Pest Management Strategic Plan
for
Bivalves
in
Oregon and Washington

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Work Group Members

Work Group Members in Attendance at Meeting:

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Paul Harris, Operations Manager, Seattle Shellfish, LLC
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David Steele, Operations Manager, Rock Point Oyster Company, Inc.
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Others in Attendance:

Dale Beasley, President, Columbia River Crab Fishermen's Association
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Summary of Most Critical Needs

Pest-specific aspects of these needs, as well as additional needs, are listed and discussed throughout the body of the document.

Research:

- Complete an economic assessment of pest impacts (including control and damage) for all major bivalve pests, including weeds.
- Research efficacy of alternative controls (chemical, cultural, and biological) and IPM alternatives for burrowing shrimp in all crops and regions where applicable.
- Research the potential for using attractants (e.g., pheromones) to develop control methods for moon snails, invasive oyster drills, and other pests.

Regulatory:

- Establish a state-authorized regulatory board under the Washington State Department of Agriculture to enforce area-wide control of state-listed invasive/noxious pests.
- Clarify shellfish growers' ability to control problem pests (i.e., clarify regulations regarding control of invasive and native pests, including Japanese eelgrass).
- Review and update regulations regarding the transport of affected product (e.g., more areas have oyster drills than have restrictions on shipping).
- Investigate methods to obtain compensation for crop damage caused by native and/or protected pests.
- Expedite registration of imidacloprid to control burrowing shrimp.
- Retain current registration of carbaryl for burrowing shrimp control.
- Clarify status of Japanese eelgrass to regulate and manage as an invasive species.
- Clarify regulations related to disturbance of native eelgrass during shellfish farming activities.
- Improve the accuracy of bivalve harvest production reports compiled by the Washington Department of Fish and Wildlife.

Education:

- Develop a pictorial guide for each major bivalve pest to aid in pest identification and monitoring.
- Educate growers, regulators, and the general public on current and past research (including IPM techniques) related to controlling burrowing shrimp, *Spartina* (cordgrass), and other pests.
- Host field days and workshops on pest identification and monitoring techniques.
- Increase awareness of pollutive and health effects of algal die-off on humans and other animals.

Process for this Pest Management Strategic Plan

In a proactive effort to identify pest management priorities and lay a foundation for future strategies, bivalve farmers, commodity group representatives, pest control advisors, regulators, university specialists, and other technical experts from Oregon and Washington formed a work group and assembled this document. Members of the group met on March 11, 2010, in Long Beach, Washington, where they drafted a document containing pest management activities, critical needs, activity timetables, and efficacy ratings of various management tools for specific pests in bivalve production. The work group, including additional members who were not present at the meeting, reviewed the resulting document. The final result, this document, is a comprehensive strategic plan that addresses many pest-specific critical needs for the bivalve aquaculture industry of Washington and Oregon.

The document begins with an overview of bivalve production followed by discussion of critical production aspects of these crops. The remainder of the document is an analysis of pest pressures during the production of bivalves, organized by pest. Key control measures and their alternatives (current and potential) are discussed. Throughout this document, "pest" means any form of plant or animal life or virus—except a virus on or in a living person or other animal—that is normally considered to be a pest or that the director (of the Washington State Department of Agriculture) may declare to be a pest (as defined by the Washington State Pesticide Control Act, Revised Code of Washington (RCW) 15.58.030; also found in RCW 17.21.020).

The entry for each pest includes descriptions of the pest's biology and life cycle, available controls (chemical, biological, and cultural), and critical needs related to the management of the pest. **Within each major pest grouping (invertebrate and vertebrate pests, diseases, weeds, etc.), individual pests are presented in alphabetical order, not in order of importance.**

Trade names for certain pesticide products may be used throughout this document as an aid for the reader in identifying the active ingredient of a pesticide. However, the use of trade names in this document does not imply endorsement of these products by the work group or any of the organizations represented.

Bivalve Production Overview

Bivalves (Phylum: Mollusca; Class: Bivalvia) are characterized by two-part shells (valves) that are connected at the hinge. 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, Manila and littleneck clams, geoduck clams, and mussels.

Growers farm bivalves on tidelands or submerged aquatic lands that they own or lease from other private owners or state agencies (the Washington State Department of Natural Resources or the Oregon Department of Agriculture) that manage state-owned tidelands and bedlands. Most bivalves 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 subtidal level, generally defined as areas that are always submerged.

Both Washington and Oregon's commercial bivalve aquaculture industries began in the mid 1800s. The driving force was high demand for the native Olympia oyster (*Ostrea lurida*) by gold miners and other residents in San Francisco, California. Later shellfish development included the littleneck clam (*Protothaca staminea*), the Native blue mussel (*Mytilus trossulus*), the Mediterranean mussel (*Mytilus galloprovincialis*), and the geoduck clam (*Panopea generosa,* previously known as *Panopea abrupta*).

The native oyster was originally commercially harvested, but native stocks declined due to overharvesting in many locations. Where native oysters persisted, they later succumbed to water quality problems from pulp mill effluent and increased siltation.

Intensive oyster cultivation in Washington 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. Eastern oysters (*Crassostrea virginica*) were introduced in the early 1900s with some initial success in Willapa Bay, Washington, but eventually most of the crops failed. Today, Eastern oysters are successfully cultured in small amounts in Puget Sound. Pacific oysters (*Crassostrea gigas*), a larger and hardier species, were introduced from Japan beginning in the 1920s in Washington and in 1934 in Oregon estuaries.

Pacific oysters have dominated oyster culture for the past 80 years, although improvements in water quality in some growing areas have allowed native oysters to rebound.

Some Pacific oysters are bred to be sterile so that they do not spawn. These oysters are referred to as "triploids," because they are bred to have an extra set of chromosomes. Triploid oysters retain good meat quality year-round as a result. They are commonly cultured along with non-sterile "diploid" oysters, which are capable of reproducing.

The Kumamoto oyster (*C. sikamea*), the Belon or European flat oyster (*O. edulis*), the American or Eastern oyster (*C. virginica*), and Manila clams (*Tapes philippinarum*) are established species that are non-native. Mediterranean mussels (*Mytilus galloprovincialis*) are also farmed, and there is debate as to whether they are introduced or indigenous to Puget Sound, Washington.

Production Facts

Production statistics for bivalve aquaculture in Washington and Oregon are not well documented, and the system does not currently provide an accurate measurement of shellfish production. For example, USDA's National Agricultural Statistics Service lists the weights and values of clam and oyster landings (the term for the amount of catch brought to land), as compiled by the National Marine Fisheries Service (NMFS) Fisheries Statistics Division (part of the U.S. Department of Commerce's National Oceanic and Atmospheric Administration [NOAA]), but it notes that these data exclude "production of artificially cultivated shellfish." Improvements are needed to increase the accuracy of the harvest production data.

According to the most recent data available, as compiled by the Pacific Coast Shellfish Growers Association (PCSGA), the West Coast states (Alaska, California, Oregon, and Washington) produced a total of approximately 87.8 million pounds of shellfish (all species, live weight/in the shell), at an estimated farm-gate/wholesale value of $117.4 million (see Table 1, below).

Among the West Coast states, Washington produced roughly 85% (weight and value) of all shellfish, at approximately 74.9 million pounds, with a value of more than $100.5 million.

Oregon produced nearly 2.4 million pounds (oysters only) at a value of more than $2.2 million. No clam or mussel landings were counted in Oregon, because these fisheries are entirely recreational in Oregon's much smaller estuaries.

Oyster production in Oregon has always been much lower than that in Washington and has suffered many ups and downs due to water quality issues and growers' inability to control major pests such as burrowing shrimp in Tillamook Bay (where use of chemicals was banned in the mid 1980s).

Table 1. Weight (live/in shell) and value of bivalve commodities produced in the western states, 2008 and 2009*

		Oysters	Clams	Mussels	Geoduck	**Total**
Washington	lbs	61,000,000	9,520,000	2,750,000	1,650,000	74,920,000
	$$	$57,750,000	$19,550,000	$3,162,500	$20,100,000	$100,562,500
California	lbs	9,270,995	741,463	315,000	N/A	10,327,458
	$$	$12,361,326	$830,000	$945,000		$14,136,326
Oregon	lbs	2,379,988	N/A	N/A	N/A	2,379,988
	$$	$ 2,253,135				$2,253,135
Alaska	lbs	206,709	7,839	1,988	N/A	216,536
	$$	$441,781	$24,841	$6,610		$473,232
Total	lbs	72,857,692	10,269,302	3,066,988	1,650,000	87,843,982
	$$	$72,806,242	$20,404,841	$4,114,110	$20,100,000	$117,425,193

*Alaska and Oregon data are from 2009, as are the data for geoducks in Washington. All other data are from 2008.

Data compiled by Pacific Coast Shellfish Growers Association.

Shellfish farms in Washington and Oregon vary in size from just a few acres to several hundred, and the majority of farms are family owned and operated.

Production Regions

Major production regions in Washington are Willapa Bay (oysters and Manila and littleneck clams); Grays Harbor (oysters); and North Puget Sound, South Puget Sound, and Hood Canal (all producing all species of shellfish farmed on the West Coast including oysters, mussels, and Manila, littleneck, and geoduck clams). These five production regions show differences in landscape, weather patterns, and water quality, all of which result in different pest problems, cultivation techniques, and market strategies.

The bulk of the oyster production for the shucked meat market in Washington comes from Willapa Bay, while single oyster production (single oysters sold live in the shell) comes largely from the Puget Sound region. 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 southern Puget Sound inlets and Penn Cove in northern Puget Sound.

In Oregon, major oyster production regions are Tillamook and Netarts (northern Oregon coast) and Yaquina, Winchester, and Coos Bay (central/southern Oregon coast). Because of similarities in growing conditions and crops grown, references to "Oregon" throughout the document include all of the above-mentioned regions unless otherwise noted.

Washington and Oregon: Major Bivalve Production Regions

Bivalve Seeding, Growing, and Harvesting

Bivalves feed by filtering phytoplankton and detritus that occur naturally in the water, thus they grow best in areas having nutrient-rich waters and acceptable ranges of temperature and salinity.

I. Seeding and Cultivation Tactics

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 the "wild" (i.e., when shellfish spawn in the growing areas), it is referred to as "natural set." Some production areas rely heavily on natural set of oysters, clams, or mussels, while others rely entirely on hatchery-supplied larvae or seed. Willapa Bay and Hood Canal are locations where there are frequently natural sets of Pacific oysters and Manila clams, although growers in some areas have reported a significant decline in natural set of oysters over the past five years.

There are six commercial hatcheries that supply larvae and seed to growers in the western states, one of which is in Alaska and serves only Alaska growers. Two of the hatcheries belong to the two largest producers, who generate larvae for their own farms as well as for others to purchase. These companies also have nursery and hatchery operations in Kona, Hawaii, and one has nurseries in South Puget Sound, Washington, and Humboldt Bay, California. Other than experiencing some natural recruitment of Pacific and Olympia oysters and native blue mussels, shellfish farmers are largely dependent on hatcheries for their seed source.

Oyster Seeding and Cultivation

For shucked oyster meat production, hatchery oyster larvae are set on old (i.e., recycled "mother") oyster shells (known as "cultch") 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 are introduced to the water, where they attach to the shells. The small developing oysters are called "spat," which growers may also refer to as "seed," just as terrestrial farmers refer to their planted crops.

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 on beds 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 1 to 5 years in a row, natural sets have declined to levels well below what could be considered viable for commercial production. The reasons for these interruptions are not entirely understood but include factors such as low water temperatures, enhanced estuary flushing, increased levels of carbon dioxide causing low pH (highly acidic) water, low levels of dissolved oxygen, changes in phytoplankton composition and abundance, and bacterial pathogens such as *Vibrio tubiashii*. Natural sets have failed to meet commercially viable levels for the last 5 years in Willapa Bay, and similarly, some growers have reported failed oyster sets in Hood Canal. As a result, growers who traditionally relied on natural sets have been forced to purchase seed from hatcheries or to initiate their own small-scale hatcheries. However, two of the three largest hatcheries have also suffered reduced production, which appears to be associated with the water quality problems listed above. This in turn has led to corresponding decreases in harvest rates over the last few years.

For the production of seed to culture single oysters, hatchery 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 (systems that force-feed nutrient-rich water to the infant oysters) are the most common nursery systems. Some growers plant single oyster seed at high densities at higher tidal elevations to harden shells prior to transplanting to lower elevations, where predators (such as crabs) are common and may negatively impact the survival of a softer-shelled oyster.

Several methods of cultivation are commonly used. Methods chosen are determined largely by the growing conditions of the tidelands available, economic situation, labor availability, market type and size, and experience of the company or individual grower. Both single oysters and clustered oysters (oysters grown in clusters for the shucked meat market) are typically cultivated directly on the beach substrate. Alternatively, on softer beaches, the mother shells (with spat attached) are entwined in ropes that are suspended horizontally between short pipes (a system known as "long-line" production). Single oysters are generally raised in nurseries and then set directly on the beach or secured in bags or placed on trays or in cages.

Growers sometimes leave oysters on grow-out beds for 1 or 2 years and then move the seed to “fattening beds” (areas where there are more naturally occurring nutrients in the water) to improve meat yield prior to harvest. Depending on the market they are destined for, the nutrient levels, and the water temperature, oysters can reach market size in 1 to 6 years.

Clam Seeding and Cultivation

Clams are planted and cultivated on intertidal beaches. At planting, tiny hatchery-raised clams are scattered by hand on the beds. Gravel and/or shell is sometimes added to beds to improve the substrate and reduce predation. While some cultivated beds rely on natural settlement, enhancement with hatchery seed is most common.

