Dichotomous Key and Illustrated Guide to the Pests of Bivalve Aquaculture in Washington and Oregon

by

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Gull identification table adapted from Dennis Paulson's, Museum Director Emeritus, Slater Museum of Natural History, University of Puget Sound, Tacoma, WA).

The guide addresses some of the complex management decisions facing bivalve producers in Washington and Oregon. Many of the organisms described in the guide may be pests at times on bivalve farms but at other times are integral members of intertidal communities, or perhaps important to both commercial producers and recreational users. Other organisms may be invasive species with the potential to severely disrupt intertidal ecology.

Contents

Dichotomous Key to Pests

1a Spends part of the time on dry land or present on shellfish beds only when exposed at low tide, or paddles over submerged beds . . . . BIRDS

1b Spends most of the time in water or present on shellfish beds at all times, or when submerged by tides; plant, fish, invertebrate, or fungus 2

2a Photosynthetic . . . . PLANTS
2b Not photosynthetic; fish, invertebrate, or fungus 3

3a With fins and scales . . . . RAY-FINNED FISH
3b Lacking fins or scales; invertebrate, or fungus 4

4a Lives within a bivalve host for at least part of life . . . . PARASITES
4b Lives within or on top of the aquaculture bed, or on related equipment, or the shell of the cultured bivalve 5

5a Dwelling directly (sessile) on bivalve shell or culture equipment production . . . . FOULING ORGANISMS (in part)
5b Not dwelling directly on shellfish or shellfish culture equipment . . . 6

6a Dwelling mostly below within the substrate, below the surface of the bed . . . . BENTHIC ORGANISMS
6b Dwelling mostly on top of aquaculture bed surface . . . . EPIBENTHIC ORGANISMS

BIRDS

1a Feet with 3 toes, the first of which always points backwards . . . . Perching birds 3
1b Web footed 2

2a With primarily white bellies and gray or black backs; call resembles human laughter . . . . Gulls p 7
2b Stocky diving birds; rarely vocalize, but males sometimes whistle . . . . Scoters and Goldeneyes p 8

3a Large robust birds; entirely black with iridescent feathers . . . . Crows and Ravens p 8
3b Other perching birds;, not problematic to bivalve aquaculture . . . . likely eagles, sand-pipers, etc.

PLANTS

1a Plant possesses a root-like, but non-vascular holdfast that anchors it to the substrate, but may foul production beds and equipment when torn from the holdfast; algae 2
1b Plant possesses a true vascular root, often with rhizomous nodes, that extend down and across the substrate; lacks bladders for buoyancy; rooted plants 4

2a Plant with floating blue-green tubular, hollow, floating filamentous stems . . . . *Ulva flexuosa* (filamentous algae) p 9
2b Plant with large floating green or golden-brown leaf-like sheets . . 3

3a Plant with very thin (2 cells), green, lettuce-like membranes
. . . . **Sea Lettuce (*Ulva lactuca*) p 9**

3b Plant with large, golden brown, leaf-like tissues embedded with bumpy gas-filled bladders to aid in buoyancy
. . . . ***Fucus gardneri* (a brown algae); not problematic**

4a Plant consisting primarily of roots and bladed leaves, lacking visible stem (eelgrasses), or else with hollow jointed stems (true grasses) . . . 5

4b Stem may be succulent (with fleshy water-storing tissues), or triangular with sharp edges (sedges), or rounded but not hollow and with 3 rows of leaves up the stem, each row arising ⅓ of the way around the stem from the previous leaf (rushes), or otherwise different from above
. . . . **Other saltmarsh and intertidal plants, not problematic**

6a Plant comprised primarily of roots and bladed leaves, lacking visible stem; entirely to mostly submerged during most of the tidal cycle.
. . . . ***Zostera spp.* (Eel grasses) 7**

6b Plant comprised of roots, hollow stem with nodes, and leaves that arise from the stem as sheathes, possesses a ligule (collar of tissue between sheath and stem); entirely submerged only on very high tides
. . . . ***Poacea* (true grasses) 8**

7a Bladed leaves grow to 3 or more feet long and over ½ inches wide by season's end. Rooted rhizomes with 5 – 20 roots per node.
. . . . **Common eel grass (*Zostera marina*) p10**

7b Bladed leaves grow to 6 or 7 inches and ~3/8 inches wide by season's end. Rooted rhizomes with 2 roots per node.
. . . . **Japanese eelgrass (*Z. japonica*) p10**

8a Ligule consisting as only a single row of hairs; leaves without prominent midribs . . . . **Cordgrasses (*Spartina spp.*) p12**

8b Ligule membranous, comprising several rows of hairs, or both; leaves may have prominent midribs
. . . . **Other saltmarsh or intertidal grasses, not problematic**

RAY-FINNED FISH

1a Asymmetrical body, protruding eyes on one side of the body
. . . . **Flatfish (Order Pleuronectiformes) p15**

1b Body symmetrical, single eye on each side of the head 2

2a Typically with large spiny heads and rounded or fanlike pectoral and caudal fins. . . . . **Sculpins (Family Cottidae) p16**

2b Dorsal and anal fins divided into anterior spiny and posterior soft-rayed portions which may be partially or completely separated
. . . . **Order Perciformes 3**

3a Deep-bodied with dark greenish back and silvery sides with fine horizontal bars with three broad yellow vertical bars.
. . . . **Shiner Perch and other Surfperches (Family Embioticidae) p16**

3b Other, not especially pestiferous to bivalve aquaculture
. . . . **Likely salmonids, Other non-pestiferous fish**

PARASITES

1a Causes damage primarily to the shell (white spots)
. . . . **Shell Disease (*Ostracoblabe implexa*) p17**

1b Resides within the bivalve; causes internal damage to the shell or organs 2

2a Primarily causes cosmetic damage to the internal shell
. . . . **"Mud" or "Blister" Worms (*Polydora* spp. (in part)) p18**

2b Primarily causes damage to the molluscan organs and tissues 3

3a Resembles a small red worm, but closer inspection reveals small limbs and 5 segmented body; actually a copepod
. . . . **Red worm (*Mytilicola orientalis*) p19**

3b Body not segmented; 2 suckers: 1 near mouth, 1 on underside
. . . . **Trematodes p20**

FOULING ORGANISMS

1a With impermeable calcite plates that cover aperture when exposed at low tide . . . . **Barnacles p21**

1b Without such plates, but may or may not be covered with a thick outer covering resembling cellulose ("tunic") 2

2a Covered with a thick outer covering resembling cellulose ("tunic"), comprised of a stalk, sack-like body, and intake and outtake siphons; in some species small individual organisms (zooids) are joined in a fleshy matrix to form large rubbery colonies . . . . **Tunicates p22**

2b Not covered with a thick "tunic"; wormlike organism that burrowing into oyster shell, causing "mud blisters" . . ***Polydora spp* (in part) p18**

BENTHIC ORGANISMS

1a All or most of body can contract within two hinged calcarous shells
. . . . **Bivalve Molluscs 6**

1b Body and appendages may be encased in an exoskeleton, but cannot be retracted 2

2a Segmented worms, with at least some segments possessing a pair of paddle-shaped appendages (parapodia), although these are nearly absent in the bamboo worm . . . . **Polychaetes (Bristle Worms) 4**

2b Segmented body covered with calcareous exoskeleton that is molted during growth; without compound eyes (as in insects) and without chelicerae (pair of 3 segmented "claw horn" on each side of the head before the mouth, as in arachnids and horseshoe crabs), with 10 pairs of legs: the first 3 pair function as mouth parts, one of which possesses enlarged pincers . . . **Order Decapoda (crabs and shrimp) 3**

3a Body wider than long; hard exoskeleton (except right after moulting); may bury itself in sediment when bed is fully exposed at low tide, otherwise highly mobile; not a true bioturbater . . . . **Crabs, in part 13**

3b Body longer than wide; soft flexible exoskeleton; nearly always within burrows deep beneath surface; pestiferous as a bioturbater (liquifies and softens benthic substrate) . . . . **Burrowing Shrimp 5**

4a Lacking in all but a few tiny appendages; both ends truncated; segments longer than wide; membranous collar on 4th segment overlaps part of the third; each individual resides inside a tube constructed from mud or sand which are connected to form colonies of hundreds of individuals; bioturbators (liquifies and softens benthic surface) . . . . **Bamboo Worm (*Clymenella torquata*) p24**

4b Rostrum nearly absent; flattened eyestalks; body color white, pink, red, or orange; . . . . **Other polychaetes – not substantive pests**

5a Large rostrum (forward extension of the carapace, the "nose"); cylindrical eyestalks; dark blue-green or gray body . . . . **Mud Shrimp (*Upogebia pugettensis*) p25**

5b Rostrum nearly absent; flattened eyestalks; body color is white, pink, red, or orange; . . . . *Neotrypaea* **spp 6**

6a No gap between dactyl ("moveable finger") and chela ("fixed finger") of larger cheliped ("pincer") when closed . . . . **Ghost Shrimp (*N. californiensis*) p25**

6b Conspicuous gap between dactyl and chela of larger cheliped when closed . . . . **Giant Sand Shrimp (*N. gigas*) p25**

7a Tube that extends from the buried bivalve to the surface ("siphon") is enlarged and cannot be totally retracted within shell; at least one end of the shell is highly truncated (not rounded), with a gap between both halves (valves) of the shell to allow for the enlarged siphon 8

7b Siphon can be totally retracted within shell; both ends of the shell rounded or pointed, not truncated; no gap between the valves 9

8a Both siphon and neck of clam are enlarged and cannot be completely retracted within shell; both ends of the shell are highly truncated (not rounded), with a gap between both valves of the shell . . . . **Pacific Geoduck, not pestiferous**

