Invasive and Non-native Aquatic Invertebrates in the Lower Coos Watershed

Summary:

- *Over 60 non-native aquatic invertebrate species have been identified in the project area, but for most, little information is available about their population status, distribution, or local impacts.*
- *Future invasions of non-native invertebrate species are likely to occur, facilitated by international and domestic shipping, new aquaculture ventures, and climate change.*
- *Significant damage has been documented in the project area caused by invasive invertebrate species (e.g. burrowing and parasitic isopods).*

Evaluation

Non-native invertebrates threaten local socio-economic or environmental systems; they should be controlled and closely monitored.

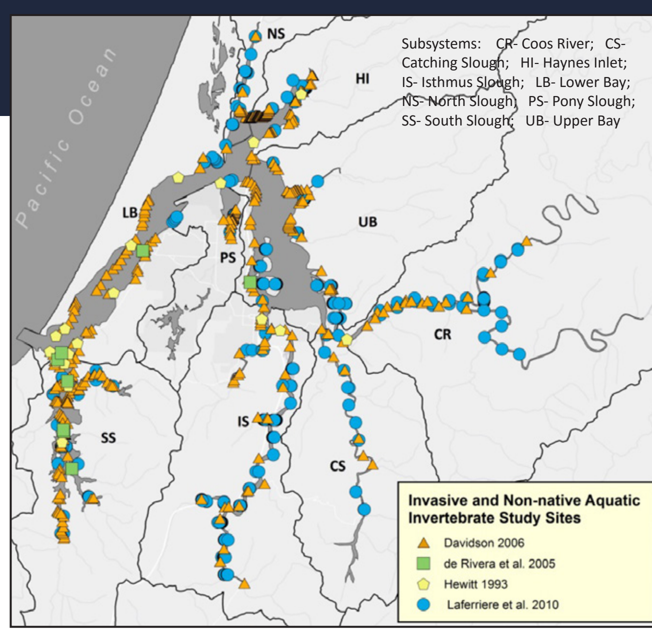


Figure 1: Invasive and non-native invertebrate study areas.

What's Happening

This data summary provides information about the 62 known non-native aquatic invertebrate species that have become established in the lower Coos watershed (project area), as well as nine high risk aquatic non-native species that are not currently in the project area but predicted to arrive here in the future.

This summary is divided into five sections:

1) Established Non-Native Species With *Known* Impacts – status of non-native species established in the project area that have documented local impacts or known impacts in nearby invaded areas.

2) Established Non-Native Species With *Unknown* Impacts – status of non-native species established in the project area for which no impacts have been studied or documented.

3) Predicted Threats – status of non-native species that are likely to arrive in the project area based on geographic proximity, available vectors, and invasion trends of the species.

4) Threats to Human Health – describes the human health threats posed by several species.

5) Background on Species with Known Impacts – describes ecological/economic impacts that have been documented for the 29 *Established Non-Native Species With Known Impacts*. In cases where no information exists for local impacts, information from nearby areas is included.

Terms Used in This Chapter

Species Origin

Native*: naturally occurs in an area without human facilitation; evolutionarily connected to an area*

Non-native: *plants or animals introduced either intentionally or accidentally to locations outside their native ranges*

Invasive: *non-native species that aggressively outcompete native species, causing significant economic loss and/or environmental harm. Not all non-native species are invasive.*

Population Status

Established: *self-maintaining populations*

Not established: *reported in an area, but does not have a self-maintaining population*

Unknown: *insufficient spatial or temporal information available to classify status*

Predicted: *established in nearby locations and likely to be introduced to Coos estuary*

Tables summarizing the species discussed begin each section (Tables 1, 3 and 4). In each section (and table) the species are organized alphabetically by scientific name within the general groupings of: *biofoulers* (sponges, hydroids, anemones, bryozoans, barnacles and sea squirts), *molluscs* (snails, clams, mussels, and oysters), *crustaceans* (crabs, shrimp, isopods, and amphipods), and *worms.*

The individual summaries describe what's known about species' introductions to the project area and current distribution (where available). Information included in this summary is based on two comprehensive published lists (Ruiz et al. 2000, Wonham and Carlton 2005), as well as data collected from more recent surveys. However, very little information exists about any particular species' spatial distribution and presence from year to year.

Species are included in *Predicted Threats* (Section 3) if they're established in nearby estuaries and have a high likelihood of becoming introduced to the project area (see "Major Vectors of Invasion" sidebar on page 18-87).

Each species listed in Section 1 (species established in the project area with known impacts) is symbolized within a yellow icon and symbol based on the type of threat they pose. Threats to native species and habitats are denoted with a fish icon. Economic threats (e.g. to industry, infrastructure, fisheries, etc.) are denoted with a dollar sign. Species that are predicted threats (Section 3) are similarly symbolized, within a red icon (see example below).

Symbol showing high environmental and economic threat for an establisehd species that has known impacts (yellow).

Symbol showing high environmental and economic threat for a species that is a predicted threat (red).

Section 1. Established Non-Native Species with Known Impacts **(Table 1)**

<u>Biofoulers (sponges, hydroids, anemones, tube-building amphipods, bryozoans, and sea squirts)</u>

Blackfordia virginica
Hydroid (no common name)

This hydroid is native to the Black and Caspian Seas, but has successfully invaded European waters, the western Atlantic Ocean, India and China. It was first collected in the 1970s on the Pacific Coast in the San Francisco estuary, (originally misidentified/correctly identified in early 1990s)(Cohen and Carlton 1995). It was later collected in the Coos estuary in 1997 and reported to be abundant by July 1999 (Carlton 2000). It was likely introduced on ship hulls as a fouling organism and through ballast water (Cohen and Carlton 1995).