Predator nets are often used over seeded beds to increase survival. A relatively new clam culture method involves seeding of clams in rows covered by netting, with spacing between rows. This row culture is well suited to mechanical harvest, also a relatively new method that utilizes a small, specially-equipped tractor that increases harvest efficiency. Other methods include growing clams in mesh bags that are placed on or partly buried in the ground.

Geoduck Seeding and Cultivation

*G*eoduck clam seed are supplied by hatcheries and may be further grown out in nurseries before being planted by hand individually onto the beach. Hollow, open-ended tubes of PVC pipe (the same grade used in municipal water systems), plastic mesh tubes, raised netting, or rigid mesh tunnels are all methods currently being employed by geoduck growers to protect seed from predators. Growers are also in the early phases of experimenting with biodegradable tubes. Where PVC pipe or mesh tubes are used, netting is placed either over each individual tube or over groups of tubes to further protect small geoducks from predation. Netting and tubes are removed after 1 to 2 years as the developing geoducks burrow deeper into the substrate.

Geoduck clams attain harvestable size (1 to 2 pounds) after 5 to 8 years, depending on location. Geoducks are grown at lower intertidal or even subtidal elevations. When ready to be harvested, the geoduck clam can reside as much as a meter deep in the sand, with its long siphon extended to the surface.

Mussel Seeding and Cultivation

Hatchery-produced Mediterranean mussel (*M. galloprovincialis*) seed are grown initially in shore-based upweller systems and later on frames of window screen or ropes for 6 to 12 weeks. 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 of the inlets in Puget Sound. Attempts to grow mussels on intertidal long-lines have not been particularly successful. In certain locations (e.g., Penn Cove in North Puget Sound), the native blue mussel (*M. trossulus*) is cultured from natural set.

II. Growing and Harvesting

Oysters: Growing and Harvesting

Fattening beds are sometimes harrowed in the spring for many reasons: to lift partially sunken oysters from the sediment, to break large clusters into smaller ones allowing for improved shell shaping, to improve feeding ability, and to allow for production of more "single" oysters. Each grower cycles their crop to meet a relatively specific range of market needs in terms of oyster shell and meat size. Some growers focus on the small- to medium-size oyster market, while others rely on the medium- to large-size market. Because feed conditions can change significantly from month to month, oysters can grow through these market sizes over a short time span in some cases and become too large for market.

Bottom-cultured oysters are often hand-picked at low tide and collected into large cages or bins that are then lifted onto barges at high tide. Mechanical harvesters may also be used: a rake or basket skims across the bed surface during high tide (or for subtidal culture) to harvest bottom-cultured oysters.

Long-line oysters are harvested by hand at low tide after the lines are cut or via barges or 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 their improved yield and meat quality over diploid oysters. Harvest of diploid oysters is lower during spawning season, when meat quality is somewhat reduced due to water temperatures and timing of natural spawning.

Manila Clams: Growing and Harvesting

Manila clams grow to harvestable size (12 to 30 clams per pound) in 2 to 7 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. Clams grown in bags are harvested intact and sorted for size and quality in-house.

Geoduck Clams: Growing and Harvesting

Like other bivalves, geoducks are harvested year round. These clams burrow deep in the sand after their first year and continue growing for a period of 4 to 6 more years. Intertidal plantings are harvested by use of a high-volume, low-pressure hose that pumps seawater into the sediment beside each individual geoduck, which loosens the sand and allows each geoduck to be extracted with a minimum of trauma and damage. Geoducks cultured intertidally are harvested during low tides or by scuba or surface air-supplied divers at high tide. Subtidal geoducks must be harvested by divers.

Mussels: Growing and Harvesting

Mussels are also harvested year round after 1 to 2 years of growth, using barges equipped with hydraulic platforms or booms. The mussels are stripped from the grow-out ropes, de-clumped, washed, and sorted by size before packing for shipping.

III. Marketing

Bivalves are marketed fresh, processed, smoked, or frozen, but are most often sold fresh, both live in the shell and shucked. If the oyster is sold in the shell, the most valuable form is a single oyster for the raw bar (half-shell) market.

Oyster clusters are typically shucked, with the meats graded for size and packed in containers of various volumes. Shell size, shape and appearance, and 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 distributors. Some growers sell to other producers or retailers who then resell the product. Growers may also sell directly to restaurants or to the public through retail outlets, farmers' markets, and the Internet.

Integrated Pest Management (IPM) Goals in Washington and Oregon Bivalve Production

The development of effective and sustainable tactics to manage bivalve pests is as varied as the cultured species, methods of culture, and location. Many tactics that are now standard in terrestrial agriculture, such as use of selective pesticides based on pest-specific growth regulators, mating pheromones, or biorational compounds, are not applicable in the estuary. The ecology of marine pests is less understood than terrestrial pests. Further, commercial shellfish beds are accessible only at low tidal intervals that last 3 to 6 hours and occur for only 5 to 7 days out of every 14. These low tides occur in daylight only 6 months of the year (roughly April to September). Most pest management in bivalve culture relies on cultural practices, including mechanical controls.

Despite these challenges, West Coast shellfish industry representatives, including the Pacific Shellfish Institute, Pacific Coast Shellfish Growers Association, Willapa-Grays Harbor Oyster Growers Association (WGHOGA), and the National Shellfisheries Association/Pacific Coast Section, in collaboration with other primary stakeholders, have included a stated goal of developing an all-encompassing IPM plan for West Coast bivalve production in their "2015 Research and Education Goals and Priorities" Goals Initiative document.

An initial IPM plan has been developed by WGHOGA for burrowing shrimp in Willapa Bay and Grays Harbor. This model IPM plan could be expanded to form the basis of an IPM plan for all pests in bivalve aquaculture in Washington and Oregon. The plan conforms in format, components, and perspective to most IPM plans that are standard in terrestrial agriculture.

The IPM plan for burrowing shrimp also ascribes to the relatively standard paradigm in IPM that views agriculture as interacting with both socioeconomic forces and ecological resources. In this paradigm, the level of IPM development depends on both socioeconomic and ecological scales. As scales increase, the level of IPM development becomes more complex but can also become more integrated. This paradigm contrasts somewhat with other views of IPM that describe a simpler approach to program development, and result in "biorational" or "reduced-risk" pest management programs.

Bivalve Production and Federal Regulatory Issues

The U.S. Environmental Protection Agency (EPA) recently completed the Food Quality Protection Act (FQPA) initial review of the dietary, ecological, residential, and occupational risks posed by registered pesticides. FQPA mandated a new registration review program with a regular review cycle, which was subsequently initiated by EPA in 2006. Its purpose is to allow the agency to modify risk assessments as new scientific data appear and as policies and pesticide use practices change over time. As an outcome of review, EPA may propose to modify or cancel some or all uses of certain chemicals in bivalve production systems. Additionally, the extra regulatory studies that EPA requires pesticide registrants to complete in the course of review may result in some pesticide companies voluntarily canceling certain registrations rather than incurring the additional costs of the required studies. These registration-related activities, along with those stemming from the Endangered Species Act and the Clean Water Act (CWA), as explained below, create uncertainty about the future availability of pest control tools in bivalve production.

The Endangered Species Act (ESA) obligates federal agencies such as EPA to consult with the U.S. Fish and Wildlife Service (USFWS) and the National Oceanic and Atmospheric Administration’s National Marine Fisheries Service (NOAA-NMFS) if the agency plans to take an action that may affect threatened or endangered (T/E) species. An example of “an action” would be registration or reregistration of a pesticide that has the potential to harm a T/E species. Formal consultation with NOAA-NMFS would result in a determination by all agencies of whether the pesticide active ingredient under review would or would not harm a T/E species when used according to the current label directions. (See http://agr.wa.gov/PestFert/EnvResources/EndangSpecies.htm for background information on the lawsuit.)

Seagrasses are viewed as valuable habitat worldwide due to their role as ecosystem engineers, and they receive “no net loss” protection status (under a wetlands policy first adopted in 1989 under George H.W. Bush) at the federal and state level. In 2007, the U.S. Army Corps of Engineers issued Nationwide Permit 48 for existing shellfish aquaculture, which has involved consultations and biological opinions from NMFS and the USFWS due to their responsibility for provisions under ESA and the Essential Fish Habitat (EFH) portions of the Magnuson-Stevens Act. Biological Opinions (BO) from both NMFS and USFWS have already been issued for Washington. The Oregon Consultation process is in process as of this writing, and the California Consultation is expected to be under way in 2010. The status of, and legal management options for, non-native Japanese eelgrass and implementation of the permit regulations regarding disturbance to native eelgrass during shellfish harvest activities, especially for state leases and new or expanded shellfish operations, are still being reviewed.

In 2009, NOAA-NMFS submitted a Biological Opinion to EPA that contained some Reasonable and Prudent Alternatives (RPA) that could affect the shrimp management program in Willapa Bay and Grays Harbor, Washington. EPA has questioned some of the RPAs in a commentary, but it has yet to implement them. The total effect of ESA implementation is yet to be determined; however, it may significantly impact pest management strategies in the bivalve industry.

The U.S. Court of Appeals for the Sixth Circuit ruled in 2009 that, under the Clean Water Act, national pollutant discharge elimination system (NPDES) permits are required for all pesticide applications that leave a residue in water when such applications are made in waters of the United States. Because it is scientifically impossible at this time to prove that zero residues remain after a pesticide application, this legal interpretation means that every application of pesticides to water will require this permit. The carbaryl-based management program for burrowing shrimp control in Willapa Bay and Grays Harbor, Washington, is already allowed under NPDES permit No. WA0040975. The Washington State Department of Ecology is currently rewriting its rules related to issuance of NPDES permits. The total effect of this action is yet to be determined but may significantly impact availability of pest management tools within the bivalve industry.

Water Quality and Bivalve Production

Shellfish farming offers several environmental and water quality benefits. Shellfish not only filter water as they feed, removing nitrogen and phosphorous, but also the nutrients that are not digested and incorporated into the tissue of the shellfish are processed and excreted in a form that is readily used by plants for growth. Additionally, shellfish, like other carbon fixers such as corals, help sequester ("fix") carbon dioxide, a "greenhouse" gas, by incorporating carbon into their shells. Finally, shellfish, as well as aquaculture gear used in their culture, can enhance habitat diversity, thereby benefiting a variety of organisms.

Shellfish farming can only take place in waters that have been certified under the National Shellfish Sanitation Program (NSSP), a stringent set of standards operated under the U.S. Food and Drug Administration. These standards include monitoring for fecal coliform bacteria (which is used as an indicator for human activity and the potential for pathogens in the water), *Vibrio* (marine bacteria), harmful algal toxins, heavy metals, and other contaminants. The NSSP standards classify growing areas as Approved, Conditionally Approved, Restricted, or Prohibited, based on water quality and shoreline sanitary surveys. These standards led to the first estuarine/marine monitoring programs, and are the most stringent of all water quality classifications, far exceeding those required for swimming.

Regular monitoring is required to maintain certification of shellfish beds, and harvest activities are restricted or curtailed—and in some cases products can be recalled—if threshold levels are exceeded. These bans remain in effect until the problem is corrected and water quality monitoring indicates the area once again meets standards.

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.

During the summer months when temperatures are warmer, growers are required to follow stringent time-to-temperature controls after harvest and up to shipment, or until the product is out of their direct control. These requirements are intended to reduce the risk to human health associated with contamination by *Vibrio parahaemolyticus*, a naturally occurring marine bacterium that can cause gastrointestinal illnesses when water or air temperatures rise above 60°F (15°C).

Bivalve Production from the Tribal Perspective

The indigenous peoples of the Pacific Northwest have been harvesting shellfish since long before contact with European explorers. Clams, oysters, mussels, and geoducks were all harvested for subsistence and/or trade with other native peoples. Modern descendants of these pre-European-contact shellfish harvesters continue to harvest shellfish for subsistence and ceremonial uses as well as for commercial sale.

Indian tribes in Washington have maintained the legal right to harvest natural shellfish populations throughout their usual and customary fishing areas. These rights were preserved in the Stevens Treaties of the mid-1800s and were later re-affirmed in federal court with the Rafeedie Decision, which defined the treaty right as 50% of the sustainable harvest of shellfish within each tribe's usual and customary fishing area. This court decision established the tribes as co-managers of shellfish resources on state-owned tidelands and clarified that the treaty right extended to wild shellfish from privately-owned tidelands.

Tribal commercial harvests of wild intertidal shellfish are regulated by the tribes themselves with respect to locations and regulations, including harvest limits. Individual tribal shellfish harvesters are usually responsible for locating wholesalers and transportation for their harvested shellfish.

On some of the tidelands that are enhanced with seed from hatcheries, the tribe's role expands to encompass seeding, predator deterrence/removal, and bed maintenance, while the role of the harvester is relatively unchanged. Additionally, there are tribally-owned shellfish companies that operate much like nontribal shellfish companies, engaging in standard aquaculture practices and hiring employees to conduct the harvest activities. In Washington, there is also a tribal shellfish hatchery that produces clam, oyster, and geoduck seed for its own use and for sale to both tribal and nontribal commercial growers.

Many tribes have been seeding natural beds of Manila clams for years in an effort to increase productivity for tribal harvests on reservation lands. Increasingly, tribes have also acquired leases for state-owned and privately-owned tidelands that require a more intensive form of management than traditional harvest of wild stocks.