8b Siphon cannot be totally retracted within shell; both ends of the shell rounded or pointed, not truncated; no gap between the valves . . . . **Horse or Gaper Clams (Family Mactridae) p28**

9a Shell with more than 30 distinct radial ribs (ridges that extend from the umbone (hinge at the top of the valves) towards the bottom of the shells; length (from end to end, perpendicular to hinges) very similar to, or slighter shorter, than height; shell usually light tan, mottled with various bands or blotches of brown; compete with geoduck for food and space, particularly within geoduck protection tubes . . . . **Cockles** (**Family Cardiidae p29**

9b Siphon can be totally retracted within shell; both ends of the shell rounded or pointed, not truncated; no gap between the valves . . . . **Non-pestiferous bivalves**

EPIBENTHIC ORGANISMS

1a All or most of body can contract within a single large, or two hinged calcarous shells . . . . **Molluscs 8**

1b Body and appendages may be encased in an exoskeleton, but cannot be contracted within shells 2

2a Body and appendages not encased in an exoskeleton; possess a mesodermal skeleton ("test") that may persist after death in sandollars; the thick skin may be covered with spines; possess pentaradial symmetry (5 similar body parts interlock at the center), mostly in later life stages . . . . **Echinoderms 3**

2b Crustaceans. Possess calcareous exoskeleton and bilateral symmetry (body comprised to 2 sides which resemble each other); 10 legs, the first 3 pair function as mouth parts, one of which possesses enlarged pincers . . . . **Order Decapoda (crabs and shrimp) 4**

3a With bilateral symmetry (has front and back, anus located near the rear) as well as top and bottom) in addition to pentaradial symmetry; lacks arms or legs, but with spines and small tube-feet that are used for locomotion; actually hyperbenthic (burrow slightly beneath the surface); disk-shaped endoskeleton ("test") may persist for months after death . . . . . **Western Sand Dollar (*Dendraster excentricus*) p30**

3b Adults with pentaradial symmetry only; with at least 5 obvious arms; resides primarily on sediment surface only; endoskeleton decays quickly after death . . . . **Sea Stars (Class Asteroidea) p31**

4a Reduced abdomen entirely hidden beneath the enlarged thorax; relatively long legs are hinged for characteristic sideways movement; hard exoskeleton . . . . **Infraorder Brachyura (True Crabs) 5**

4b Not as above . . . . **Other shrimp and shrimp-like animals (Crangon Shrimp, Mysid Shrimp), generally not pestiferous**

5a Fifth pair of legs flattened into broad paddles; five spines ("teeth") on the front edge of each side of the carapace and carapace widest between hindmost (fifth) spines; color of dorsal (top) side of carapace quite variable for juveniles, but usually dark green with yellow marking for adults; color of ventral (bottom) side of carapace often bright red or yellow . **European Green Crab (*Carcinus maenas*) p32**

5b Fifth pair of legs not as flattened; lacking a prominent rostrum (frontal extension of carapace between the eye stalks); carapace broadly oval; color not as above . **Family Cancridea (Cancer Crabs) 6**

6a Tips of chilipeds (enlarged pincers) very dark to black; lacks serrations on the ventral (bottom) side of the claws; adults brick red in color . . . . ***Cancer productus* (Red Rock Crab) p33**

6b Tips of chilipeds not darkened; serrations present on ventral side of claws; adults may be reddish, but not brick red 7

7a Carapace widest at the 10th tooth in a line that extends along the side of the carapace from the first next to the eye; spiny ridges on parts of the chilipeds (enlarged pincers); last segment of tail flap curved . . . . ***Metacarcinus (=Cancer) magister* (Dungeness Crab) p33**

7b Carapace widest at the 9th tooth in a line that extends along the edge of the carapace from the first next to the eye; no spiny ridges on parts of the chilipeds (enlarged pincers); last segment of tail flap pointed . . . . ***Metacarcinus (=Cancer) gracilis* (Graceful Rock Crab) p33**

8a All or most of body can contract within a single shell; some are predators that drill holes into bivalves and feed on the body; some are attached to the shells of other snails or bivalves
. . . . Gastropod Molluscs (Snails) 9
8b All or most of body can contract within two hinged Asymmetrical shells; attach themselves to substrates via a byssus (tuft of fine silky filaments) . . . . Mussels 14

9a Shell conical or cap shaped, not coiled; interior of shell with shelf
. . . . Slipper Snails (Family Calyptraeidae) 10
9b Shell coiled, with or without tall spire; interior of shell lacks shelf 12

10a Shell definitely arched, higher than wide, apex beaklike
. . . . *Crepicula adunca* (Hooked Slipper Snail) p34
10b Shell not arched; lower than wide; lacking beaklike apex 11

11a Shell whitish, but with a shaggy, yellow brown periostracum (outermost, thin layer of shell; composed of organic material that lends color to the shell; often lacking in older, dead specimens); shell almost flat . Western White Slipper Snail (*Crepicula nummaria*) p34
11b Shell whitish, but with brown periostracum, or without obvious periostracum; shell may be flat, concave, or misshapen ,depending on habitat . . . . White Slipper Snail (*Crepidula perforans*) p34

12a Diameter nearly equal to height, almost globular, consisting mostly of the body whorl. Produces gelatinous ring or collar of eggs
. . . . Lewis's Moon Snail (*Euspira (Polinices) lewisii*) p35
12b Height greater than diameter, but with no more than 7 whorls; axial ribs (ridges that run across the shell, perpendicular to body and spiral whorls) present on both upper (spire) and lower (body whorl)
. . . . Drills (Family Muricidae) 13

13a Edges of the siphonal canal (extension at the bottom of the aperture (body opening) touching or nearly touching for at least part of the canal, essentially a closed tube; outer lip of the aperture thickened to more than half the width of the aperture (in mature specimens)
. . . . Japanese Oyster Drill (*Ocinebrellus inornatus*) p36

13b Edges of the siphonal canal do not touch, the canal is essentially an open trough; outer lip of the aperture not as thick as half the width of the aperture; much less than twice the diameter
. . . . . Eastern or Atlantic Oyster Drill (*Ocinebrellus inornatus*) p36

14a Small (up to 1½"); olive-green, yellow-green or greenish-brown in color, with pale purple stripes that extend from the center of growth to the hind margin of the shell, and wavy brown lines surrounding the center of growth
. . . . . Asian or Japanese Green Mussel (*Musculista senhousia*) p37
14b Large (up to 4½"); dark blue to black, sometimes brown to black in color, with fine (not coarse) radial ribs . . . . . . Blue mussel complex (*Mytilus edulis/trossulus/galloprovincialus*) p38

Gulls (primarily *Larus* spp.)

Status: Gulls, along with other waterfowl, are a primary pest of mussel and clam aquaculture, particularly those grown on the ground or that are otherwise exposed at low tide. Gulls are omnivores and feed on other aquatic items aside from bivalves, including fish, carrion and garbage. Gulls will aggregate and feed on burrowing shrimp that exit their burrows due to habitat disruption, but not to the extent to substantially suppress populations. Members of the genus, *Larus*, (primarily) have become highly hybridized due to their broad feeding habits and association with expanding human civilization and loss of wild habitat.

Description: Medium to large grey white birds that have harsh wailing or squawking calls that may resemble human laughter. Primary species along the Oregon and Washington coast can be generally characterized by the patterns of black markings on the head and wings, the color of the mantle, color and pattern of spots on the bill, and color legs and the color of rings that surrounds the eyes. See table below (from Dennis Paulson's, Museum Director Emeritus, Slater Museum of Natural History, University of Puget Sound, Tacoma, WA).

Identification guide to common gull species along the Washington and Oregon coasts based on color of head, mantle, bill, legs, and eye ring.

Species	Mantle	Bill	Legs	Eye Ring
White head				
Herring	pale gray	yellow with red spot	pink	yellow-orange
Thayer's	pale gray	yellow with red spot	pink	reddish-purple
Ring-billed	pale gray	yellow with black ring	pink	orange-red
Glaucous-winged	neutral	yellow with red spot	red	pink to purple
California	neutral	yellow with red and black	pink	red
Mew	neutral	dull yellow	green to	red
Black-legged	neutral	yellow	dull yellow	red
Western	dark gray	yellow with red spot	black	yellow-orange
Dark head				
Bonaparte's	pale gray	black	orange red	black
Sabine's	neutral	black with yellow tip	black	red

Management: See p 8

Diving Seaducks (Scoters & Goldeneyes, Family Anatidae)

Status: Scoters and goldeneyes can be a primary pest of unprotected bivalves cultured on the ground. They feed on crustaceans as well as bivalves and other molluscs. They breed further north or inland during summer. The White-winged Scoter (*Melanitta deglandi*), the Surf Scoter (*M. perspicillata*), the Black Scoter (*M. nigra*), and the Common Goldeneye (*Bucephala clangula*) are common to the coastal regions of the PNW during the winter. Another seaduck, the Harelquin, (*Histrionicus histrionicus*) (Harelquin duck), is uncommon in the region.

Description: Medium stocky ducks. Males have broad swollen bills and are black; females are brown.

Management: Passive measures include substrate covers, fencing, and nets on Manila clams, geoducks, and mussels (suspended culture). Hazing (harassing to disturb the animals, causing them to leave) is often difficult as these birds are often on the bed at the same times as workers.

