(Mikrocytos mackini)*

Denman Island Disease is caused by a protist. Symptoms include lesions and discolorations in the muscles and flesh of oysters, especially those over two years old. Mortality can exceed 30% if water temperatures remain below 10˚C for two to three months. Participants of a workshop on Denman Island Disease, held in Tacoma, WA in October 2004, concluded that the risk of exporting Denman Island Disease from Washington State to other growing areas is low since most oysters are harvested before the disease manifests itself. The disease is more common in British Columbia, but can be reduced by harvesting older oysters or moving them to higher tidal elevations in March and by not planting oysters at low tidal elevations after June.

Other parasites

Other parasites are of negligible direct impact, but may cause cosmetic damage (e.g., *Ostracoblabe implexa*), or loss of vigor (e.g., oyster trematodes, *Mytilicola orientalis*, etc.). Most of these parasites were introduced to Washington waters from other growing regions and no direct control methods exist.

Critical Needs

Beginning in 2003, the amount of carbaryl used on oyster beds per year has been successively reduced to a final upper limit of 4480 lbs a.i. Under a legal agreement, all carbaryl applications are to be terminated by 2012. At present there is no economically viable alternative for management of the pest driving this application.

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