In 2007, the Puget Sound tribes, commercial shellfish growers, the state of Washington, and the federal government signed the Puget Sound Shellfish

Growers Settlement. This settlement agreement provides the tribes with funds to purchase tidelands and engage in shellfish enhancement activities in lieu of harvesting wild shellfish from shellfish growers' tidelands. As the funding is used, tribes will be better able to invest in exclusively-managed tidelands and standard aquaculture practices designed to increase production from shellfish beds. Some of the potential uses for this settlement money that have been discussed or have been employed are seeding Manila and geoduck clams, employing staff to maintain shellfish beds, and purchasing existing shellfish companies. While wild harvest of shellfish has been a constant for generations of indigenous peoples, harvest from more intensely managed beds is expected to increase as tribal populations grow and funding becomes available.

Bivalve Culture Activities

Hatchery

Broodstock selection; pathology testing; water pumping, filtering, and heating; conditioning; spawning; microalgae culture; setting; primary nursery; cultural controls for disease prevention and reduction

Nursery

<u>Shore based:</u> rearing in upwellers, downwellers, on substrates, or in raceways; sorting; microalgae culture or screened bay water; screen and bin cleaning; harvesting; shipping

<u>Floating:</u> rearing in upwellers, suspended systems, sorting, fresh water washing, fresh water dipping, bin and screen cleaning, harvesting, shipping

Oysters

<u>Seed setting:</u>

<u>Wild caught set:</u> shell cleaning, shell packing, shell placement, bottom harrowing, shell or shell bag collecting, transplanting to seed beds

<u>Remote setting:</u> tank preparation, water heating, microalgae culture, shell preparation, shell placement in tanks, larvae introduction, aeration, shell bag (or tubes) removal, transport to seed beds

<u>Bottom culture:</u>

<u>Shucked product:</u> scattering shell from seed bags or seed bed on bottom; seed bed rearing; hand picking or dredging from seed beds; transferring to fattening beds; harrowing; pest removal or control; harvesting by hand, dredging, or both

Single oyster product: receiving seed from nursery, planting seed, maintaining density by hand or dredge, hand harvesting, pest removal or control

Long-line culture: controlling pests, setting posts, preparing shell lines, setting larvae, nursery seeding on bottom, hanging long-lines, harvesting in tubs or by boat roller, hand picking bottom drop-off

Bag/cage culture: filling bags with single seed, hanging bags or cages on bottom lines or long-line posts, maintaining lines, harvesting, controlling pests (bottom and bags) and fouling

Manila clams

Extensive: preparing beds for seeding, assessing wild set, spreading seed clams, laying predator nets, replacing fouled nets, net cleaning, controlling pests, harvesting by hand or mechanical digging

Intensive: preparing beds by rototilling, laying nets, seeding through nets, maintaining nets, controlling pests, sweeping algae, pulling nets, harvesting by hand or mechanical digging

Littleneck clams

Wild setting, maintaining beds, controlling pests, harvesting by hand digging

Geoducks

Seeding small geoducks directly onto beach or into sand nurseries, installing predator protection (tubes, etc.), harvesting nursery geoducks, planting on grow-out beds, installing nets, maintaining gear, removing protection, controlling pests, harvesting by water pump at low tide or by divers at high tide

Mussels

Hanging seed in nursery, dipping in freshwater, harvesting seed from nursery, hanging on grow-out lines, hanging and maintaining predator nets, changing nets to control fouling, harvesting mechanically, transporting to plant for declumping and washing or declumping at the harvest site

Bivalve Major and Sporadic Pest List

I. Major Pests

Invertebrate Pests:
Bamboo worm
Barnacle
Burrowing shrimp
Cockles
Crabs
Flatworms
Horse clams
Moon snail
Oyster drills
Sand dollars
Starfish

Weeds:
Algae
Grasses
Japanese eelgrass
Native eelgrass

Vertebrate Pests:
Perch
Seagulls, crows and ravens, and waterfowl

II. Diseases

Bonamiasis
Denman Island disease
MSX
Oyster velar virus disease (OVVD)
Vibriosis

III. Sporadic and Minor Pests

Invertebrate Pests:
Mussels (*musculista* and native blue)
Polydora
Slipper Shells (*Crepidula*)
Tunicates
Other Parasites

Vertebrate Pests:
Flatfish and sculpins
Raccoon
River otter

Bivalve Pests and Management Options

I. Major Pests

(Note: Individual pests are presented in alphabetical order, not in order of importance.)

a. Invertebrate Pests

Bamboo worm (*Clymenella torquata*)
Other polychaete pests (lugworm, etc.)

The bamboo worm is an invasive, tube-dwelling polychaete (Capitellida: Maldanidae) native to the Northwest Atlantic. It is currently restricted to a few farms in Samish and Similk Bays, Washington (North Puget Sound region), where it severely impacts oyster culture by softening the ground, causing oysters to sink and suffocate. Polychaetes (a class of segmented worms) also affect cultured Manila clams in other estuaries like Willapa Bay and Tillamook Bay, where they create large burrow/mound colonies that act to soften substrate.

Chemical Control:

- No chemicals are currently registered.

Biological Control:

- No potential biological controls have been identified.

Cultural Control:

- Some control has been achieved by draining infested areas thoroughly at low tide and rototilling. But the efficacy is only minor on small patches, and it is only a fallow or preplant control.

Critical Needs for Bamboo Worm and Other Polychaete Pest Management in Bivalves:

Research:

- Establish efficacy of imidacloprid for control of bamboo worm and other polychaete pests.

- Identify effective methods of bamboo worm control (chemical, cultural, and/or biological).
- Complete a species-mapping project to identify which species of worms are causing damage in which regions.
- Research life cycle and biology of worm species.

Regulatory:

- Investigate the possibility of obtaining an aquatic use of imidacloprid.

Education:

- Educate growers on results of species mapping project, once completed, to aid in species identification in different regions.

Barnacle (*Balanus* spp., *Chthamalus* spp.)
And other fouling species

Barnacles are crustaceans that form a hard, conical, calcareous (composed of calcium carbonate) shell on hard substrates. They adhere very strongly to surfaces and often form extensive, dense colonies. The larvae generally settle in the spring through summer in most bivalve culture areas. They are ubiquitous throughout the culture areas but settle in greater numbers in some areas. Barnacles are a problem in most growing regions and have been a serious problem in Oregon.

Barnacles are fouling organisms of oysters, mussels, and aquaculture gear and equipment. When barnacles settle on single oysters they can degrade the product from a premium grade to a lower grade single or shucked oyster. Oyster bags must be cleaned periodically to remove barnacles. In mussel culture they can add considerably to the cost of processing the product and make the shells unsightly. Geoduck aquaculture gear (tubes) is heavily impacted by barnacles, causing higher labor costs in handling and cleaning.

Barnacles settle on and in hatchery intake pipes. They also colonize the bottoms of boats and scows, increasing fuel consumption, causing engine wear, and requiring the expense of cleaning and of painting protective barriers at regular intervals.

Chemical Control:
- Bottom paints of boats and scows can inhibit settlement of barnacles for a period of time. (Various copper, zinc, and tributyltin coat products are registered for barnacle control.)

Biological Control:
- No biological controls are used.

Cultural Control:
- Timing (of seeding, thinning, gear placement and cleaning, and harvest) is an important control in fast-growing crops like single oysters and mussels.
- Hatchery intakes are doubled to allow one to remain inactive to kill barnacles and other fouling organisms. Screens are changed regularly.
- Boats, scows, and gear are cleaned by hand or machine.
- Areas of heavy barnacle settlement are avoided when possible.

Critical Needs for Barnacle Management in Bivalves:

Research:
- Identify effective controls for barnacle growth on both bivalve gear (boat bottoms and other production equipment) and the crop itself.
- Research the use of sound waves and electrical current for control.

Regulatory:
- Preserve uses of currently registered bottom paints to protect against barnacles and other fouling organisms.

Education:
- None at this time.

<u>Burrowing shrimp</u>
Ghost shrimp (*Neotrypaea californiensis*)
Mud shrimp (*Upogebia pugettensis*)
Giant sand shrimp (*Neotrypaea gigas*)

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 they are highly mobile both within and between estuaries.

Although these organisms compete with other estuarine fauna for food (e.g., plankton), their main effect on bivalves is indirect. They reside beneath the substrate surface, where they displace, mix, and re-suspend 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 sediment layer. Tide flat bottom dwellers, like bivalves, literally sink in the resulting sediment and suffocate.

Both large oysters and smaller oyster-seeded shells will sink and die within a year at shrimp burrow densities of 10 or more per square meter. At densities of 30 or more shrimp burrows per square meter, oyster death can occur 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 also churn up newly graveled clam ground, making it too soft to protect clams from predators and sinking the predator nets. This can result in reduced yield and increased harvest expenses.

Geoducks grown in shrimp-infested areas are known to be smaller, and the tubes are prone to sinking, causing retrieval and growth impacts.

Burrowing shrimp affect all crops except geoducks grown at deep intertidal or subtidal levels. They are a considerable problem for almost all regions in Oregon and Washington, with ghost shrimp being 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. They are particularly a problem for geoduck production in the South Puget Sound region in mid- to upper-tidal areas. Due to lack of an effective control, beds on the Skokomish flats in the Hood Canal are so infested that their use for clam and oyster culture has been abandoned.

Mud shrimp have declined in numbers in the past decade, likely due to attack by the non-native parasitic bopyrid isopod, *Orthione griffenis*, a crustacean. Now only isolated bivalve growing areas have mud shrimp populations. Areas that still support high densities of mud shrimp, however, are problematic.

The distribution of the giant sand shrimp is not well known across production regions.

All three species of burrowing shrimp have the same economic effect for growers, and control mechanisms are sought for the broad category of burrowing shrimp.

Chemical Control:

- Carbaryl (Sevin 4F) is the only material registered for use against burrowing shrimp, and **can only be used in Willapa Bay and Grays Harbor, Washington. It is not registered for use in any other region**. It is applied in Willapa Bay and Grays Harbor on beds with shrimp densities greater than a threshold of 10 burrows per square meter. Carbaryl is applied according to several Best Management Practices that are legally formalized on the Section 24(c) pesticide label (WA-900013 and WA-100001) and in accordance with the National Pollutant Discharge Elimination System (NPDES) permit program, under the jurisdiction of the Washington State Department of Ecology. Growers in Willapa Bay and Grays Harbor consider carbaryl to be their only current viable management tool for burrowing shrimp control on a commercial scale.

  A treated bed usually remains farmable for several years after a single application of carbaryl. However, growers in Willapa Bay and Grays Harbor monitor burrowing shrimp closely, because once chemical applications are made, they can't harvest for another year per EPA label restrictions. If temperatures are warm, oysters may grow too large in a year's time for the target market size. If the grower decides to skip the treatment and immediately harvest the crop instead, he or she risks losing the bed for replanting until the infestation can be controlled.

Biological Control:

- Burrowing shrimp are an indigenous species with a wide distribution along the West Coast. They have an ecological role in these estuaries, and therefore the goal of pest management is to control populations in the shellfish culture areas only, not necessarily influencing their wider distribution. The introduction of a foreign biological control agent is therefore not being considered. However, a parasitic isopod, *Orthione griffenis,* was likely (inadvertently) introduced to West Coast estuaries via ballast water in the early 1980s and appears responsible for a recent precipitous decline in mud shrimp populations. These isopods typically infest less than 5% of the shrimp in their native waters, but *O. griffenis* currently parasitizes up to 80% of the mud shrimp in Pacific Northwest estuaries, which could alter the distribution of this shrimp. Attempts to enhance the abundance of native burrowing shrimp predators and parasites have been unsuccessful to date, and concerns remain about restricting their impact to the shellfish beds.

Cultural Control:

- Alternative cultivation techniques (long-line, bags, raft) to suspend bivalves are sometimes used to reduce mortality caused by soft sediments for some bottom-cultured bivalves. However, oysters that fall from the line on severely infested beds will still sink, as can the lines and stakes themselves. When mussels are grown using intertidal long-line cultivation, they too are susceptible to sinking in infested beds. Thus, long-line techniques are not considered by growers to be a viable replacement for bottom culture in affected areas, but they are a viable culture practice when used for reasons not necessarily related to pest management.
- Many growers have also found stake culture to be an ineffective management tactic for controlling 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, or the harvest cycle is shortened, which may slightly suppress burrowing shrimp, but the economic impact has not been measured.

Critical Needs for Burrowing Shrimp Management in Bivalves:

Research:

- Complete an economic assessment of effective cultivation and production techniques to control burrowing shrimp.
- Research efficacy of alternative controls (chemical, cultural, and biological) for burrowing shrimp in all crops and regions where applicable.
- Investigate nontarget impacts of available and potential controls for burrowing shrimp.
- Research the life cycle and biology of burrowing shrimp.
- Develop improved monitoring techniques for burrowing shrimp.

- Develop improved economic thresholds to aid in initiating treatment for burrowing shrimp.

Regulatory:

- Establish single source regulatory oversight under the Washington State Department of Agriculture to facilitate an efficient permitting structure for shellfish aquaculture, and address issues related to burrowing shrimp.
- Expedite registration of imidacloprid to control burrowing shrimp.
- Seek registration for other potential chemical controls (once they are proven effective) for controlling burrowing shrimp.
- Retain current permits and registrations for carbaryl for burrowing shrimp control.

Education:

- Educate growers, regulatory agencies, and the general public on current and past research projects related to burrowing shrimp control.
- Host field days and workshops on burrowing shrimp identification and monitoring techniques.
- Hold demonstration trials for growers, regulatory agencies, and the general public.