Crows and Ravens (Family Corvidae)

Status: Crows and raven may feed on ground cultured, unprotected bivalves that are exposed by low tides. Like waterfowl, crows and ravens may contribute to higher fecal coliform bacteria levels on commercial bivalve beds, which could result in downgrades or closures of growing areas. The American Crow (*Corvus brachyrhynchos*) and the Common or Northern Raven *©. corax*) are members of the Family Corvidae, which includes the magpies and jays. The distributions of other crows and ravens do not include the most of the primary bivalve producing areas in Washington and Oregon, although the Northwestern Crow *©. caurinus*) is distributed along the outer Olympic Peninsula north to Alaska.

Description: Both crows and ravens are large black birds, but the Common Raven has a larger and heavier, slightly curved beak, shaggy plumage on the throat and above the beak, and a wedge-shaped tail. The call of the Common Crow is a short “caaw, caaw, caaw”, while the Raven’s call is deeper and more resonant. Both species produce a wide variety of other sounds, including the ability to mimic the calls of other birds. Crows form flocks (or murders) while ravens are solitary.

Management: Passive measures include substrate covers, fencing, and nets on Manila clams, geoducks, and mussels (suspended culture). Hazing (harassing to disturb the animals, causing them to leave) is often difficult as these birds are often on the bed at the same times as workers. The highly intelligent, often brazen, crows and ravens are more difficult to haze than other birds. Shooting is illegal.

Filamentous Algae and Sea Lettuce (*Ulva spp.*)

<u>Status:</u> Filamentous algae (*Ulva flexuosa*, formerly *Enteromorpha flexuosa*) and sea lettuce (*U. lactuca*) can foul aquaculture equipment and developing bivalves if detached leaves and stems reach high densities. Blankets of sea lettuce can become thick enough to smother epibenthic organisms, including developing bivalves, resulting in high levels of hydrogen sulfide, causing further mortality.

<u>Description:</u> *U. flexuosa* is a yellow to light green alga that can grow about 1 ft tall. The fronds are tubular with cylindrical stalks and are attached to a small round basal disc. *Ulva lactuca* is a very thin flat green alga that also grows from a holdfast, up to 6 or 7 long and a foot wide. The "leaves" are ruffled and often frayed or torn.

<u>Management:</u> Nets are sometimes placed over ground cultured shellfish, primarily clams, then are removed and cleaned of algae periodically. Some growers mechanically sweep the nets while in place. Thick blankets of algae can be removed by hand.

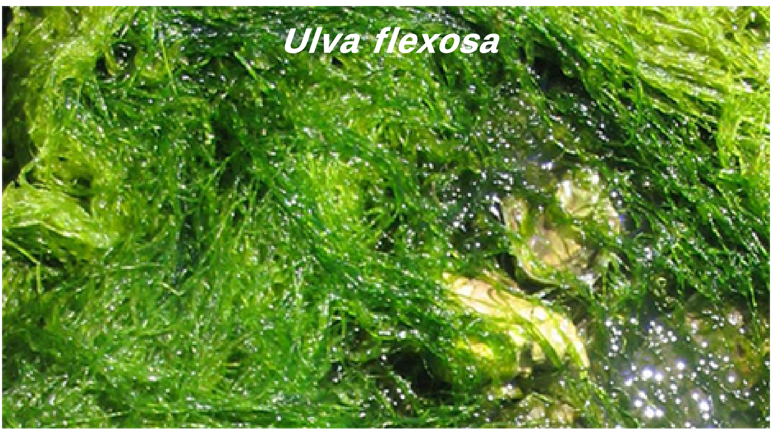

Photo: Steve Booth

Photo: Steve Booth Photo: Brian Allen

Eelgrasses (*Zostera marina* and *Z. japonica*)

Status: *Zostera marina* and *Z. japonica* are two of 20 eelgrass species worldwide, but only *Z. marina* and *Z. japonica* are present in Washington and Oregon. *Z. marina* is native to the region but *Z. japonica* was introduced, likely from Korea and Japan, possibly as early as the 1930s. The distribution of Japanese eelgrass (*Z. japonica*) has expanded greatly, especially in the last decade. *Z. japonica* inhabits higher intertidal ground than *Z. marina*, so has not directly replaced the latter. Both are important to ecosystem function and aid in sediment deposition and stabilization. They provide substrate for many epiphytic algae and invertebrates, habitat for many marine vertebrates, and forage for waterfowl. Accordingly, these species have historically been granted "protected" status on public lands.

Z. japonica is now particularly dense on upper tidal elevation commercial clam beds in parts of Willapa Bay and Samish Bay, where it interferes with commercial clam production by restricting or redirecting water currents and associated nutrients and oxygen and accelerating sediment deposition. Japanese eelgrass may discourage Green Sturgeon, a listed species, from foraging on burrowing shrimp.

Description: Although eelgrasses are perennial plants, the bladed leaves die back in the winter months, leaving just a few strands on the rooted nodules. When regrowth begins in the spring, *Z. japonica* may be difficult to distinguish from *Z. marina* but the latter quickly outgrows *Z. japonica*; the leaves reach lengths of 3 feet or more by August, but are often less as they can break into sections. The leaves of *Z. japonica* are narrower than *Z. marina* (<¼" vs nearly ½", respectively for mature individuals, but young *Z. marina* can have similarly narrow leaves). The leaves of *Z. japonica* are generally <1 ft long whereas those of *Z. marina* can reach 3 ft or more in length. Both species produce seeds, but population growth is primarily by sub-surface rhizomes, which plant a rooted nodule every few feet from which a new group of leaves can sprout. *Z. japonica* has 2 roots per nodule whereas *Z. marina* has 5 to 20.

Management: Until recently, all *Zostera* species in Washington were protected under several state and federal laws including the Hydraulic Code Rules, the Shoreline Management Act, the Growth Management Act and Fish and Wildlife Habitat Conservation Areas (Washington) and by the Army Corps of Engineers permitting processes for commercial shellfish culture (Federal). The Washington Department of Fish and Wildlife listing of Priority Habitats and Species exempted *Z. japonica* from protection in early 2011. In late 2011, the Washington State Weed Commission listed *Z. japonica* as a Class C noxious weed on Washington commercially managed shellfish beds only. The Hydraulic Code has been revised to redefine seagrass to exclude *Z. japonica*, but other parts the Washington Authorization Code still consider it a seagrass. Nevertheless the Washington Department of Ecology is drafting a National Discharge Elimination System (NPDES) permit for the use of the herbicide imazamox on commercial clam beds in Willapa Bay and Grays Harbor, only. In Oregon, *Z. japonica* is neither protected nor listed as a noxious weed.

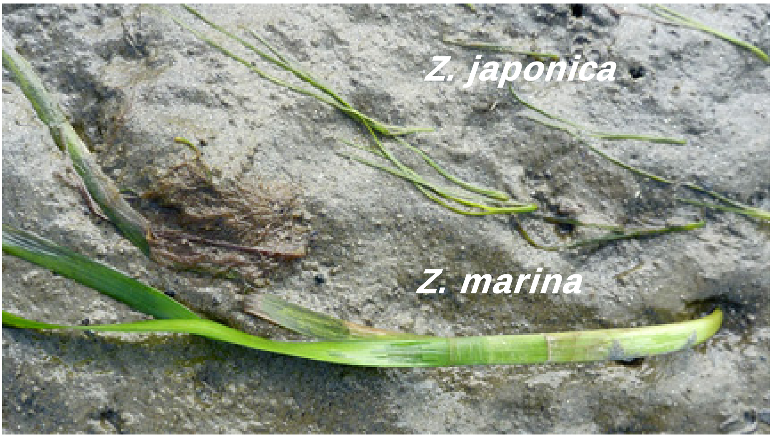

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Photo: Steve Booth

Photo: PSI

Status: Four species of invasive *Spartina* are currently of concern in Washington State (*S. alterniflora*, *S. angelica*, *S. densiflora* , and *S. pattens*) but the first has been the most problematic. After remaining at tolerable levels for 100 years since its introduction, likely in the 1890s, *S. alterniflora* expanded into hundreds of acres of formerly bare mudflats in all coastal counties except Whatcom, especially Pacific. These *Spartina* species were designated Class A noxious weeds by the Washington State Noxious Weed Board. A collaborative eradication program involving the Washington State Department of Agriculture with strong collaborative efforts from U.S. Fish and Wildlife, Washington Department of Natural Resources, Washington Department of Fish and Wildlife, Shoalwater Tribe, and Willapa National Wildlife Refuge made remarkable progress towards the eradication of *Spartina* in Pacific County. In 2011, only 2 net ac of Spartina remained within Willapa Bay, representing 0.02% of the peak acreage of the infestation in 2003, 9000 net ac. About 100 acres (of mostly *S. angelica*) remain in Puget Sound. The eradication program features several integrated control strategies, as outlined below. Growers are acting as scouts for weed appearance and, when found, notifying state agencies for targeted management efforts.

Spartina is currently not a major problem for Oregon shellfish growers. Spartina presence in Oregon is currently limited to *S. patens* on the Nature Conservancy's Cox Island Preserve in the Siuslaw River estuary. Oregon has a Spartina response plan that addresses new infestations as they arise.

Description: All *Spartina* species are best distinguished from other saltmarsh plants by their hollow stem and the presence of straight hairs on ligule or joint where the leaf attaches to stem. They are similar to one another, differing somewhat in height, habitat preferences, and flowering season. *S. angelica* reaches a maximum height of 1.5 m, *S. alterniflora*, 2 m; *S. angelica* lives throughout the tidal marsh (low – high elevations) and blooms in June – September. More thorough species descriptions are presented at many websites (i.e., (http://www.psparchives.com/our_work/protect_habitat/ans/spartina.htm)

General characteristics of invasive *Spartina* species.