Cockles (*Clinocardium nutalli*)

Cockles are bivalve mollusks common on sandy beaches of the region. Cockles often settle in dense numbers in the geoduck protection tubes in Puget Sound. As the cockles grow in the protection of the tubes, they can become dense enough to completely fill the upper sediment within the tube. At lower densities they compete for food with the juvenile geoducks, and at high densities they occupy the entire area, preventing the geoducks below from accessing the surface. When the tubes are removed from the substrate, the cockles attract moon snails into the geoduck bed. Cockles can be a serious pest for geoduck culture throughout growing regions. However, in some regions cockles are also an incidental crop.

Chemical Control:

- None.

Biological Control:

- None.

Cultural Control:

- Cockles are removed by hand from the tubes when they reach high densities, adding substantial labor and cost to the culture operation.

Critical Needs for Cockle Management in Bivalves:

Research:

- Perform an economic assessment of the market potential for cockles.
- Research cockle settlement behavior to determine more effective control techniques.

Regulatory:

- None at this time.

Education:

- Educate growers regarding the economic potential for marketing cockles.

Crabs

Dungeness crab (*Cancer magister*)
Rock crab (*Cancer productus*)
Green crab (*Carcinus maenas*)
Graceful crab (*Cancer gracilis*)

Dungeness and rock crabs are native species and have economic as well as ecological importance in estuaries of the Pacific Northwest. This is especially true of Dungeness crabs, which support a sizeable fishery. Nevertheless, they impact the production of all commercially-grown bivalves in both Oregon and Washington, especially those cultured on the bottom. Young, uncovered clams and cultchless oyster seed are particularly vulnerable, but adult clams are also vulnerable both with and without the use of nets. (Young crabs can settle under nets.) Dungeness crabs burrow into beds and eat seed.

While not commercially valuable, the Graceful crab also preys on clams, oysters, and mussels of all sizes.

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. Given the current low populations in Washington and Oregon estuaries, green crabs pose few problems for growers in Washington and Oregon at this time.

While green crabs in Oregon and Washington are rare, they are thriving in some inlets on the west coast of Vancouver Island, Canada. The highest densities of green crabs occur primarily in microhabitats where larger native crabs are rare or absent, and they are confined to wave-protected shellfish beaches with freshwater outfall. In the absence of competition and predation by these larger native crabs, green crabs appear to flourish. Given future warming events, these small populations could become more dense and numerous, spread to new areas like Puget Sound, and potentially be detrimental to bivalve production.

Chemical Control:
- No chemicals are currently registered.

Biological Control:
- No potential biological controls have been identified.

Cultural Control:
- Bags, nets, and tubes are the primary cultural controls used by growers.
- Hand removal and relocation of crabs.
- Upland storage of cultch.
- Rock and Dungeness crabs can help control green crab populations.

Critical Needs for Crab Management in Bivalves:

Research:
- None at this time.

Regulatory:
- Resume green crab monitoring and trapping programs (WDFW).
- Encourage regional regulatory agencies (California, Oregon, Washington, and Vancouver Island, Canada) to collaborate on green crab monitoring.
- Investigate laws concerning states or countries harboring invasive pests that are known to be source populations infesting neighboring states or countries.

Education:
- Continue educational efforts on crab species identification.
- Improved monitoring for crab species.

Flatworms (*Psuedostylochus ostreophagus* and others)

The flatworm pests in bivalve culture are of the polyclad order. They are small (under 3 centimeters for *Psuedostylochus* on oyster seed, and larger for some of the flatworms in mussel and floating nurseries), much longer than they are wide, and very flat.

Psuedostylochus was introduced from Japan and prefers moist, protected conditions in the intertidal area, such as the underside of oyster cultch. They are common in muddy areas of many oyster-growing bays. Floating subtidal nurseries provide protected enclosures, which are a good environment for flatworms. Mussel seed nurseries are particularly impacted.

The flatworms are carnivorous and eat small oyster, clam, and mussel seed. They are able to colonize a substrate and grow rapidly. Flatworms will cause significant losses of seed in some areas if they are left uncontrolled. In the nurseries, flatworms are controlled by washing or dipping the seed in fresh water, which kills the flatworms. In beach oyster culture the cultch is stacked at a higher tide height and location to minimize losses. This pest can be found in most regions, but it can be a particular problem in North and South Puget Sound and Hood Canal.

Chemical Control:

- No chemicals are currently used to control flatworms.

Biological Control:

- None.

Cultural Control:

- Fresh water dips or washes are used in the nursery to kill flatworms.
- Relocate seed to higher beach levels for drying.
- Avoidance of heavily infested areas.

Critical Needs for Flatworm Management in Bivalves:

Research:

- Survey growers in all regions on the presence of flatworms.
- Identify effective alternative controls for flatworms.

Regulatory:

- None at this time.

Education:

- Educate growers on proper pest identification and monitoring for flatworms.

<u>Horse Clam</u> (*Tresus capax*)

Horse clams are large clams, similar to the geoduck, with a long siphon that cannot be retracted fully into the shell. Their habitat overlaps with the geoduck habitat.

Horse clams settle in the geoduck protection tubes, where their survival is much more likely than outside the protection. Horse clams compete for space and food with the geoducks. They also increase the density of clams within the tubes and slow the growth of the geoducks. After the tubes are removed, the horse clams continue to compete for food and reduce the growth capacity of the bed for geoducks.

Like cockles, horse clams are also an incidental crop in some areas, and a small market exists for tribal harvest of horse clams.

Chemical Control:

- None.

Biological Control:

- None.

Cultural Control:

- Although horse clams are removed during geoduck harvest, this is not an effective method for preventing crop damage.

Critical Needs for Horse Clam Management in Bivalves:

Research:

- Perform an economic assessment of the market potential for horse clams.
- Research horse clam settlement behavior to determine more effective control techniques.

Regulatory:

- None at this time.

Education:

- Educate growers regarding the economic potential for marketing horse clams.

<u>Moon snail</u> (*Polinices lewisii*)

Moon snails are large, predatory gastropods that drill holes through the shells of bivalves. Their presence is often indicated by their characteristic egg case, which holds hundreds of fertilized eggs. Snails hatch and are dispersed when the case bursts and sinks to the bottom. *P. lewisii*, named for Meriwether Lewis, is indigenous to the West Coast. Moon snails impact cultured oysters and Manila and geoduck clams. They are a problem in Hood Canal and Puget Sound, and they are present in Willapa Bay. Snails are managed mainly by hand removal**.**

Chemical Control:

- No chemicals are currently registered for use.

Biological Control:

- No potential biological controls have been identified.

Cultural Controls

- Bags, nets, and tubes are somewhat effective in excluding snails.
- Hand removal (of both snails and egg cases).

Critical Needs for Moon Snail Management in Bivalves:

Research:

- Research life cycle and biology of moon snails, including behavioral tendencies (e.g., day versus night activity, and traveling behavior).
- Research the potential for pheromone trapping of moon snails.
- Investigate the economic potential for sale of moon snail meat.
- Determine efficacious methods for locating moon snails on beds.

Regulatory:

- Investigate potential to market moon snails.

Education:

- Educate growers on proper identification of moon snail infestation (includes both proper pest identification and how to locate snails on beds).
- Educate growers on the regulations related to control of this native pest.

Oyster drills

Japanese oyster drill (*Ocinebrellus inornatus*)
Eastern oyster drill (*Urosalpinx cinerea*)

These non-native snails drill holes in the shells 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.

Oyster drills are a problem pest on oysters in many regions of Oregon and Washington. They can also prey on Manila clams and mussels. Any culture method with bottom contact, such as bottom culture, long-line pipes, nursery grow-out, etc., is vulnerable, because drills can access shellfish either directly on the bottom or by climbing along pipes or stakes.

Oyster drills congregate at localized locations to collectively lay eggs on shells, stakes, or other more stable bottom substrate. They appear to travel significant distances to these egg-laying sites in spring, thus it appears there is some method or sense that allows the drills to congregate. In addition, oyster drills seem to have the ability to sense seed or thinner-shelled shellfish, which are easier to drill.

The transfer of shellstock is formally restricted from infested estuaries to uninfested estuaries. This restriction has eliminated the ability of growers to move seed or shellstock between some estuaries. Extra labor is required to clean trucks and equipment that have handled shellstock from infested areas. Given the wide range of infestation, these restrictions may not be aligned with actually preventing the spread of drills.

Chemical control:

- None.

Biological control:

- None.

Cultural control:

- 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 in the spring.
- Rototilling is sometimes used to control drills.
- Copper fencing can serve as a barrier to exclude drills.
- Seed treatment (fresh water wash) prior to transport can be used to control drills, but it is very labor-intensive.
- Upland storage of cultch.

Critical Needs for Oyster Drill Management in Bivalves:

Research:

- Identify potential attractants (e.g., pheromones) that could be used to develop a control method for oyster drills.
- Identify effective alternative methods of control (in addition to attractants).
- Perform a life cycle review of the oyster drill.

Regulatory:

- Update and enforce regulation regarding transportation of affected bivalve products (e.g., more areas have drills than have restrictions on shipping).

Education:

- Disseminate results of current study researching the potential for identification of chemoattractants and pheromones of oyster drills.
- Educate growers and researchers on most effective control techniques at each point in the oyster drill's life cycle.

<u>Sand dollar</u> (*Dendraster excentricus*)

Sand dollars encroach upon geoduck growing ground (soft sand) such that the ground becomes nearly impenetrable. They are generally found layered within the top 3 to 8 inches of sand, either in a patchy fashion or completely covering in some areas.

Sand dollars can prohibit insertion of geoduck protection devices, such as tubes. In addition, if planted areas become covered with sand dollars, it can be difficult for geoduck siphons to reach the surface of the sand (to feed), and it can also impact geoduck harvest activities.

Chemical Control:

- None.

Biological Control:

- None.

Cultural Control:

- Control efforts have mainly been to relocate sand dollars by hand with rakes, forks and baskets, which is very labor intensive and only about 70 percent effective.
- Use of barriers to exclude sand dollars.

Critical Needs for Sand Dollar Management in Bivalves:

Research:

- Research biology and life cycle of sand dollars.
- Determine potential biological control organisms for sand dollars.

Regulatory:

- None at this time.

Education:

- Educate growers on appropriate methods for transplanting sand dollars away from culture areas.

Starfish (sea stars) (many genera, including *Evasterias, Pycnopodia, Leptasterias, Solaster,* and *Pisaster*)

Starfish are echinoderms (a phylum of marine animals) well known to anyone who walks a beach at low tide. A variety of starfish species is found throughout Washington and Oregon bivalve growing areas. They are a constant pest in many areas, with some years worse than others.

Starfish are predators of clams (including geoduck clams) and oysters. They eat bivalves by wrapping their arms around their prey to pry shells apart, extruding their stomach into the bivalve, and digesting/absorbing the meat. They are more of a problem on deeper intertidal ground, in subtidal shellfish beds, and in higher salinity areas. On higher ground they are exposed to desiccation and predation by birds, limiting their upper range. Occasionally starfish will settle on suspended mussel lines or inside oyster bags, where they grow and cause seed losses.

Starfish are a problem in all bivalve growing regions.

Chemical Control:
- None.

Biological Control:
- None.

Cultural Control:
- Hand picking of starfish from the shellfish ground.
- Use of barriers to exclude starfish.

Critical Needs for Starfish Management in Bivalves:

Research:
- Research life cycle, biology, and travel tendencies of starfish.
- Investigate the potential for use of pheromone or other attractants for starfish control.
- Identify alternative, effective methods of starfish control.

Regulatory:
- None at this time.

Education:
- Educate growers on life cycle, biology, and travel tendencies of starfish.

b. Weeds

Algae *(Ulva* spp.*)*
Filamentous algae (*Ulva flexuosa)*
Sea lettuce (*Ulva lactuca)*
Others

Filamentous algae, previously called *Enteromorpha flexuosa*, have been reclassified as *Ulva flexuosa*. This alga has caused major problems in the Willapa Bay growing region. The sea lettuce *Ulva lactuca* is more of a problem in Puget Sound.

Ulva lactuca is a green alga that forms a thin sheet with blades up to several feet long. *Ulva flexuosa* forms long, threadlike strands that intertwine through tidal action. Both *Ulva* species can form dense mats in the intertidal and shallow subtidal zones during spring and summer. After dense growth the *Ulva* dies, creating a zone of low oxygen in the water (anoxia) during decomposition. The mats of algae often settle over large areas and can cause serious problems for some types of bivalve culture.

Algae can also be a fouling pest on bivalve production gear and equipment such as nets, tubes, long-lines, and boundary markers. *Ulva* growth on protective netting and tubes restricts water flow to the bivalves, can pull nets out of the ground, causes anoxia resulting in clams coming to the surface, and can cause death.

Ulva growth causes losses of oysters and Manila and geoduck clams, particularly juveniles. *Ulva* fouling on oysters increases labor to process the product. Much effort is expended by growers to change and clean protective nets and to clean beds before planting. Algae can also be so thick as to prevent mechanical harvest. Algae are a problem for bivalve growers in all regions of Oregon and Washington.

A number of potentially threatening macroalgae species have been identified and are detailed in Section IV: Potentially Serious Pests to Pacific Northwest Bivalve Production.

Toxic algae blooms can also be a major problem for bivalve production, but because this is not a pest that can be directly managed by growers, it is discussed in the Section V: Other Issues Affecting Bivalve Production.

Chemical Control:

- No chemicals are currently used to control algae.

Biological Control:

- None.

Cultural Control:

- Hand removal of algae.
- Protective nets are swept clean periodically or are removed from the beach for cleaning. Some growers use tractor-mounted sweepers to sweep the *Ulva* from the nets during the growing season.
- Harrowing for other purposes can help thin algae density.

Critical Needs for Algae Management in Bivalves:

Research:

- Identify and evaluate other effective controls for algae management.
- Identify impacts of algae on bivalve larvae and estuarine processes.
- Perform an economic analysis of crop damage impacts for algae and all bivalve weed pests.

Regulatory:

- Explore the possibility of increasing the harvestable limits of algae.

Education:

- Clarify growers' ability to control algae and other shellfish pests (invasives, natives, etc.).
- Increase awareness of pollutive and health effects of algae die-off to humans and other animals.

<u>Grasses</u>

Smooth cordgrass (*Spartina alterniflora*)
Common cordgrass (*Spartina angelica*)
Saltmeadow cordgrass (*Spartina patens*)
Denseflower cordgrass (*Spartina densiflora*)
Common reed (*Phragmites australis*)

Spartina is native to the American Southeast. It is thought to have been accidentally introduced to the Pacific Northwest in the late 1800s and remained at tolerable levels until the early 1990s.

S. alterniflora expanded into hundreds of acres of formerly bare mudflats in all coastal counties of Washington, trapping sediments within its dense root structure and creating huge racks of floating organic debris during annual fall diebacks. *S. angelica* has a somewhat less extensive distribution, especially in Puget Sound; nevertheless, it causes similar problems.

Much of the area infested by *Spartina* is soft and muddy, which makes access difficult on the ground. *Spartina* has also extended into tributaries of the estuaries, which are difficult to access due to heavy woods and brush surrounding these tidally influenced areas within the uplands.

All cordgrass species have been designated "Class A" noxious weeds by the Washington State Noxious Weed Board. An eradication program administered by the Washington State Department of Agriculture, with strong collaborative efforts from the U.S. Fish and Wildlife Service and the Washington Department of Fish and Wildlife, the Washington State Departments of Agriculture and Natural Resources, the University of Washington, Washington State University, Pacific County, Friends of Willapa, private landowners, and the Willapa-Grays Harbor Oyster Growers Association (WGHOGA), has made substantial progress in a plan to eradicate cordgrass by 2012.

At the time of this writing, less than 40 acres (mostly *S. alterniflora*) remain in Willapa Bay and Grays Harbor, and about 100 acres (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. When weeds are found, they notify state agencies for targeted management efforts.

Spartina is currently not a major problem for Oregon oyster farmers. *Spartina* presence in Oregon is currently limited to S. *patens* on the Nature Conservancy's Cox Island Preserve in the Siuslaw River estuary. To address new infestations as they arise, Oregon has a *Spartina* response plan. (See "References" for more information on this plan.)

However, not all states are in agreement regarding *Spartina* monitoring and eradication techniques. Some states, such as Oregon and California, are utilizing techniques different from those being used by Washington's long-term program development, and concerns exist regarding the efficacy of these techniques. Research has shown that estuaries in these states can act as seed sources that have the ability to reinfest other areas of the Pacific Northwest, Canada, and Alaska.

Chemical Control:

- Imazapyr (Habitat) is currently registered in Washington and Oregon. It is applied annually to infested areas and is very effective. Imazapyr has been applied both by air and by ground-operated equipment, including airboats, large and small tracked vehicles, four-wheelers, and backpack 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 considered much more effective than glyphosate, which was formerly used with limited effectiveness.
- Glyphosate (Rodeo) is also registered in Washington and Oregon, but it is considered less effective than imazapyr. In certain areas it is applied as a check for effective coverage of imazapyr. Plants treated with glyphosate turn brown as they die, whereas those treated with imazapyr do not.

Biological control:

- A non-indigenous plant hopper, *Prokelesia marginata* (Delphacidae: Homoptera), was introduced to Willapa Bay stands of *Spartina* in experimental plots as a potential biological control agent in 2001. It took several years for the plant hopper to adapt to the local climate. By 2005, plants in areas of high plant hopper infestation (greater than 5000 per square meter) were visibly stressed. The experiment was terminated in 2007 when the herbicide-based eradication program with imazapyr proved successful. Many growers felt that the hopper could not achieve commercially acceptable levels of control.

Cultural Control:

- Excavation and removal (from the marine environment) is effective for eradicating small patches. Viable fragments, however, could detach and aid in spreading the infestation.
- Plastic ground coverings can be effective for very small patches in protected sites. However, maintaining a complete cover in the estuarine environment for the several years required would be extremely challenging.
- Seedlings can be pulled by hand in areas of sparse infestation.
- Monthly mowing below the mudline during the growing season for many years can be used to control small plots of *Spartina*. Its effectiveness for eradication from a site has yet to be proven.
- Physical removal of seed heads can help prevent additional infestations until eradication is achieved.

- Digging, disking, or pulling could potentially spread vegetative propagules and aid in plant dispersal and rerooting. It is critical if these methods are utilized that all root remnant materials are contained and removed to an upland area.

Critical Needs for Grass Management in Bivalves:

Research:
- Identify effective control options for the eradication of *S. densiflora*.
- Research impacts of root masses on water chemistry and estuarine processes of decomposition (e.g., hydrogen sulfide and other compounds).
- Identify the best methods of finding the remaining grass outliers in order to achieve eradication.

Regulatory:
- Enforce tri-state regulatory agreement on *Spartina* monitoring and eradication based on the "West Coast Governors' Agreement on Ocean Health, *Spartina* Eradication Action Coordination Team Work Plan." (See "References" for more information.)
- Establish a state-authorized regulatory board to enforce area-wide control of state-listed marine invasive/noxious pests.
- Enforce current regulations per "Class A" noxious weed designation.
- Maintain imazapyr registration on aquatic sites.
- Support third party annual monitoring and reporting regarding program effectiveness and results to ensure that an accurate record is maintained for delivery to the legislature and other entities.

Education:
- Educate growers, regulatory agencies, and the general public on identification and location monitoring of grasses.
- Educate growers and the general public on laws surrounding noxious weeds.

Japanese eelgrass (*Zostera japonica*)

Japanese eelgrass was unintentionally introduced to the West Coast many decades ago, likely in shipments of Japanese oyster seed in the 1920s. In recent years it has since spread to most growing regions in Oregon and Washington, where it forms thick blankets over the higher intertidal areas, affecting water drainage and chemistry, sedimentation, temperature, and nutrient composition.

Research has shown that this invasive grass damages shellfish beds by significantly reducing shellfish seed recruitment and growth rate, depending on the density of infestation.

Japanese eelgrass is not protected like native eelgrass in Washington; however, policy regarding its status is unclear and currently evolving. Recent U.S. Army Corps of Engineers permits are clear that protection is only extended to native eelgrass. California has switched to an eradication policy for Japanese eelgrass.

Chemical Control:
- No herbicides are currently registered for use against Japanese eelgrass.

Biological Control:
- None.

Cultural Control:
- Mechanical control can help thin grass populations.

Critical Needs for Japanese Eelgrass Management in Bivalves:

Research:
- Determine impacts of Japanese eelgrass on shellfish production (crop yield, maturation rate, etc.).
- Determine impacts (economic and ecological) of Japanese eelgrass on estuarine resources.
- Identify effective management options for Japanese eelgrass.
- Map and monitor Japanese eelgrass populations, including historical baseline data.

Regulatory:
- Clarify status of Japanese eelgrass to regulate and manage it as an invasive species.

Education:
- Engage in outreach activities with state and federal agencies, growers, and the general public on the differences between native and Japanese eelgrass and the impacts of Japanese eelgrass on ecology, wildlife and marine organisms, and shellfish production.

Native eelgrass *(Zostera marina)*

Native eelgrass causes similar problems for bivalve production as Japanese eelgrass. However, native eelgrass is regarded by the federal government as essential fish habitat. Because of its protection, growers do not currently manage it.

The appearance of native eelgrass on shellfish beds where it has never been previously, and the spread and growth of small patches within bivalve production beds, causes extensive crop, bed, and equipment damage. Crop yields, seed recruitment, and growth are reduced. Labor is increased due to fouling, and equipment damage is common. Thick eelgrasses can completely cover and hide shellfish on the beds, making harvest difficult.

Thick stands of eelgrass are not conducive to geoduck farming; therefore, growers generally do not plant geoduck in existing beds of native eelgrass. However, eelgrass has been observed to recruit into geoduck farming areas where there are tubes. It has been postulated that the tubes provide protection and a place for eelgrass seed to settle.

In some areas, native eelgrass can become so dense it impedes water flow over oyster beds, which interferes with the transport of food and nutrients. Heavy eelgrass growth can also hinder the settlement of oyster larvae during the spawning season. Further, it can plug up mechanical harvest bags and other production implements, complicating harvest and routine crop maintenance techniques. Some growers are also concerned about the appearance of native eelgrass meadows on natural native oyster beds. Although this has not been documented, growers fear such an appearance could threaten the survival of these natural native beds.

A more serious concern among growers relates to the potential for eelgrass to take over an established production area and the limitations and/or regulations that could be placed on the crop's harvest if this happens.

Chemical Control:

- None.

Biological Control:

- None.

Cultural Control:

- None.

Critical Needs for Native Eelgrass Management in Bivalves:

Research:

- Determine what densities of eelgrass are beneficial to fish yet not detrimental to shellfish production and other estuarine processes.
- Research the potential for Brant (a marine bird) foraging as a management tool.
- Map and monitor native eelgrass populations, including historical baseline data.

Regulatory:

- Clarify regulations surrounding potential eelgrass disturbance during shellfish farming activities.
- Clarify potential for management options for native eelgrass during shellfish farming activities.

Education:

- Educate growers regarding the regulations surrounding native eelgrass disturbance during shellfish harvest activities.
- Educate the public and regulatory agencies regarding the equivalent habitat value provided by shellfish culture.

c. Vertebrate Pests

<u>Perch</u>

Shiner (*Cymatogaster aggregata*)
Others

Perch species (members of the Embiotocidae family) nibble on long-lined oysters and suspended culture oysters and mussels and can cause substantial yield losses. They also prey on small clam, oyster, and mussel seed.

Shiner perch eat small mussels up to several millimeters in size in the nursery. Small-mesh nets are necessary to keep shiner perch off the mussels.

Pile perch are voracious consumers of mussels up to about a centimeter in size. Nets are necessary to keep pile perch away from mussels on recently seeded rafts or long-lines. Use of small-mesh nets for perch adds considerably to the labor of mussel farming. Nets foul quickly and must be changed, taken to shore, and dried out.

Perch have also been observed eating small oyster seed from newly planted long-line oyster culture in Willapa Bay, Washington, and suspended culture oysters in Yaquina Bay, Oregon.

Growers in Grays Harbor seem particularly affected, but perch also impact oyster growers in Willapa Bay, mussel growers in the South Puget Sound region in Washington, and oyster growers in Yaquina Bay, Oregon. Perch may be a problem in other regions as well.

Management of Shiner Perch:

- Nets are used on mussel nurseries and grow-out farms to keep the perch off the mussels.
- Timing of oyster seed placement is important in controlling losses to perch.

Critical Needs for Perch Management in Bivalves:

Research:

- Determine the degree of perch problem in all regions.
- Research the life cycle and biology of perch species.

Regulatory:

- None at this time.

Education:

- Educate growers on proper exclusion devices and timing of placement of such devices.

Seagulls, Crows and Ravens, and Waterfowl

Predation by waterfowl is a significant problem for most growers in most regions. Especially a problem are Scoter ducks and Goldeneye ducks that favor mussels and littleneck and Manila clams. While overall waterfowl populations are depressed, shellfish growers have observed a greater number of Scoter ducks on their farms. Scoter ducks are particularly a problem in Hood Canal and North and South Puget Sound.

Predation of littleneck and Manila clams by crows and ravens (*Corvus* spp.) is also a significant problem for many growers. Overall populations of *Corvus* species are increasing, and their intelligence makes management difficult. Crows are a particular problem in Willapa Bay but are present in all areas.

In addition to feeding on littleneck and Manila clams, all of these birds may also feed on single oyster seed and geoducks. Further, their presence on or near production areas contributes to higher fecal coliform bacteria levels, which could result in downgrades or closures of growing areas.

Management of Seagulls, Crows and Ravens, and Waterfowl:

- Passive measures include substrate covers, fencing, and nets on Manila clams, geoducks, and mussels (suspended culture).
- Hazing (harassing to disturb the animal's sense of security so it leaves) is 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; therefore depredation permits are not available.

Critical Needs for Management of Seagulls, Crows and Ravens, and Waterfowl in Bivalves:

Research:

- Perform population density research on waterfowl, crow, raven, and seagull presence.
- Document waterfowl damage, including coliform impacts.

Regulatory:

- Discuss population research data with appropriate regulatory agencies.
- Investigate methods to obtain compensation for pest damage.

Education:

- Educate growers on life history and seasonal distribution of birds.
- Educate growers on regulations related to bird management.

II. Diseases

(Note: Individual pests are presented in alphabetical order, not in order of importance.)

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 without the use of therapeutants (healing or curative agents). Regulations governing product handling, storage, and transportation also prevent diseases and outbreaks.

Currently, the diseases of most concern often impact hatchery production rather than harvested bivalves. Diseases affecting bivalves are not as well understood as other pest issues.