Species	Maximum Height (m)	Tidal Elevation	Flowering Season
S. angelica	1.5	low – high	Jun – Sep
S. alterniflora	2	mean high water – 1 m above mean low water	late Jul – Oct
S. densiflora	1.5	high	Jun – Sep
S. pattens	1.2	high; infrequent tidal flooding	Jun – Sep
S. angelica	2	low – high	Jun – Sep

Photos: WDFW / WSDA

Photo: T. Forney (ODA)

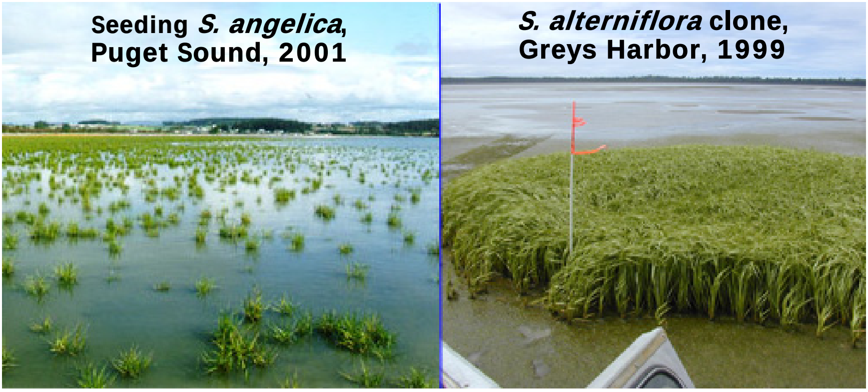


Photo: WDFW / WSDA

<u>Management</u>: The *Spartina* eradication program featured several integrated control strategies. Crushing of *Spartina* using large heavy tract vehicles (e.g., the Marshmaster™, Coast Machinery, LLC; Baton Rouge, LA) was effective in localized areas by state agencies. Seedlings were pulled by hand at areas of sparse infestation and difficult access. Mowing before seed development slowed infestation rates. In 2001 and 2002, the plant hopper *Prokelesia marginata* (Delphacidae: Homoptera), was introduced to small, selected study sites in Willapa Bay that were heavily infested with *S. alterniflora*. Although hopper populations initially remained sparse and declined each winter when cordgrass went dormant, they showed substantial increases at some sites by 2005. Plants in areas of high hopper infestation ($>5000/m^2$) were visibly stressed. Hoppers increased in distribution range as well as density. The experiment was terminated in 2007 when the herbicide-based eradication program with imazapyr proved successful. Imazapyr (Habitat™), applied at 6 pt/ac to infested areas once per year, is quite effective. It has been applied both by air and ground-operated equipment including airboats, large and small tracked vehicles, 4-wheelers, and back-pack sprayers. Glyphosate (Rodeo™), applied at 3% v/v in 100 GPA spray volume, is less effective than imazapyr, but was applied as a check for effective coverage of imazapyr, as plants treated with glyphosate will turn brown as they die whereas those treated with imazapyr will not.

Continuing efforts to eradicate *Spartina* in Washington depend on vigilant monitoring by resource users, primarily shellfish growers.

In 2003, Oregon developed a Spartina Response plan that outlined a strategy to "prevent, detect, identify, and eradicate the weed in Oregon".

Any person finding live *Spartina* plants should call 1-360-902-1923 (Washington State Spartina Coordinator or the Oregon Invader hotline (1-866-INVADER; e.g., 1-866-468-2337).

Status: Flatfish are minor pests of bivalve production, preying directly on unprotected bottom crops, particularly if they enter culture tubes for juvenile geoduck. Flatfish (Order Pleuronectiformes) comprise 10 suborders and hundreds of species worldwide. Common species in PNW coastal areas include Starry Flounder (*Platichthys stellatus*), Petrale Sole (*Eopsetta jordani*), and others. Adults of most species inhabit deeper waters, but juveniles often live in shallow intertidal estuarine waters favorable to bivalve production.

Description: Flatfish are easily characterized by their flattened bodies. They reside directly on the substrate surface with their top side camouflaged to match that substrate or otherwise colored. Eyes protrude and are also on the top side of the head.

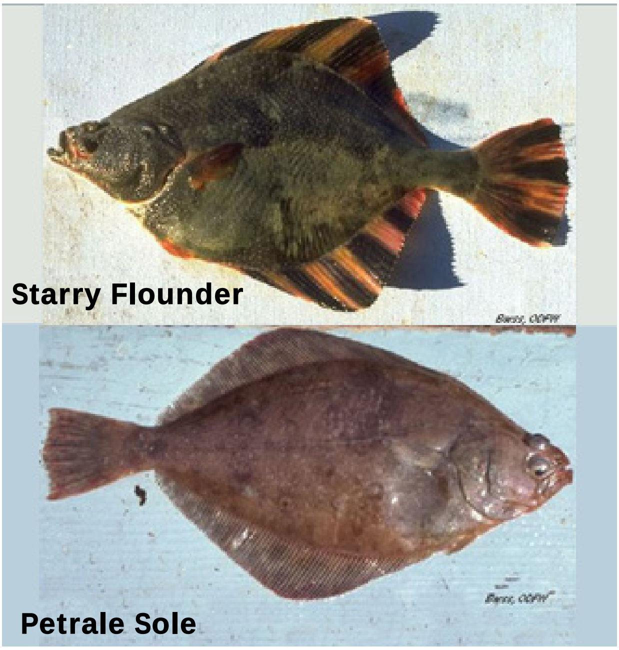


Photo: Bill Barss (ODFW)

Management: Passive measures include substrate covers, fencing, and nets on Manila clams, geoducks, and mussels (suspended culture).

Sculpins (Family Cottidae) and Surfperches (Family embioticidae)

Sculpins

Status: At least 10 species of sculpin (Family Cottidae) reside in the coastal estuaries of Washington and Oregon, and in Puget Sound, where they feed on bivalves and other mollusks. Sculpins are usually a minor pest, but can be of concern to geoduck production if they enter the culture tubes and prey on juveniles.

Description: Most sculpins have a large head and mouth, and an elongate tapering body partly covered with scales or prickles. The large eyes are placed high on the head, and there are usually one to five well-developed spines in front of the eyes. The pectoral (front) fins are broad and fan-like. Most species have a deeply notched or divided dorsal fin.

Cabezon

Photo: Steve Lonhart (SIMoN)

Surfperches

Status: Shiner perch (*Cymatogaster aggregata*), and other surfperches like redtail perch (*Amphistichus rhodoterusis*), Calico Surfperch (*Amphistichus koelzi*), and Striped Surfperch (*Embiotoca lateralis*) and others (Family Embioticidae) nibble on long lined oysters and suspended culture oysters and mussels, often causing substantial yield losses. They also prey on small clam, oyster, and mussel seed in nursery.

Description: Surfperches have compressed and oval to oblong shaped bodies. The dorsal fins are not notched and the tail fin is forked. Bodies are usually white with stripes or bars, but color may change depending on breeding status and age. Sufperch have a greenish back and silvery sides with fine horizontal bars with three broad yellow vertical bars. Breeding males turn almost entirely black and speckles obscure the bars.

Striped Surfperch

Redtail Surfperch

Photo: Steve Lonhart (SIMoN) Photo in public domain (NOAA)

Management of both sculpins and surfperches: Passive measures include substrate covers, fencing, and nets on Manila clams, geoducks, and mussels (suspended culture).

Shell Disease (*Ostracoblabe implexa*)

Status: Shell disease (*Ostracoblabe implexa*, initially called *Myotomus ostrearum*), is a parasitic fungus that infects oysters by growing through the shell and creating small raised white spots or rings on the inner surface. Infection may be stimulated by presence of oyster drill holes.

Description: Damage is largely cosmetic, but can be severe enough to affect marketability. As growth continues, the spots become larger and turn black, the shell margin thickens, and the adductor muscles weaken, eventually leading to death. A more thorough diagnosis involves microscopic examination and measurement of the mycelial (fungal) network after decalcification of affected shells in 5% solution of disodium diaminoethylenetetraacetate (EDTA) (From: Synopsis of Infectious Diseases and Parasites of Commercially Exploited Shellfish. Fisheries and Oceans Canada. www.dfo-mpo.gc.ca)

Management: No practical direct controls exist. As for other diseases and parasites, bivalves from areas of known infestation should not be moved to areas lacking infection. Better control of oyster drills should result in some suppression of shell disease.

Blister or Mud Worms (*Polydora* spp.)

Status: Some species in this genus of polychaete worms have been dubbed “blister worms” or “mud worms” as they cause small pockets (“blisters”) in the bivalve shell, which often fill with mud, turn black, and degrade the appearance and value of the bivalve product. *P. websteri* enters the bivalve as a larvae and develops next to the mantle where it blisters the inner shell. *P. cornuta* (formerly *P. ligni*) bores into the shell, creating mud-filled pockets mostly on the shell exterior, but sometimes entering the mollusc, where it can cause mortality or affect development, especially in already stressed individuals. *P. cornuta* is common in Washington and Oregon estuaries but remains a minor pest.

Description: Small (~1 to 1.5" long and ¼” wide) non-descript bristle worm. Prostomonium tip (flap overhanging mouth) is T-shaped.


Worm in Oyster Beak


Worm out of Oyster


Severe Damage


Typical Damage

John McCabe, www.oysters.us

Management: The experimental exposure of infested Eastern oysters to both freshwater (12 hr) and heated seawater (70°C for 40 s) significantly reduced average infestation per oyster without significantly increasing oyster mortality. The oysters were cultured in crates hung on longlines. The crates were temporarily removed from the longlines for the experimental treatment. Similar exposures of infested oysters to brine solution (15 minutes followed by 15 minutes air-drying or 1 minute exposure followed by 2 hr air-drying) was similarly effective against mudworm infested Pacific oysters in Australia. These tactics may be practical in South Africa and Australia, where mudworm infestation rates are remarkably high, but are likely not cost effective oysters in Washington or Oregon, where oysters are more often cultured directly on the ground or as singles on long-lines.