Note: Organisms described here that cause mollusc diseases are not the same organisms that cause human illness and disease (i.e., *Vibrio parahaemolyticus*).

Bonamiasis (*Bonamia ostreae*)

This is a parasite that infects blood cells of the European flat oyster, *Ostrea edulis*. In Washington it has caused mortalities of *O. edulis* in cultures. This disease contributed to the collapse of the European flat oyster industry in France. Some oysters may have resistance to the disease, limiting mortality.

The production of European flat oysters in Washington has dropped off largely due to lack of production of seed by the hatcheries (because of the risk of introducing the disease into their facilities).

Chemical Control:

- None.

Biological Control:

- None.

Cultural Control:

- Broodstock must be certified disease-free to use in a hatchery.

Critical Needs for Bonamiasis Management in Bivalves:

Research:
- Investigate disease resistance in broodstock (for Bonamiasis and other diseases, such as MSX and Vibriosis).
- Research potential methods for field identification of Bonamiasis.

Regulatory:
- None at this time.

Education:
- If and when a method for identifying Bonamiasis in the field has been established, educate growers on the method.

Denman Island Disease (*Mikrocytos mackini*)

Denman Island Disease is caused by a protist (a simple-celled organism lacking specialized tissues). Symptoms include lesions and discolorations in the muscles and flesh of oysters, especially those more than two years old. Mortality can exceed 30 percent if water temperatures remain below 10°C for 2 to 3 months.

Participants in a workshop on Denman Island Disease, held in Tacoma, Washington, 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. However, Denman Island Disease has been found in several areas in Washington. The state of Washington created "Prohibited Areas" for the disease, which has resulted in increased disease testing costs to the industry for these areas. One hatchery is located in a prohibited area. The existence of the disease and the prohibited areas has implications for the export of product from those areas, and it increases costs to the industry overall for surveillance and testing for the disease.

The disease is more common in British Columbia, Canada, than in Oregon and Washington.

Chemical Control:
- None.

Biological Control:
- None.

Cultural Control:

- Harvesting older oysters or moving them to higher tidal elevations in March and not planting oysters at low tidal elevations after June can aid in reducing the prevalence of this disease.

Critical Needs for Denman Island Disease Management in Bivalves:

Research:

- Research the potential for field identification of Denman Island Disease.

Regulatory:

- None at this time.

Education:

- If and when a method for identifying Denman Island Disease in the field has been established, educate growers on the method.
- Educate commercial growers and managers of public tidelands on the importance of harvesting older, diseased (or disease-prone) oysters to reduce opportunities for disease transmission.

MSX (*Haplosporidium nelsoni*)

MSX in oysters is caused by a parasitic protist that has caused high mortality of Eastern oysters (*Crassostrea virginica*) along the Atlantic coast, particularly in relatively warm temperatures and higher salinities. A similar parasite has been reported in juvenile Pacific oysters in California but not in cultured oysters in Washington and Oregon.

C. virginica broodstock is held in quarantine until pathology tests determine broodstock is free of MSX. MSX-free broodstock is used in the hatchery for larval production. Pathology tests and the quarantine system add considerably to the cost of operation.

Chemical Control:

- None.

Biological Control:

- None.

Cultural Control:

- 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 parts per thousand (ppt) or less and temperatures above 20°C for periods of 2 weeks or longer.
- Some broodstocks of Eastern oysters show resistance to MSX.

Critical Needs for MSX Management in Bivalves:

Research:

- Investigate the prevalence of MSX and the extent of damage to Eastern Oyster (*C. virginica*).
- Identify a less expensive and rapid identification method (and potential for field identification) for MSX.

Regulatory:

- None at this time.

Education:

- Educate growers on the existence of MSX for proper identification.
- If and when a method for identifying MSX in the field has been established, educate growers on the method.

Oyster velar virus disease (OVVD)

OVVD affects mid-stage oyster larvae and can occasionally cause significant morbidity and mortality in hatcheries.

Chemical Control:

- None.

Biological Control:

- None.

Cultural Control:

- Control is achieved by sanitation, including destruction of affected groups followed by tank disinfection.
- Regulating the movement of broodstock also prevents viral transmission, as the virus is likely transmitted from infected broodstock.

Critical Needs for OVVD Management in Bivalves:

Research:
- Explore the possibility of tank inoculations for larvae protection against OVVD.
- Research inoculation in hatchery systems as a means to control OVVD and other bivalve diseases.

Regulatory:
- None at this time.

Education:
- None at this time.

Vibriosis (*Vibrio tubiashii* and others)

Vibrios are naturally occurring marine bacteria that originate from ocean sources. These sometimes-virulent pathogens occur primarily in bivalve larvae and juveniles, both from the 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 these pathogens.

In 2006 and 2007, *V. tubiashii* was thought to be the chief cause of high larval mortalities in two of the three main hatcheries serving the West Coast, and similar declines were reported during early 2008. Since that time it has been determined that the presence of *V. tubiashii* is only one of possibly several ocean water conditions contributing to larval mortalities. Also, while it is suspected that this disease may have contributed to the reduction in the natural set in Willapa Bay since 2004, no direct evidence exists at this time. Continued declines in natural set, larvae, and seed production put the West Coast bivalve industry at great risk.

Chemical Control:
- None.

Biological Control:
- None.

Cultural Control:

- Various water treatments have been assessed and are proving somewhat successful in hatcheries affected by *V. tubiashii*.

Critical Needs for Vibriosis Management in Bivalves:

Research:

- Evaluate seawater treatment methods (e.g., filtration, probiotics, ultraviolet light, ozone and other gasses) as a management tool in hatcheries.
- Continue research on water chemistry and *Vibrios* in the natural estuary and their relationship to larval survival.

Regulatory:

- Encourage ongoing research by state and federal agencies to determine the reasons for the decline in natural set in Willapa Bay.

Education:

- None at this time.

III. Sporadic and Minor Pests

(Note: Individual pests are presented in alphabetical order, not in order of importance.)

Invertebrate Pests

Mussels
Japanese green mussel (*Musculista senhousia*)
Native blue mussel (*Mytilus trossulus*)

Musculista is a small introduced mussel that can grow to up to 3 centimeters. It settles in dense numbers near the head of some South Puget Sound bays. It usually settles in areas used for seed oysters, but it occasionally has fouled grow-out beds as well. The mussel density varies from year to year but can cause blankets of mussels in heavy set years.

The mussel competes for food with oysters, can smother oysters, and causes oysters to stick together in clumps, making seed handling difficult.
Mussel mats can also foul predator nets, and as mussel mats break down, clumps of mussels can wash onto adjacent areas, fouling other production gear and equipment.

Mytilus trossulus can set on single oysters in bags and cages, causing them to grow together or become misshapen. Mussel sets on oysters increase the labor required at harvest to clean mussel fouling from the oyster shells.

Mussel mats can also affect clams. If smothered, clams will move to the surface, just below the mussel mat. When the mussel mat is removed by rake, the clams are exposed and weak and may not be able to dig into the substrate. The clams are generally not marketable at this stage and must be allowed to fatten before re-digging.

Mussels are noticed in spring, grow through summer and fall, and die off in winter. This is a serious but sporadic pest in the South Puget Sound and Hood Canal regions of Washington and in Yaquina Bay in Oregon.

Chemical Control:

- None.

Biological Control:

- None.

Cultural Control:

- Oyster seed must be moved before mussels smother the seed.
- Harvest oysters only after mussels have died off.
- Infested areas are used only for seed, not for grow-out or fattening.
- Weed burners (propane flame throwers) have been used to burn off thick mussel blankets covering clam ground.
- Predator nets can be removed and dried to kill mussels that adhere to the nets.

Polydora (*Polydora* spp.)

Polychaete worms of the genus *Polydora*, sometimes called mud worms, burrow into the shells of Pacific oysters (*C. gigas*), forming a condition growers often call mud blisters. *Polydora* species are found on oysters throughout the world, including those grown in Washington and Oregon. A dark blister can be seen on the inside of the shell after the oyster is opened. The worms may not cause mortality in the oyster, but the main impact to the grower is the loss of value of single half-shell oysters. The black, mud-filled blisters are unsightly in the oyster and can cause customers to reject shipments or stop buying from the source. Various treatments to kill *Polydora* have been tried in other parts of the world where infestation rates are high. The infestation rate in our region is not well known, and no treatments are used.

Chemical Control:

- None.

Biological Control:

- None.

Cultural Control:

- None currently employed.

Slipper shells (*Crepidula* spp.)

Slipper shells are a major pest on single oysters in the South Puget Sound region in old Olympia oyster dykes and deep ground (sand or gravel bottoms). Slipper shells settle in dyked beds of oysters or clams, thereby displacing or smothering the cultured bivalves.

Slipper shells compete with other filter-feeding invertebrates (clams and oysters) for food and space. By settling in large numbers they can modify the nature of the substrate due to the accumulation of shells, can slow the bottom currents, and can increase silting. Individuals of *Crepidula* pile up on each other. The older specimens are females, and the younger (on top) are males that will eventually turn into females as the pile grows.

Chemical Control:
- None.

Biological Control:
- None.

Cultural Control:
- Hand removal and relocation to non-used tideland areas or uplands.

<u>Tunicates</u>

Ascidians (or tunicates) are a group of organisms that are either solitary or colonial and that attach to substrates in the subtidal or very low intertidal area. Solitary ascidians, or sea squirts, have a leather-like texture and protrude from the substrate. Colonial ascidians form a rubbery mat covering the substrate. These are significant fouling organisms of mussel culture and suspended culture along the northeast coast of the United States and Canada, but they are a minor problem in Washington and Oregon. Some species are native, and some are introduced. The Washington Department of Fish and Wildlife lists three species of invasive non-native tunicates that are of concern.

Chemical Control:
- None.

Biological Control:
- None.

Cultural Control:
- Ascidians are washed off at harvest time.
- Gear and other equipment is dried or washed to free it of ascidians.

<u>Other Parasites</u>

Some parasites have a negligible direct impact on bivalves 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 for Sporadic/Minor Invertebrate Pests in Bivalve Production

Research:

- Identify effective control options for sporadic and minor invertebrate pests.
- Identify distribution and impacts of sporadic and minor invertebrate pests.

Regulatory:

- None at this time.

Education:

- Educate growers and recreational divers on reporting requirements and identification of pests, particularly invasives.

Vertebrate Pests

<u>Flatfish and Sculpins</u> (various species)

A number of flatfish and sculpins inhabit the shellfish beds of Washington and Oregon. Fish in this group have not been well studied as predators of shellfish, but many clam and geoduck growers consider them to be predators of seed clams.

Video cameras and divers have recorded these fish inside geoduck tubes. Growers sometimes find these fish stranded in Manila clam nets at low tide. It is difficult to estimate the damage caused by fish because of the many other predators present, including crabs and ducks. Protection efforts on clam beds are intended to exclude these fish as well as other predators.

Management of Flatfish and Sculpins:

- Nets are placed over the clam beds to exclude fish and other predators.

Raccoon

Raccoons are a problem for Manila clams in Hood Canal. Raccoons also affect water quality and can result in high levels of coliform bacteria if their concentration is high. Raccoons most often enter shellfish beds at night, making it difficult to locate and remove them.

Management of Raccoons:

- Raccoons are generally removed by harassment, live trapping and relocation, or hunting as permitted. No other methods have been identified for reducing or restricting their populations.

River Otter

River Otters eat clams and are a problem particularly for Manila clams in the Hood Canal and North Puget Sound regions. They also foul gear and other equipment with their fecal matter. Currently, growers do not actively control river otters.

Critical Needs for Sporadic/Minor Vertebrate Pests in Bivalve Production

Research:

- Identify the extent of damage by flatfish and sculpins on geoducks and Manila clams.
- Investigate methods to deter pests from entering shellfish areas.
- Quantify shellfish crop consumption by sporadic and minor pests, and determine economic threshold aligned with crop damage and gear maintenance/repair.

Regulatory:

- Investigate the possibility of live trapping and removal of problem vertebrate species.

Education:

- Educate growers on approved and effective control methods for sporadic and minor pests.

IV. Potentially Serious Pests to Pacific Northwest Bivalve Production

(Note: Individual pests are presented in alphabetical order, not in order of importance.)

In addition to indigenous and invasive pests that are already present in shellfish beds in the Pacific Northwest, there are a number of aquatic invasive species that could become rapidly established in the future. Their impacts could range from minor to extremely serious. The number of potential invasive species, including seaweeds, angiosperms, and vertebrate and invertebrate species, is too large to list individually. However, four macroalgae (seaweed) species that pose the most serious threat to shellfish production are detailed below.

Caulerpa **spp.**

Caulerpa taxifolia is considered a major threat to native marine biodiversity. In June 2000, the Mediterranean invasive strain of *C. taxifolia* was identified in southern California and has since been eradicated from those sites. It remains a serious potential threat to the Pacific Northwest shellfish industry.

Chemical Control

- Bleach (both liquid injections and solid form treatments) has been used as an eradication treatment.

Biological Control:

- None known.

Cultural Control:

- None known.

Codium fragile (Including subspecies *tomentosoides*, and others)

C. fragile overgrows and smothers oyster beds; hence its nickname, “oyster thief.” It makes its home on the shells of oysters, scallops, and clams. It is currently a problem in northwest Atlantic shores, and it is problematic because the attached adult plant can hinder the movement and feeding of the shellfish. In cases where the attached plant is relatively large and wave exposure is high, the shellfish can be swept away with the plant. It is also known to smother mussels and interfere with the collecting of clams.