<u>Status:</u> *Mytilicola orientalis*, sometimes called Thunberg's parasite, was likely introduced to the west coast of the United States in the 1930s from Japan and again in the 1970s from France, and is now distributed along the entire coast. However, it seems restricted to sheltered muddy estuaries, probably areas with greater wave and tidal action affect the free-swimming larvae. *M. orientalis* infests all oysters along the west coast, including the Olympic oyster, as well as mussels, clams, and cockles. Infestation has been reported as affecting the weight of oyster meat, but the degree of impact is variable. Otherwise very healthy bivalves may be less affected and lower infestation rates (< 10 parasites / animal) result in lower impact.

<u>Description:</u> A reddish colored copepod in the stomach and intestines of bivalves. Resembles a worm but has five thoracic segments, each with paired triangular protuberances extending to the side. A genital segment follows the thorax, then a narrower abdomen with incomplete segmentation. The female is about 6 to 12 mm in length, 1.3 mm in greatest width and can have paired elongate ovisacs (about 7 mm in length each containing about 200 eggs) attached to the genital segment and possibly extending beyond the posterior end of the abdomen. The male is smaller than the female with a total length of about 2 to 5 mm and greatest width of about 0.5 mm. The head of *M. orientalis* carries a median red eye spot, the first pair of antennae has four segments and the second has two. The second antennae are modified as a pair of stout hooks that are used as anchors for resisting expulsion from the host. There is an overall reduction in the length and complexity of the appendages in comparison to free living copepods. (From: Synopsis of Infectious Diseases and Parasites of Commercially Exploited Shellfish. Fisheries and Oceans Canada. www.dfo-mpo.gc.ca)

<u>Management:</u> Tactics to quickly reduce infestations have not been identified. Bivalves from areas known to be affected (currently or historically) should not be moved to areas lacking infections.

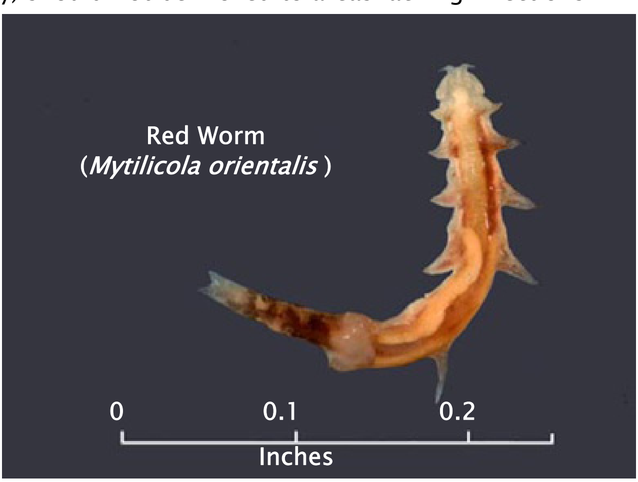


Photo: Ralph Elston

Parasites

Status: Most species are innocuous, however some species are reported to affect some clam behaviors, such as disorientation; or can severely damage tissues, leading to mortality, castration, or shell deformities. Problematic species include members of the sub-class Digenea, including *Gymnophalloides tokiensis* (Family Gymnophallidae), *Bucephalus haimeanus*, *B. cucullus*, other *Bucephalus spp* (Family Bucephalidae), and *Proectoeces maculatus* (Family Fellodistomatidae).

Description: Diagnosis is complex and depends on slide preparation of tissues. Individuals suspected of infection should be packed and shipped under controlled conditions to bivalve pathologists. (Synopsis of Infectious Diseases and Parasites of Commercially Exploited Shellfish. Fisheries and Oceans Canada. www.dfo-mpo.gc.ca)

Management: Tactics to quickly reduce infestations have not been identified. Bivalves from areas known to be affected (currently or historically) should not be moved to areas lacking infections.

Barnacles (Family Balanidae)

Status: Barnacles may increase costs of bivalve production by fouling boat hulls and other aquaculture equipment, or by causing cosmetic damage to an in-shell product. The Little Brown Barnacle or Small Acorn Barnacle (*Chthamalus dalli*) inhabits the upper intertidal elevations, can tolerate long intervals out of the water, so frequently fouls bivalves cultured on long-lines or other tactics which allow such exposure. Larger barnacles (e.g., *Semibalanus cariosus*, *Balanus glandula*, *B. crenatusi*) inhabit a wider range of tidal elevation and may foul mussel rafts and other equipment that is underwater for longer time periods.

Description: The Little Brown Barnacle reaches a maximum diameter of 0.3 inches in diameter. When closed, the cover plates intersect so as to form a cross. The Giant Acorn Barnacle reaches a diameter of 6 inches.

Management: Oyster bags and equipment should be cleaned periodically to remove barnacles. Timing of seeding, thinning, gear placement, and harvest is an important control in fast-growing crops like single oysters and mussels. Boats, scows, and gear should be cleaned by hand or machine. 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, but some metal-free or reduced-metal biocides are also available for preventative use on boat bottoms. Most of these work by creating slick films that suppress barnacles from attaching. Finally, avoid areas of heavy barnacle settlement when possible.

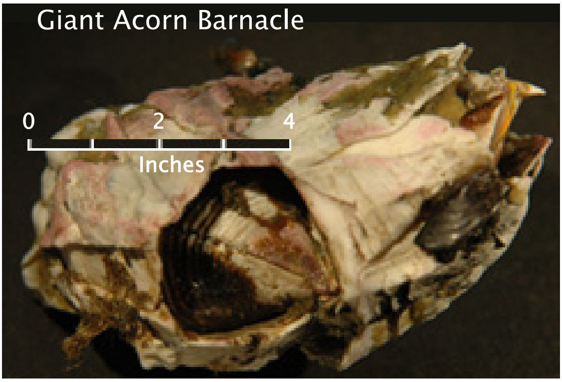


Photo: Dave Cowles

Photo: Steve Booth

<u>Status:</u> Tunicates, in particular the sea squirts (Class Asidiacea), occur as both solitary and colonial species. The latter are perhaps more detrimental to oyster cultural, as they form dense rubbery mats which foul suspended cultured bivalves (i.e., mussel rafts). Several species of sea squirts are common in the intertidal marine and estuarine waters of Washington and Oregon: Flattop sea squirt (*Chelyosoma productum*), Brooding Transparent tunicate (*Corella inflata*), and Mushroom tunicate (*Disaplia occidentalis*). Native sea squirts can foul docks, boats, and shellfish culture, but invasive sea squirts, which proliferate more quickly, pose a greater threat.

Washington State has identified three High Priority Invasive species of sea squirts: *Styela clava* (Club tunicate), *Ciona savignyi* (Transparent tunicate), and Whangamata sea squirt (*Didemnum vexillum*; Colonial). A 2006 survey of Washington state marinas, harbors, and shellfish grounds found the *Didemnum vexillum* at 10 sites, mostly in Central Puget Sound, but also at a single site in Totten Inlet, South Sound. *Ciona savignyi* was found at 14 sites in South Hood Canal and Central Puget Sound. *Styela clava* was found only at Pleasant Harbor, Hood Canal and at the Blaine and Semiahmoo Marinas on the North Washington Coast. *Styela clava* has been found in Oregon, only in Coos Bay, where it has been established since at least 1993. *Didemnum vexillum* was found in both Coos Bay and Winchester Bay, OR in 2010 and, judging by the size of the colonies, probably established in both bays in 2008. Further surveys indicate the tunicates are isolated to those areas.

<u>Description:</u> Tunicates are filter feeders and consist primarily of a sack-like body, intake and outtake siphons, and a stalk that is used to attach to a rock or some other stable part of the ocean floor, or to a dock, boat, or shellfish culture equipment.

Tunicates cannot be definitively identified in the field. Diagnostic characters need to be closely examined and in some cases, tissue samples need to be examined under a microscope. Nevertheless, the habit (solitary or colonial), color, and size can be used to roughly identify species.

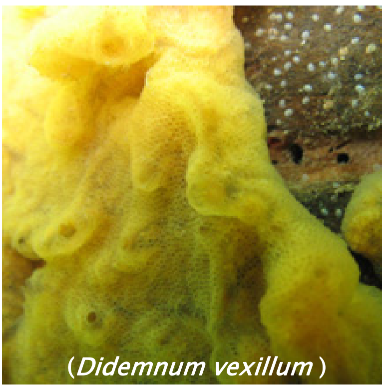
Styela clava can reach lengths of 5-6" and have a leathery, bumpy brown-to-rust color body. Their siphons are smooth and banded and the stalk is thin. They often grow hanging from docks or boats.

As the name suggests, Transparent tunicates are clear. However, the native brooding tunicate incorporates some foreign material into its tunic whereas the invasive *Ciona savignyi* is entirely transparent and grows upright from a short stalk that is not always visible.

A native colonial sea squirt, the Red ascidian (*Aplidium solidum*), is distinguished from the *Didemnum vexillum* partly by color; the former are most often red as the name suggests whereas the latter are yellow. *A. californicum* is found in Washington and Oregon waters, and is sometimes yellow, but more some colonies are white or red.