C. fragile spp. *tomentosoides* can also lead to the fouling of shellfish beds, clogged dredges, and increased sediment trapping. It is also a fouling agent on the nets used for catching fin fish, and it increases labor costs during harvesting and processing due to fouling of wharf pilings, jetties, ropes, and beaches. Furthermore, the accumulation of rotting masses of *C. fragile tomentosoides* produces a foul odor. It is currently not a problem in the Pacific Northwest, but it is ranked as the number one invasive macroalgae in Europe. Its spread to the Pacific Northwest could have serious repercussions.

Chemical Control:

- It is unknown which herbicides may be efficacious against *Codium.*

Biological Control:

- Sea slugs have been shown to be herbivorous on *Codium* thalli (vegetative tissue).

Cultural Control:

- Hand-removal of plant fragments from shellfish equipment and small infested areas.
- Bottom barriers (without chemical injections) can be effective in areas of dense monotypic *Codium* growth.
- Diver dredging may also be an option in shallow areas with condensed sediments.
- Mowing or rotovation (using rototiller-like blades to churn substrate and uproot plants) is not an option. *Codium fragile* spp. *tomentosoides* is able to reproduce vegetatively as well as sexually, and propagation from buds and branch fragments may contribute to more infestations in new sites.

<u>Sargassum muticum</u>

S. muticum is a large brown seaweed that forms dense monospecific (single species) stands. It can accumulate high biomass and may quickly become a strong competitor for space and light. Dense stands may reduce light, decrease water flow, increase sedimentation, and reduce ambient nutrient concentrations available for native kelp species. Dense growths of *S. muticum* on oyster beds (such as in British Columbia, Canada) could make it difficult to see cultured oysters. It is also feared that the buoyant fronds of *Sargassum* attached to the oyster shells could carry them out of the culture area. The extensive development of *Sargassum* populations on French oyster beds can hinder the growth and harvesting of the shellfish.

Sargassum is currently present in marine waters in Oregon, Washington, and California but it has not yet been considered a serious problem.

Chemical Control

- None available.

Biological Control:

- None available.

Cultural Control:

- Hand removal.

Undaria pinnatifida

U. pinnatifida is described as an opportunistic seaweed, able to rapidly colonize new or disturbed substrata and artificial floating structures. It occurs in dense, vigorous stands. *Undaria* inhabits cold, temperate coastal areas and grows best in waters below 12°C.

Undaria grows epiphytically (non-parasitically) on the shells of abalone and bivalves, invertebrates, and on other seaweeds. *Undaria* can grow on any hard surface, including artificial substrates such as rope, pylons, buoys, the hulls of vessels, bottles, floating pontoons, and plastic.

U. pinnatifida has the potential to become a problem for shellfish growers by increasing labor and harvesting costs caused by fouling problems on oyster racks, mussel ropes, and other farm machinery. It can also slow the growth of mussels and restrict water circulation. *U. pinnatifida* causes physical displacement of native species through over-growing and shading of underlying species. This species has been nominated to be among "100 of the World's Worst Invasive Alien Species." It is currently present in several locations in California, including Monterey Bay.

Chemical Control

- None available.

Biological Control:
- None available.

Cultural Control:
- Mechanical removal.

Critical Needs for Potentially Serious Pests in Bivalve Production

Research:
- Establish a monitoring program for early detection of these potential pests.

Regulatory:
- Encourage the development of a monitoring plan by the Invasive Species Task Force.

Education:
- Educate growers on the importance of monitoring, identification (using a pictorial guide to aid in identification), and reporting of these potentially serious pests.
- Educate the public on how to prevent transport of these potential pests (regulations, etc.).

V. Other Issues Affecting Bivalve Production

In addition to pests that have a direct impact on bivalve production, there are a number of issues that affect bivalve production indirectly. Growers cannot manage these issues, yet they have an influence on a grower's ability to sell a crop. Examples include bacterial contamination (*Vibrio parahaemolyticus* and fecal coliform bacteria) and toxic algal blooms. Weather (affecting tides and production activities) and land use conflicts can also impact bivalve production.

Over the past 5 to 6 years, growers have been affected by oyster larval mortalities. The current state of knowledge has led growers and researchers to conclude that one of the root causes of mortality is upwelling events, where highly acidic deep ocean waters are elevated to shallower depths and brought into bays and estuaries. These deep waters are also very low in oxygen, which is an environment in which *V. tubiashii* thrives. More research is currently under way to better correlate oceanic conditions with larval conditions.

Another major issue affecting bivalve production is summer oyster mortality. Summer oyster mortality is the occurrence of substantial mortality of certain oyster species (e.g., *C. gigas*) in major oyster producing areas during the summer. The mortality generally occurs in oysters at or near market size. This type of mortality has occurred for years in the Pacific Northwest and has also occurred in major oyster producing areas of France. Several studies have attempted to find the cause, but as yet the mortality can not be attributed to one particular causal agent. It is possible that a complex set of conditions leads to mortality. Among the factors believed to be associated with mortality are high water and air temperatures, low dissolved oxygen, pathogens, toxic algae, and high siltation. The industry approach has been to support research on the mortality problem and to produce mortality-resistant broodstock through a genetics program. Summer oyster mortality has impacted the industry through large losses of product as well as the high costs associated with research and the development of resistant broodstock.

Critical Needs for Other Issues Affecting Bivalve Production

Research:

- Investigate the impact of high levels of invasive and native grasses (causing restricted water flow) on the presence of *Vibrio parahaemolyticus* in and around shellfish beds.

Regulatory:

- Implement a mandatory septic and point discharge source inspection program in situations where the degradation of water quality in closed or restricted shellfish areas indicates that residential, agricultural, industry, etc. are likely contributors.

Education:

- None at this time.

References

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2. Pacific Coast Shellfish Growers Association Web site: www.pcsga.org

3. Pacific Shellfish Institute, "West Coast Shellfish Research and Education 2015 Goals and Priorities": http://www.pacshell.org/pdf/2015.pdf

4. "Oregon's *Spartina* Response Plan": http://www.clr.pdx.edu/docs/SpartinaPlan5-8.pdf

5. "West Coast Governors' Agreement on Ocean Health—*Spartina* Eradication Action Coordination Team Work Plan": http://westcoastoceans.gov/Docs/Spartina_Final_Work_Plan.pdf

6. Elston, Ralph A., *Mollusc Diseases: Guide for the Shellfish Farmer*, University of Washington Press, 1990.

Activity Table for Bivalve Hatchery Production

Note: An activity may occur at any time during the designated time period but generally not continually during that time period.

Activity	J	F	M	A	M	J	J	A	S	O	N	D
Broodstock selection	X	X	X	X	X	X	X	X	X	X	X	X
Microalgae culture	X	X	X	X	X	X	X	X	X	X		
Setting		X	X	X	X	X	X	X	X	X		
Spawning	X	X	X	X	X	X	X	X	X	X		
Water pumping, filtering, and heating	X	X	X	X	X	X	X	X	X	X	X	X

Activity Table for Bivalve Nursery Production

Note: An activity may occur at any time during the designated time period but generally not continually during that time period.

Activity	J	F	M	A	M	J	J	A	S	O	N	D
Freshwater dips/washes (floating nursery)	X	X	X	X	X	X	X	X	X	X	X	X
Harvest	X	X	X	X	X	X	X	X	X	X	X	X
Microalgae culture/screened bay water			X	X	X	X	X	X				
Rearing	X	X	X	X	X	X	X	X	X	X	X	X
Screen and bin cleaning	X	X	X	X	X	X	X	X	X	X	X	X
Shipping	X	X	X	X	X	X	X	X	X	X	X	X
Sorting	X	X	X	X	X	X	X	X	X	X	X	X

Activity Table for Oyster Production

Note: An activity may occur at any time during the designated time period but generally not continually during that time period.

Activity	J	F	M	A	M	J	J	A	S	O	N	D
Bag/Cage Culture:												
Filling bags with seed				X	X	X	X	X				
Hanging bags/cages on lines/posts				X	X	X	X	X				
Maintaining lines			X	X	X	X	X	X	X	X		
Bottom Culture (Single Oyster Product):												
Harvest	X	X	X	X	X	X	X	X	X	X	X	X
Maintaining density (hand or dredge)	X	X	X	X	X	X	X	X	X	X	X	X
Pest removal from beds			X	X	X	X	X	X	X			
Planting seed			X	X	X	X	X	X	X	X		
Spraying for burrowing shrimp (Willapa Bay and Grays Harbor only)							X	X	X	X		
Bottom Culture (Shucked Product):												
Hand picking or dredging from seed beds	X	X	X	X	X	X	X	X	X	X	X	X
Harrowing	X	X	X	X	X	X	X	X	X	X	X	X
Harvest	X	X	X	X	X	X	X	X	X	X	X	X
Scattering cultch shell on seed beds				X	X	X	X	X				
Seed bed rearing	X	X	X	X	X	X	X	X	X	X	X	X
Transferring to fattening beds	X	X	X	X	X	X	X	X	X	X	X	X
Long-line Culture:												
Hanging long-lines			X	X	X	X	X	X	X	X		
Harvest	X	X	X	X	X	X	X	X	X	X	X	X
Preparing posts and shell lines			X	X	X	X	X	X	X	X		
Setting larvae		X	X	X	X	X	X	X	X	X		
Spraying for burrowing shrimp (Willapa Bay and Grays Harbor only)							X	X	X	X		
Seed Setting:												
Aeration (remote setting)		X	X	X	X	X	X	X	X	X		
Bottom harrowing (wild caught)	X	X	X	X	X	X	X	X	X	X	X	X
Larvae introduction (remote setting)		X	X	X	X	X	X	X	X	X		
Microalgae culture (remote setting)		X	X	X	X	X	X	X	X	X		
Shell collecting	X	X	X	X	X	X	X	X	X	X	X	X
Shell preparation and placement (bags)	X	X	X	X	X	X	X	X	X	X	X	X
Tank preparation (remote setting)		X	X	X	X	X	X	X	X	X		
Transporting to seed beds			X	X	X	X	X	X	X	X		

Activity Table for Manila and Littleneck Clam Production

Note: An activity may occur at any time during the designated time period but generally not continually during that time period.

Activity	J	F	M	A	M	J	J	A	S	O	N	D
Hand removal of pests	X	X	X	X	X	X	X	X	X	X	X	X
Harvest	X	X	X	X	X	X	X	X	X	X	X	X
Laying nets (intensive)			X	X	X	X	X	X	X	X		
Laying nets (extensive)			X	X	X	X	X	X	X	X		
Maintaining beds and gear	X	X	X	X	X	X	X	X	X	X	X	X
Preparing beds	X	X	X	X	X	X	X	X	X	X	X	X
Spreading seed				X	X	X	X	X	X	X		
Sweeping algae				X	X	X	X	X	X			

Activity Table for Geoduck Clam Production

Note: An activity may occur at any time during the designated time period but generally not continually during that time period.

Activity	J	F	M	A	M	J	J	A	S	O	N	D
Bed preparation			X	X	X	X	X	X	X	X	X	
Hand removal of pests	X	X	X	X	X	X	X	X	X	X	X	X
Harvest	X	X	X	X	X	X	X	X	X	X	X	X
Harvest nursery geoducks				X	X	X	X	X	X	X	X	
Installing nets			X	X	X	X	X	X	X	X	X	
Installing predator protection tubes			X	X	X	X	X	X	X	X	X	
Maintaining gear	X	X	X	X	X	X	X	X	X	X	X	X
Planting on grow-out beds				X	X	X	X	X	X	X	X	
Removing protection	X	X	X	X	X	X	X	X	X	X	X	X
Seeding into sand nurseries				X	X	X	X	X	X	X		

Activity Table for Mussel Production

Note: An activity may occur at any time during the designated time period but generally not continually during that time period.

Activity	J	F	M	A	M	J	J	A	S	O	N	D
Changing nets to control fouling	X	X	X	X	X	X	X	X	X	X	X	X
Declumping/washing	X	X	X	X	X	X	X	X	X	X	X	X
Fresh water dips				X	X	X	X	X	X			
Hanging on grow-out lines	X			X	X	X	X	X	X	X	X	X
Hanging predator nets	X	X	X	X	X	X	X	X	X	X	X	X
Hanging seed in nursery		X	X	X	X	X	X	X	X			
Harvest	X	X	X	X	X	X	X	X	X	X	X	X
Harvesting seed from nursery	X			X	X	X	X	X	X	X	X	X

Seasonal Pest Occurrence for Oysters

Notes:

1. "X" = times when pest management strategies are used to control these pests, not all times when pest is present.
2. In the "Region" column, W/G = Willapa Bay/Grays Harbor, NP = North Puget Sound, SP = South Puget Sound, HC = Hood Canal, and O = Oregon.

Invertebrate Pests	Region	J	F	M	A	M	J	J	A	S	O	N	D
Bamboo worm	NP			X	X	X	X	X	X	X			
Barnacle	All			X	X	X	X		X				
Burrowing shrimp	W/G							X	X	X	X		
Crabs	All	X	X	X	X	X	X	X	X	X	X	X	X
Flatworms	All			X	X	X	X	X	X				
Moon snail	All			X	X	X	X	X	X				
Oyster drills	All		X	X	X	X	X	X	X	X	X		
Sea stars	All	X	X	X	X	X	X	X	X	X	X	X	X
Diseases		J	F	M	A	M	J	J	A	S	O	N	D
Bonamiasis	All						X	X	X				
Weeds		J	F	M	A	M	J	J	A	S	O	N	D
Algae	All			X	X	X	X	X	X	X			
Grasses	All					X	X	X	X	X	X		
Japanese eelgrass	W/G			X	X	X	X	X	X	X	X		
Vertebrate Pests		J	F	M	A	M	J	J	A	S	O	N	D
Perch	All					X	X	X	X				
Seagulls, crows and ravens, and waterfowl	All	X	X	X	X	X	X	X	X	X	X	X	X

Seasonal Pest Occurrence for Manila and Littleneck Clams

Notes:

1. X" = times when pest management strategies are used to control these pests, not all times when pest is present.
2. In the "Region" column, W/G = Willapa Bay/Grays Harbor, NP = North Puget Sound, SP = South Puget Sound, HC = Hood Canal, and O = Oregon. More than one region may be designated, separated by commas, or "all" will be noted. Additionally, pests may be repeated if the timing of pest management activities differs by region.