(*Styela clava*)


(*Ciona savignyi*)


(*Didemnum vexillum*)


(*Didemnum vexillum*)


Native tunicate


Native “Peanut” tunicate

All Photos: Janna Nichols

<u>Management:</u> The occurrence, density, and distribution of these and other potentially non-native species should be diligently monitored. Hand removal, primarily by divers, is fairly effective. Pressure washing is also effective, but is not selective towards tunicates only and can be destructive to wooden docks or structures. Wrapping tunicates in plastic is likely effective, although a test of the procedure was not successful for several reasons, but primarily because the entire wharf could not be wrapped. Treatment with acetic acid (vinegar) is also effective.

Invasive Bamboo Worm (*Clymenella torquata*)

<u>Status:</u> *Clymenella torquata* are native to the Asian Pacific, but have spread to the coasts of England and the East and West Coasts of North America. Their distribution in West Coast estuaries so far seems to be limited to small areas in Samish Bay and Puget Sound, Washington, but they nevertheless are present on the Washington State Non-Native Aquatic Species Watchlist. They are bioturbators and disrupt the substrate to such an extent that shellfish production in the parts of Samish Bay where they occur has been essentially eliminated. Other members of the genus are native to Washington and Oregon but are not nearly as problematic to bivalve aquaculture.

<u>Description:</u> All members of the Family Maldanidae (Phylum Polychaeta) are commonly referred to as Bamboo Worms, as they vaguely resemble the plant. Like many polychaetes, Bamboo Worms reside within tubes constructed from fine sediments. Body segments are longer than wide and swollen where they connect. While some species in the family have a collar around the upper segments, *C. torquata* has an especially noticeable one on the fourth segment, extending into the third.

<u>Management:</u> Bamboo Worms have tried to be suppressed mechanically by covering with oyster shell or carpets and by roto-tilling. Sediments were significantly more compact in worm infested areas after any of these treatments, but only roto-tilling significantly suppressed worm biomass and tube density. Cutting resulted in some regeneration, but high percentages of cut worms were ecologically dead within a matter of days. These tactics are severely labor intensive and also negatively effect the suitability of substrates to culture bivalves. The neo-nicotinoid pesticide, imidacloprid, effectively killed bamboo worms in the lab, but field trials have not been conducted.

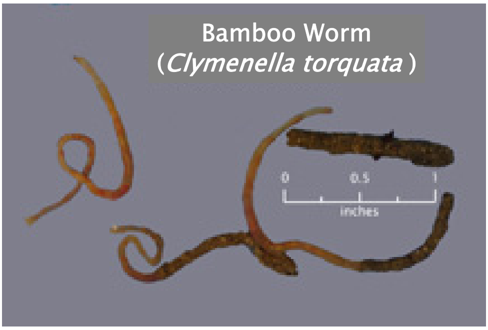
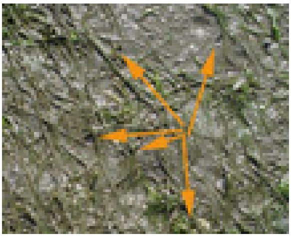


Photo: Steve Booth



All Photos: PSI

Ghost and Mud Burrowing Shrimp (*Neotrypaea spp., Upogebia pugettensis*)

Status: Burrowing shrimp affect bivalve cultivation, especially ground culture, by pumping water through their burrows and the surrounding sediments, destabilizing them and causing surface dwelling organisms to sink and drown. Ghost shrimp (*Neotrypaea californiensis*) are the most common species in most areas, as a host-specific parasitic isopod, *Orthione griffinis* , has caused precipitous declines in mud shrimp (*Upogebia pugettensis*) populations within the last decade, especially in Willapa Bay. The giant sand shrimp (*N. gigas*) is not as common as the other two species, but densities are high in northern parts of Willapa Bay. Burrowing shrimp are mostly a problem to bivalve aquaculture in the coastal estuaries, as pelagic larvae disperse there from nearby ocean currents. Puget Sound bivalve farms are further inland and subject to lower salinities that suppress development. Burrowing shrimp can impact almost all techniques of bivalve production of all bivalve species. Geoducks grown in shrimp infested areas are smaller and the tubes will sink. Mussels grown on rafts are unaffected, but this growing method is not available in shallow intertidal areas. Burrowing shrimp densities are high and very much a problem in the relatively shallow Willapa Bay.

Description: Burrowing shrimp are distinguished from other shrimp or shrimp-like animals by their 10 legs (Order Decapoda), that the females carry fertilized eggs on their abdomen until they hatch (Sub-order Pleocyemata) and an elongate, flexible body with broad setose ("hairy") pleopods (abdominal appendages) to pump water, and broad uropods (frontal "claws") for sealing burrows (Infra-Order Thalassinidea).

Photos: Katylin Bosley

Photo: Tony D'Andrea

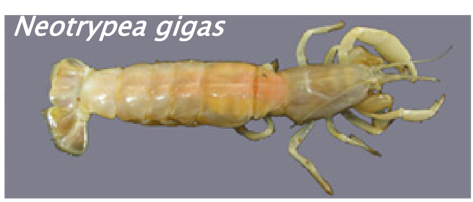


Photo: PSI

26 **Ghost and Mud Burrowing Shrimp (*Neotrypaea spp., Upogebia pugettensis*)**

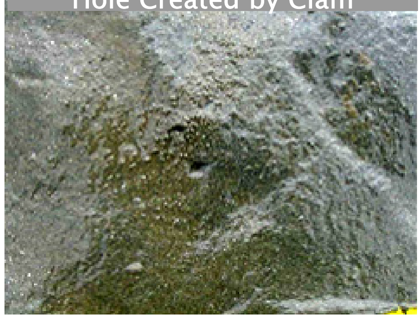
In the field, subterranean burrowing shrimp are usually distinguished from other benthic organisms by the size and shape of their burrows. This an inexact method, as burrows vary according to the species and size of the shrimp, level of the tide, and the presence or strength of water current. Small holes do not always indicate smaller shrimp, as burrows possess multiple holes and primary ones are larger than secondary ones. Small holes also indicate benthic dwelling clams. If currents are not strong, a mound of sediment will form around the burrow. When burrows are especially deep, (often the case with mud shrimp), the sediments will differ in color from the normal surface sediments. Small fecal pellets are often present near the hole, in contrast to some polychaetes (lugworms) that create larger piles of cylindrical coils.

Shrimp burrows at low tide

Burrow sediments from depth

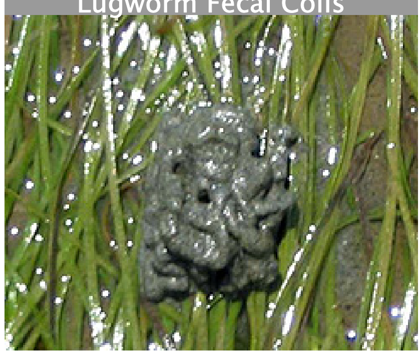
Hole Created by *N. gigas*

Hole Created by Clam



Burrowing Shrimp Fecal Pellets

Lugworm Fecal Coils



All Photos: Steve Booth

Management: Mechanical and biological control tactics against burrowing shrimp have been demonstrated as ineffective except at a very small scale of production. Heavy vehicles temporarily crush burrows and drive some shrimp to the surface, where they are exposed to predators, especially sea gulls, but burrow densities rebound within a few weeks, indicating partial and inadequate suppression. Attempts to smother shrimp with tarps is deleterious to other benthic and epibenthic organisms. Gravel quickly sinks after it is added to harden soft sediments. Ghost shrimp have largely replaced mud shrimp in areas where they have been impacted by the isopod described above. A similar host-specific isopod infests only about 1% of the ghost shrimp populations and has a complicated life cycle that involves an alternate host; it is unlikely that it can be implemented as a biological control tactic in the near future.

Currently, the only effective tactics to effectively manage burrowing shrimp are chemically based. Following a thorough assessment of several alternative management tactics, including other chemicals besides carbaryl, that compound was selected for use on selected acreage in both Oregon and Washington in the early 1960's. Oregon banned its use in 1985, resulting in the loss of hundreds of acres suited to oyster and clam production. Carbaryl was registered and permitted for use on limited acreage in Willapa Bay and Grays Harbor for several decades but was discontinued after 2013. An alternative compound, which is much less toxic to vertebrates and most invertebrates, imidacloprid, has received registration by the EPS and is undergoing the permitting process by the Washington Department of Ecology.

Horse or Gaper Clams (*Tresus capax, T. nuttallii*)

Status: These very large clams can enter unprotected geoduck tubes and compete with them for space and food. Horse clams are an incidental crop in some areas, especially tribal shellfish grounds.

Description: Fat Gaper clams (*T. capax*) are thicker than Pacific Gaper clams (*T. nuttalli*) (~1.5 as long as high, compared to >1.5 as long as high) with umbones (hinge between the shell valves) located ~ 1/3 from the anterior end (the one without the siphon) compared to 1/4 from the end in the Fat Gaper. Both are distributed along the entire west coast, but Pacific Gapers are more common in Washington and Oregon north to Alaska, whereas Fat Gapers are more south to Baja, CA.

Management: Geoduck tubes should be covered to prevent Horse clam settlement and removed by hand and relocated. The market potential for horse clams in Washington and Oregon has not been well studied, but if it were high enough, their status as a pest could be changed to that of crop in some areas.

Photos: Steve Booth

Cockles (*Clinocardium nuttallii*)

Status: Cockles can enter unprotected geoduck tubes and compete with them for space and food. High densities of cockles in clam beds also attract moonsnails, which also indiscriminately consume the commercial product. Cockles are an incidental crop in some areas, especially tribal shellfish grounds.

Description: Cockles are very thick heart-shaped bivalves with prominent raised radial ribs. *Clinocardium nutalli*, the dominant species in Washington and Oregon, has more than 30 radial ribs and is shell is usually light tan, mottled with various bands or blotches of brown. The long and especially strong " foot" that cockles possess allow them to jump when startled as an escape mechanism.

Management: Geoduck tubes should be covered to prevent cockle settlement and removed and relocated by hand when observed. The market potential for both horse cockles has not been well studied in Washington and Oregon, but if it were high enough, their status as a pest could be changed to that of a crop in some areas.

Photos: Steve Booth

Western Sand Dollar (*Dendraster excentricus*)

Status: Sand dollars live in dense colonies in the top 3 to 8 inches of sandy sediments, and prevent the insertion of geoduck tubes, fences, or other protection devices. Layers of sand dollars also smother juvenile geoducks and impede the harvest of adults.

Description: Sand dollars, like other echinoderms, exhibit five-fold radial symmetry and possess an internal rigid skeleton (e.g., test), covered by velvety spines. The Western Sand Dollar is beige to dark gray in color.

Management: Removal and relocation by hand is effective, but very labor intensive and time consuming. Barriars may be also prevent establishment. Geoduck tubes should be covered to prevent colonization.

Photo: Gordon E. Robertson

Photo: Dave Cowles

Sea Stars (Class Asteroidea)

Status: Sea stars (or Starfish) feed directly on unprotected bivalves, especially larger species like oysters and geoduck. Sea stars most often impact bivalves cultured on ground at lower intertidal levels (e.g., geoducks and some oysters), but can also attack oysters on higher ground and longlines in areas of high salinity.

Description: In Washington and Oregon, Sea stars (Phylum Echonidermata, Class Asteroidea) are represented by several genera including *Pisaster* (Pink or Short-Spined Sea Star, Ochre Sea Star, and Giant Sea Star), *Evasterias* (Mottled Star, False Ochre Sea Star,Troschell's True Star, *Pycnopodia* (Sunflower Star), *Leptasterias* Six-rayed Sea Star, and *Solaster* (Sun Sea Star). Adults are radially symmetrical with 5 or more spiney appendages that surround a ventrally positioned mouth.

Management: Removal and relocation by hand removal is effective, but very labor intensive and time consuming. Barriers may be also prevent establishment. Geoduck tubes should be covered to prevent colonization.

Photo: Steve Booth

Photos: Dave Cowles

European Green Crab (*Carcinus maenas*)

Status: European Green Crab (*Carcinus maenas*) are not primary pests of bivalve aquaculture in Washington and Oregon due to their currently sparse distribution and density. They are aquatic invasive species with potential to threaten not only both cultured and native bivalves, but also native crabs with which they share common habitat and food. Green crab prey upon young oysters and clams. A single green crab can consume 40 half-inch clams a day, as well as other crabs its own size.

Green Crab were first noted on the west coast of North America in San Francisco Bay in 1989 and were sighted in the coastal estuaries of Oregon and Washington in the late 1990s. Established populations currently appear to be small and limited to Yaquina Bay, Oregon and Willapa Bay, Washington, apparently due to unfavorable and perhaps relatively short-term conditions of ocean currents and associated weather patterns. Recent trapping by the Pacific States Marine Fisheries Commission and by Fisheries and Oceans Canada indicate that small populations are reproducing at selected sites on the coast and islands of British Columbia, principally in marginal areas where larger native crabs are not present.

Description: Green crab are smaller than Dungeness and Rock Crab, with a maximum size of ~3". Colors are generally as described in the key above, but changes from green to red as the molting cycle progresses.

Management: A monitoring program administered by the Washington State Department of Fish and Wildlife was established in the late 1990s but was severely reduced in 2002 then disbanded in 2005 due to a lack of funds and after conclusions that the relatively cool Pacific Northwest waters could not support sustainable population. Currently, both Washington and Oregon encourage citizens to look for and recognize green crab. Any individuals should be removed and state agencies should be notified. Rock and Dungeness crabs help suppress green crab.

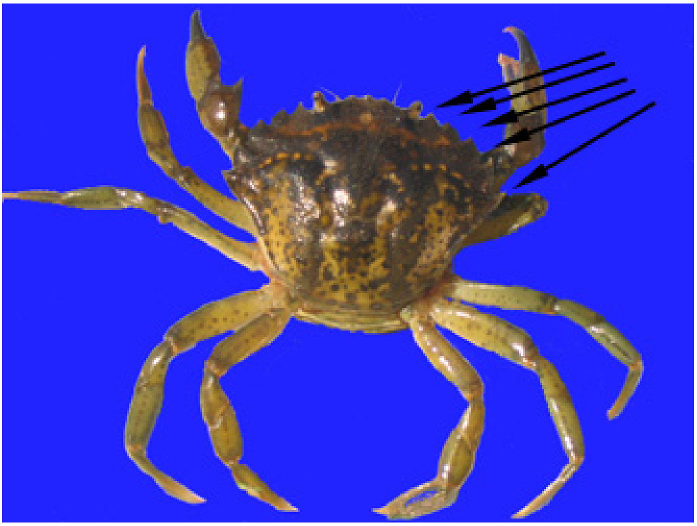


Photo in Public Domain

Red Rock, Dungeness, and Graceful Rock Crabs (*Cancer, Metacarcinus spp.*)

<u>Status:</u> The Red Rock Crab (*Cancer productus*), Dungeness Crab (*Metacarcinus magister*), and Graceful Rock Crab (*Metacarcinus gracilis*), are native to Washington and Oregon. Both Red Rock and Dungeness are important recreational resources while Dungeness further contributes as a commercial resource. Nevertheless, all three species of crab prey directly on all bivalves, especially seed, so can be significant pests.

<u>Description:</u> As noted in the key, Red Rock Crab adults are brick red and the tips of primary pincers are dark. Pincer tips are not darkened on both Dungeness and Graceful Rock. Dungeness Crab are not quite as red as Red Rock and can reach a larger maximum width (>10" vs 6¼"). Graceful Crab reach ~4¼" maximum width and lack ridges along the pincers.

<u>Management:</u> Predator nets and bags help protect clams and oysters from clams. Geoduck tubes should be covered.

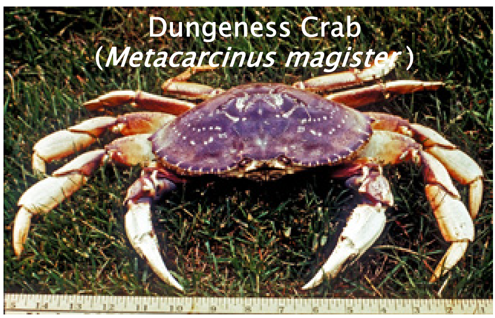


Photo: Dan Boon (USFW); in the public domain

Photo: Dave Cowles

Photo: Dave Cowles

Photo: PSI

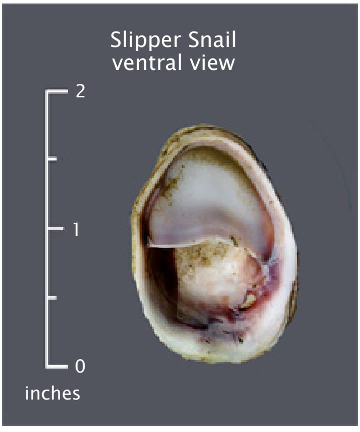
Photo: PSI

Status: Slipper Snails, often called Slipper Shells, are a major pest on single oysters in the South Puget Sound region in old Olympia oyster dykes and on sand or gravel substrates at deeper elevations. They settle on top of oysters or clams, displacing them, competing with them for food, and sometimes smothering them. Slipper snails are born and set as males, but after a couple of months, they become female. The odds of fertilization are improved by settling on females, but eventually the strategy in large piles of shells that can modify the substrate, slow the bottom currents, and increase silting. These three species are the most common species in Washington and Oregon state, but the Common (or Atlantic) Slipper Snail (*Crepidula fornicata*) is probably also present, as least in Washington. That species, as well as the Hooked Slipper Snail *©. adunca*) are native to the east coast, rather than the west coast of North America. The Western White Slipper Snail *©. nummaria*) and the and the White Slipper Snail *©. perforans*) are native to the west coast.

Description: Most Slipper Snails are actually limpets, with a simple, single shell than can be flattened, or even concave (western white), but most often is an irregular cap-shape with the apex hooked to the rear. They are often attached to shells of other mollusks, especially inside those occupied by hermit crabs and the shape of the host shell in part determines the shape of the slipper. Length up to 5.5 cm but usually not much over 2.5 cm.

Only the Hooked Slipper Snail has a prominent raised cap. The cap is as tall or taller than the width of the shell, and is characteristically curved, or hooked. Live Hooked Slipper Snails are brown. Live White Slipper Snail are whiter than the Western White Snail, which has a yellow-brown periostracum (the thin live tissue covering the outer shell). White Slipper Snails are among the few slippers that live inside the shells of other gastropods (snails). The Common Slipper Snail is whiteish with spots of brown or radiating lines.

Management: Slipper snails should be moved or relocated to non-cultivated areas.



Photos: Steve Booth

Lewis' Moon snail (*Euspira (Polinices) lewisii*)

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

Description: The shell of the Lewis' Moon snail, the largest moon snail, can reach a diameter of more than 5" and the foot, when extended, can be more than 12" in diameter. The rounded, globular adults are usually partially buried in sand. As noted above, moon snail infestations are also indicated by their discarded egg cases, which are gelatinous to rubbery depending on age.

Management: Predator nets or caps prevent moon snails from entering geoduck tubes. They can also be removed and relocated by hand, which greatly increases costs.