Invertebrate Pests	Region	J	F	M	A	M	J	J	A	S	O	N	D
Bamboo worm	NP	X											
Burrowing shrimp	W/G							X	X	X	X		
Crabs	All	X	X	X	X	X	X	X	X	X	X	X	X
Moon snail (adult)	W/G, SP, HC	X	X	X	X	X	X	X	X	X	X	X	X
Moon snail (eggs)	W/G, SP, HC			X	X	X							
Oyster drills	W/G		X	X	X	X	X	X	X	X	X		
Weeds		J	F	M	A	M	J	J	A	S	O	N	D
Algae	NP, SP, W/G				X	X	X	X	X	X			
Grasses	W/G, NP, SP, O			X	X	X	X	X	X	X	X		
Japanese eelgrass	W/G			X	X	X	X	X	X	X	X		
Vertebrate Pests		J	F	M	A	M	J	J	A	S	O	N	D
Seagulls, crows and ravens, and waterfowl	All	X	X	X	X	X	X	X	X	X	X	X	X

Seasonal Pest Occurrence for Geoduck Clams

Notes:
1. "X" = times when pest management strategies are used to control these pests, not all times when pest is present.
2. In the "Region" column, SP = South Puget Sound.

Invertebrate Pests	Region	J	F	M	A	M	J	J	A	S	O	N	D
Barnacle	SP	X	X	X	X	X	X	X	X	X	X	X	X
Crabs	SP	X	X	X	X	X	X	X	X	X	X	X	X
Cockles	SP				X	X	X	X	X				
Horse clams	SP	X	X	X	X	X	X	X	X	X	X	X	X
Moon snail	SP	X	X	X	X	X	X	X	X	X	X	X	X
Sand dollars	SP		X	X	X	X	X	X	X				
Starfish	SP	X	X	X	X	X	X	X	X	X	X	X	X
Weeds		J	F	M	A	M	J	J	A	S	O	N	D
Algae	SP			X	X	X	X	X	X	X	X	X	

Seasonal Pest Occurrence for Mussels

Notes:

1. "X" = times when pest management strategies are used to control these pests, not all times when pest is present.
2. In the "Region" column, WG = Willapa Bay/Grays Harbor, NP = North Puget Sound, SP = South Puget Sound, HC = Hood Canal, and O = Oregon. More than one region may be designated, separated by commas, or "all" will be noted. Additionally, pests may be repeated if the timing of pest management activities differs by region.

Invertebrate Pests	Region	J	F	M	A	M	J	J	A	S	O	N	D
Barnacle	SP, NP				X	X	X						
Vertebrate Pests		**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Perch	All				X	X	X	X	X	X			
Seagulls, crows and ravens, and waterfowl	All	X	X	X	X	X	X				X	X	X

Efficacy Ratings for Invertebrate/Vertebrate Pest Management Tools in Oyster Production

Rating scale: E = excellent (90–100% control); G = good (80–90% control); F = fair (70–80% control); P = poor (< 70% control); ? = efficacy unknown, more research needed; * = used but not a stand-alone management tool; NU = not used for this pest; chemistry or practice known to be ineffective.

MANAGEMENT TOOLS	Bamboo worm	Barnacle	Burrowing shrimp	Crabs	Flatworms	Horse clams	Moon snails	Oyster drills	Starfish	Perch	Seagulls, crows and ravens, and waterfowl	COMMENTS
Registered Chemistries												
Bottom paints for boats	NU	F	NU	NU	NU	NU	NU	NU	NU	NU	NU	See “barnacle” entry for example ingredients.
Carbaryl	NU	NU	E	NU	NU	NU	NU	NU	NU	NU	NU	Certain regions of Washington only, 24(c) label.
Unregistered/New Chemistries												
Imidacloprid	NU	NU	?	NU	NU	NU	NU	NU	NU	NU	NU	Research in progress; showing fair results.
Biological												
None												
Cultural/Non-Chemical												
Alternative cultivation tactic for pest exclusion (e.g., long-line instead of bottom culture)	NU	NU	P	P	NU	NU	NU	P	P	NU	NU	
Bags, baskets, nets, tubes, fencing for pest exclusion	NU	NU	F	G	NU	NU	G	P	P	NU	G	
Fresh water dips/washes	NU	NU	NU	NU	NU	NU	NU	NU	NU	NU	NU	
Hand removal of pest	P	G	P	P	NU	NU	P-G	G	NU	NU	NU	
Hazing	NU	NU	NU	NU	NU	NU	NU	NU	NU	NU	P	
Hunting	NU	NU	NU	NU	NU	NU	NU	NU	NU	NU	P	
Higher beach levels for drying	NU	NU	NU	NU	G	NU	NU	NU	NU	NU	NU	

Efficacy Ratings for Invertebrate/Vertebrate Pest Management Tools in Manila and Littleneck Clam Production

Rating scale: E = excellent (90–100% control); G = good (80–90% control); F = fair (70–80% control); P = poor (< 70% control); ? = efficacy unknown, more research needed; * = used but not a stand-alone management tool; NU = not used for this pest; chemistry or practice known to be ineffective.

MANAGEMENT TOOLS	Bamboo worm	Burrowing shrimp	Crabs	Moon snails	Oyster drills	Seagulls, crows and ravens, and waterfowl	COMMENTS
Registered Chemistries							
Unregistered/New Chemistries							
Imidacloprid	NU	?	NU	NU	NU	NU	Research in progress; showing fair results.
Biological							
None							
Cultural/Non-Chemical							
Bags, baskets, nets, tubes, fencing for pest exclusion	NU	P	G	P	P	G	
Hand removal of pest	NU	P	P	P	P	NU	
Hazing	NU	NU	NU	NU	NU	P	
Hunting/fishing	NU	NU	P	NU	NU	P	

Efficacy Ratings for Invertebrate/Vertebrate Pest Management Tools in Geoduck Clam Production

Rating scale: E = excellent (90–100% control); G = good (80–90% control); F = fair (70–80% control); P = poor (< 70% control); ? = efficacy unknown, more research needed; * = used but not a stand-alone management tool; NU = not used for this pest; chemistry or practice known to be ineffective.

MANAGEMENT TOOLS	Barnacle	Cockles	Crabs	Horse clams	Moon snails	Sand dollars	Starfish	COMMENTS
Registered Chemistries								
None								
Unregistered/New Chemistries								
None								
Biological								
None								
Cultural/Non-Chemical								
Alternative cultivation tactic for pest exclusion	F	NU	NU	NU	NU	NU	NU	
Bags, baskets, nets, tubes, fencing for pest exclusion	NU	NU	G	NU	F	NU	F	
Fresh water dips/washes	NU	NU	NU	NU	NU	NU	NU	
Hand removal of pest	G	G	NU	NU	P	P	P	
Hazing	NU	NU	NU	NU	NU	NU	NU	
Hunting	NU	NU	NU	NU	NU	NU	NU	
Incidental harvest	NU	NU	NU	G	NU	NU	NU	

Efficacy Ratings for Invertebrate/Vertebrate Pest Management Tools in Mussel Production

Rating scale: E = excellent (90–100% control); G = good (80–90% control); F = fair (70–80% control); P = poor (< 70% control); ? = efficacy unknown, more research needed; * = used but not a stand-alone management tool; NU = not used for this pest; chemistry or practice known to be ineffective.

MANAGEMENT TOOLS	Barnacle	Perch	Seagulls, crows and ravens, and waterfowl	COMMENTS
Registered Chemistries				
None				
Unregistered/New Chemistries				
None				
Biological				
None				
Cultural/Non-Chemical				
Alternative cultivation tactic for pest exclusion	F	NU	NU	
Bags, baskets, nets, tubes, fencing for pest exclusion	NU	E	G	
Fresh water dips/washes	NU	NU	NU	
Hand removal of pest	G	NU	NU	
Hazing	NU	NU	P	
Hunting	NU	NU	NU	
Incidental harvest	NU	NU	NU	

Efficacy Ratings for Disease Management Tools in Bivalve Production (Hatchery)

Rating scale: E = excellent (90–100% control); G = good (80–90% control); F = fair (70–80% control); P = poor (< 70% control); ? = efficacy unknown, more research needed; * = used but not a stand-alone management tool; NU = not used for this pest; chemistry or practice known to be ineffective.

MANAGEMENT TOOLS	Bacteria contamination of algae	Bonamiasis*	Larvae and seed mortalities—unknown causes	MSX Disease	Vibriosis, OVVD, and other pathogens	COMMENTS
Registered Chemistries						
None						
Unregistered/New Chemistries						
None						
Biological						
None						
Cultural/Non-Chemical						
Bleach and acid sanitation	G	NU	G	G	F	
Broodstock testing or certification	NU	G	NU	E	F	
Disease-resistant broodstock	NU	?	NU	NU	NU	
Ozone water treatment	G	NU	G	G	?	
Protein skimmer	NU	NU	?	NU	?	
Quarantine	NU	NU	NU	G	*	
UV/heat water treatment	G	NU	G	G	?	
Water filtration	G	NU	G	NU	?	
Water monitoring	?	NU	?	NU	*	

* Bonamiasis is a grow-out disease, not a hatchery disease, but has been included here for simplicity.

Efficacy Ratings for Weed Management Tools in Oyster Production

Rating scale: E = excellent (90–100% control); G = good (80–90% control); F = fair (70–80% control); P = poor (< 70% control); ? = efficacy unknown, more research needed; * = used but not a stand-alone management tool; NU = not used for this pest; chemistry or practice known to be ineffective.

MANAGEMENT TOOLS	Algae	Grasses (invasive)	Japanese eelgrass†	Native eelgrass‡	COMMENTS
Registered Chemistries					
Glyphosate	NU	G	NU	NU	
Imazapyr	NU	E	NU	NU	
Unregistered / New Chemistries					
Imazamox	NU	NU	G^	NU	^Registered by EPA in marine environments in many states, but required National Pollutant Discharge Elimination System (NPDES) permits have not been obtained in Oregon or Washington.
Biological					
None					
Cultural/Non-chemical					
Hand removal†	NU	P	G	NU	†For seedling cordgrass only—not practical on large plants or large infestations.
Mowing	NU	P	NU	NU	For suppression of seed production.
Sweeping of protective nets (hand/machine)	P	NU	NU	NU	Efficacy dependent on algal species, seasonal temperatures, and cultural technique.
Tilling/disking	P	P	P - G	NU	For removal of Japanese eelgrass seedlings, dead *Spartina* wrack and stems, or algal mats.

† The status of Japanese eelgrass as invasive is currently unclear and under review. Clarification is needed regarding growers' ability for control.

‡ Native eelgrass is a federally protected species and is not currently managed by growers.

Efficacy Ratings for Weed Management Tools in Manila and Littleneck Clam Production

Rating scale: E = excellent (90–100% control); G = good (80–90% control); F = fair (70–80% control); P = poor (< 70% control); ? = efficacy unknown, more research needed; * = used but not a stand-alone management tool; NU = not used for this pest; chemistry or practice known to be ineffective.

MANAGEMENT TOOLS	Algae	Grasses (invasive)	Japanese eelgrass§	Native eelgrass**	COMMENTS
Registered Chemistries					
Glyphosate	NU	P	NU	NU	
Imazapyr	NU	G^	NU	NU	^ Registered by EPA in marine environments in many states, but required National Pollutant Discharge Elimination System (NPDES) permits have not been obtained in Oregon or Washington.
Unregistered / New Chemistries					
Imazamox	NU	NU	?	NU	
Biological					
None					
Cultural/Non-chemical					
Hand removal	P	P	P	NU	Would be rated "E" for seedlings or single plants only—not practical for large plants or large infestations.
Mowing	NU	P	NU	NU	
Sweeping of protective nets (hand/machine)	P	P	P	NU	

§ The status of Japanese eelgrass as invasive is currently unclear and under review. Clarification is needed regarding growers' ability for control.

** Native eelgrass is a federally protected species and is not currently managed by growers.

Efficacy Ratings for Weed Management Tools in Geoduck Clam Production

Rating scale: E = excellent (90–100% control); G = good (80–90% control); F = fair (70–80% control); P = poor (< 70% control); ? = efficacy unknown, more research needed; * = used but not a stand-alone management tool; NU = not used for this pest; chemistry or practice known to be ineffective.

MANAGEMENT TOOLS	Algae	COMMENTS
Registered Chemistries		
Glyphosate	NU	
Imazapyr	NU	
Unregistered / New Chemistries		
None		
Biological		
None		
Cultural/Non-chemical		
Hand removal	P	
Mowing	NU	
Sweeping of protective nets (hand/machine)	P	

Note:

A Weed Management Efficacy Table has not been completed for mussel production, as mussel production is generally “suspended production” and therefore not impacted by weeds.