Photos: Steve Booth

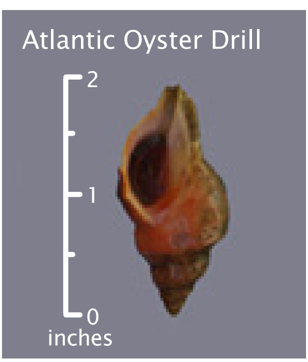
Oyster Drills (*Ocinebrellus inornatus, Urosalpinx cinerea*)

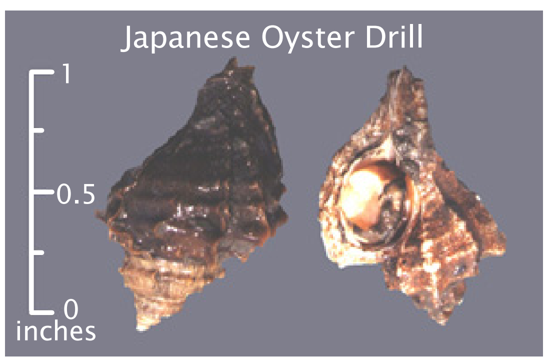
Status: As their common names imply, neither the Japanese (*O. inornatus*) nor the Atlantic Oyster Drill (*U. cinerea*) are native to Washington and Oregon. They drill holes through the shells of oysters and clams and feed on the organism, often killing it. Mortality is higher among smaller or younger individuals. Damage levels vary from low to high among farms and bed locations.

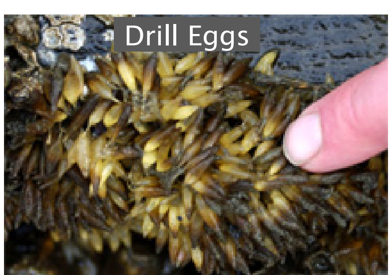
Oyster drills aggregate in the spring, often traveling long distances, in response to a pheromone, to collectively lay eggs on shells or other stable bottom substrates.

Description: As members of the Family Muriciae, the oyster drills exhibit a raised spire with distinct spiral ridges and axial whorls on both the upper and lower parts of the body. *O. inornatus* has 5-6 whorls, each with ~8 ribs; *U. cinera* has 5 whorls with 9-12 ribs per whirl. The canal at the base of the aperture is entirely open. *O. inoratus* reaches a length of 1½" whereas *U. cinerea* is restricted to ¾" in length. Females of both species produce bright yellow egg cases that are slightly larger than grains of rice that eventually will hold 8-12 eggs.

Management: Restrictions on the transfer of shell stock from infested to uninfested estuaries were established to curtail the spread of oyster drills and other pests of bivalves. Trucks and handling equipment that are used to move seed from infested sites must be thoroughly cleaned, costing extra time and labor. Given the widespread distribution of oyster drills, these measures may be infeasible.







Photos: Steve Booth

Asian or Japanese Green Mussel (*Musculista senhousia*)

Status: *Musculista senhousia*, the Japanese green mussel, is an introduced species that competes for food and space with oysters and also causes them to stick together in clumps. They can form dense mats that foul predator nets and other production and gear. High densities settle in near the head of some South Puget Sound bays.

Description: In their native ranges, *M. senhousia* is smaller than other mussels, growing to 3 centimeters compared to the 7-10 cm sized Pacific or blue mussels (*Mytilus* complex). *M. senhousia* is also greenish compared to the blueish 3 species *Mytilus* complex.

Photos released to public domain without conditions by Graham Bould

38 **Blue Mussel Complex (*Mytilus edulis/trossulus/galloprovincialus*)**

Status: The blue mussel, *Mytilus edulis*, the bay mussel, *M. trossulus*, and the southern bay or Mediterranean mussel, *M. galloprovincialus* are very similar morphologically and appear to have hybridized in most of their ranges. *M. californianus* may also co-occur on the open Washington and Oregon coasts, misplacing *M. trossulus*, which is less tolerant of high wave action. All species can set on oysters cultured in bags and cages, causing the oysters to grow together or become misshapen. Mussel sets on oysters increase the labor required at harvest to clean mussel fouling from the oyster shells. Large mats of mussels can smother clams, causing them to move to the surface where they will be exposed and weaken if the mats are removed.

Description: The *Mytilus* species have relatively smooth shells with smooth growth lines and no major radiating ridges. The periostracum is a smooth, shiny black or brown and without hairs.

Photo: Steve Booth

I, Primary Pest
II, Secondary Pest

A, Benthic (dwells mostly subsurface)
B, Epibenthic (dwells primarily on the surface)
C, Fouling or sessile
D, Parasitic
E, Inhabits the open water, planktonic, pelagic

Kingdom Anamalia
Class Trematoda
Sub-Class Digenea
Oyster Trematodes **II - D**, comprising at least:
Family Gymnophallidae
Gymnophalloides tokiensis
Family Bucephalidae
Bucephalus haimeanus, Bucephalus cucullus, Bucephalus spp.
Family Fellodistomatidae
Proectoeces maculatus
Phylum Annelida (Segmented Worms)
Class Polychaeta (Bristle worms)
Order Spionida
Family Spionidae
Polydora corunuta (Mud or Blister Worm) **II - C**
Order Scolicida
Family Maldanidae
Clymenella torquata (Invasive Bamboo worm) **I - A**
Class Oligochaeta
Phylum Mollusca
Class Gastropoda (Snails)
Order Neotaenioglossa
Family Calyptraeidae
Crepidula adunca (Hooked slipper snail) **II - B**
Crepidula nummaria (Western white slipper snail) **II - B**
Crepidula perforans (White slipper snail) **II - B**
Family Naticidae
Euspira (Polinices) lewisii (and others) Lewis' Moon snail (and others) **I - B**
Order Neogastropoda
Family Muricidae (Drills)
Ocinebrellus inornatus (Japanese oyster drill) **I - B**
Urosalpinx cinerea (Atlantic or Eastern oyster drill) **I - B**
Class Bivalvia (Bivalve molluscs)
Order Mytiloida
Family Mytilidae
Musculista senhousia (Asian or Japanese Mussel) **II - B**
Mytilus edulis / trossulus / galloprovincialus (Blue mussel complex) **II - B**
Order Veneroida
Family Mactridae (Horse and Gaper Clams)
Tresus capax (Horse clam) **I - B**
Tresus nuttallii (Pacific gaper clam) **I - B**

Pylum Arthropoda – Sub Phylum Crustacea
Class Malacostraca
Order Decapoda
Family Callianassidae
Neotrypaea californiensis (Ghost shrimp) **I – A**
Neotrypaea gigas (Giant sand shrimp) **I – A**
Upogebia pugettensis (Mud shrimp) **I – A**
Family Cancridae
Cancer magister (Dungeness crab) **I – B**
Cancer productus (Rock crab) **I – B**
Carcinus maenas (Green crab) **I – B**
Cancer gracilis (Graceful crab) **I – B**
Class Cirripedia
Order Thoracica
Family Balanidae (Barnacles)
Balanus spp. **I – C**
Chthamalus spp. **I – C**
Class Maxillopoda (Copepods)
Order Poecilostomatoida
Family Mytilicolidae
Mytilicola orientalis (Thunberg's parasite or red worm) **II – D**
Phylum Echinodermata
Class Echinoidea
Order Clypeasteroidea
Family Dendrasteridae
Dendraster excentricus (Western, Excentric sand dollar) **I –B**
Class Asteroidea
Order Forcipulatida
Family Asteriidae (Sea stars) **I – B**
Pisaster (Purple sea star, Ochre sea star)
Evasterias (Mottled star, False ochre sea star; Troschell's true star)
Pycnopodia (Sunflower star)
Leptasterias (Six-rayed sea star)
Solaster (Sun sea star)
Phylum Chordata
Class: Ascidiacea (Tunicates or Sea Squirts) **II – C**
Many species, 3 High Priority Invasive Spp:
Styela clava (Club tunicate)
Ciona savignyi (Transparent tunicate)
Didemnum vexillum (Colonial tunicate)
Class Actinopterygii
Order Pleuronectiformes (Flatfish) **II – A**
Order Scorpaeniformes
Family Cottidae (Common Sculpins) **II – E**
Order Perciformes
Family Embiotocidae
Cymatogaster aggregata (Shiner Perch) **I – E**
Other Perch species **I – E**

Class Aves
Order Anseriformes
Family Anatidae
Melanitta deglandi (White-winged Scoter) **I – B**
Melanitta perspicillata (Surf Scoter) **I – B**
Melanitta nigra (Black Scoter) **I – B**
Bucephala clangula (Common Goldeneye) **I – B**
Order Charadriiformes
Family Laridae
Larus spp. (Gulls) **I –B**
Order Passeriformes
Family Corvidae
Corvus caurinus (Northwestern crow) **I – B**
Corvus corax (Common Raven) **I – B**
Kingdom Plantae (Plants)
Phylum Chlorophyta
Class Ulvaceae
Order Ulvales
Family Ulvales
Ulva flexuosa (Filamentous algae) **I – A**
Ulva lactuca (Sea lettuce) **I –A**
Angiosperms
Monocotyledons
Order Poales
Family Poacea (Grasses)
Spartina alterniflora (Smooth cordgrass) **I – A**
Spartina angelica (Common cordgrass) **I – A**
Spartina patens (Saltmeadow cordgrass) **I – A**
Spartina densiflora (Denseflower cordgrass) **I – A**
Phragmites australis (Common reed) **I – A**
Order Alismatales
Family Zoasteracea
Zostera japonica (Japanese eelgrass) **I – A**
Kingdom Fungi
Division Mitosporic
Ostracoblabe implexas **II – D**