Botrylloides violaceus
Orange sheath sea squirt

This sea squirt is considered native to Japan, although difficulty in species identification (and uncertainty of species status) has complicated the delineation of accurate native and introduced ranges for species in the genus. However, it's fairly well agreed that it was not found north of Southern California

Established Non-Native Aquatic Invertebrates With Known Impacts

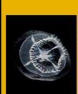
Defining Group	Scientific Name	Common Name	Photo	(salmon icon)	$	Distribution in Project Area	Substrate	Native Location*	Vector**	Detection Date	Status Information (pg)	Background Information (pg)
Biofouler	*Blackfordia virginica*	Hydroid	 Photo: Fredrik Pleijel	✓		IS	Hard	PC	BW, SF	1997	18-81	18-109
Biofouler	*Botrylloides violaceus*	Orange sheath sea squirt	 Photo: Marham	✓		LB, IS, SS, UB	Hard	WP	CO, SF	1988-1990	18-81	18-109
Biofouler	*Botryllus schlosseri*	Golden star sea squirt	 Photo: Daniel Vaulot	✓		SS	Hard	NA	CO, SF	1988-1990	18-85	18-109
Biofouler	*Bugula neritina*	Spiral-tufted bushy bryozoan	 Photo: Bob Gunderson	✓		SS	Hard	UNK	CO, SF	1988-1990	18-85	18-110
Biofouler	*Cliona sp.*	Boring sponge	 Photo: Melissa Frey		✓	Unspecified	Hard	WA	BW, CO	UNK	18-86	18-110
Biofouler	*Cordylophora caspia*	Freshwater Hyrdroid	 Photo: Gretchen Lambert	✓		CR, HI	Hard	PC	SF	1988-1990	18-86	18-110
Biofouler	*Didemnum vexillum*	Carpet sea squirt	 Photo: Tvarminne	✓	✓	SS	Hard	WP	SF	2012	18-87	18-110
Biofouler	*Diplosoma listerianum*	Colonial sea squirt	 Photo: Ian Boyd	✓	✓	IS	Hard	WP	BW	1992	18-87	18-111
Biofouler	*Ectopleura crocea*	Pink-mouthed hydroid	 Photo: Marco Faasse	✓	✓	IS, UB	Hard	NA	CO, SF	1948	18-88	18-111
Biofouler	*Molgula manhattensis*	Sea grapes	 Photo: Blaise Barrette	✓	✓	LB, HI, SS, IS, UB	Hard	NA	BW, CO, SF	1974	18-88	18-111
Biofouler	*Monocorophium acherusicum*	Amphipod	 Photo: H. Hillewaert	✓		SS, LB	Hard	NA	CO, SF	1905	18-89	18-111
Biofouler	*Styela clava*	Club sea squirt	 Photo: Brandon Seah	✓	✓	SS	Hard	WP	BW, SF	1993	18-89	18-111
Biofouler	*Watersipora subtorquata*	Bryozoan	 Photo: Moorea Biocode	✓		SS	Hard	WP	BW, CO, SF	1990s	18-89	18-112
Crustacean	*Ampithoe valida*	Amphipod	 Photo: Coastsandreefs.net	✓		UB	Soft	WA	BW, CO, SF	1950	18-90	18-112

Table 1 (continued on next page): Non-native aquatic invertebrates established in the project area that have documented threats to habitat/native species (salmon icon at column head) and/or the local economy (dollar sign icon). Detection date indicates the first known date of project area invasion. Project area subsystem codes (see also Figure 1): CR- Coos River; CS- Catching Slough; HI- Haynes Inlet; IS- Isthmus Slough; LB- Lower Bay; NS- North Slough; PS- Pony Slough; SS- South Slough; UB- Upper Bay

* SH = Southern Hemisphere; WP = West Pacific (e.g., China, Japan); UNK = unknown; PC = Ponto-Caspian; NA = North Atlantic; EA = East Atlantic (e.g., Europe north of Spain); WA = West Atlantic.

** BW = ballast water; SF = ship fouling; CO = commercial oyster culture; IP = intentional plantings; UNK = unknown.

Established Non-Native Aquatic Invertebrates With Known Impacts (Continued)

Defining Group	Scientific Name	Common Name	Photo		$	Distribution in Project Area	Substrate	Native Location*	Vector**	Detection Date	Status Information (pg)	Background Information (pg)
Crustacean	*Caprella mutica*	Japanese skeleton shrimp	 Photo: SERC	✓		Unspecified	Hard	WP	BW, CO, SF	1983	18-90	18-112
Crustacean	*Carcinus maenas*	European green crab	 Photo: Jeff Cordell	✓		SS, PS, NS, HI, LB	Hard, Vegetative	EA	BW, CO, SF	1997	18-90	18-112
Crustacean	*Jassa marmorata*	Amphipod	 Photo: Christopher Boyko	✓		UB	Hard	WA	BW, CO, SF	1954	18-91	18-113
Crustacean	*Limnoria tripunctata*	Gribble, wood-boring isopod	 Photo: Brent Wilson		✓	UB	Hard	UNK	CO, SF	UNK	18-91	18-113
Crustacean	*Orthione griffenis*	Parasitic isopod	 Photo: Arthur Anker	✓	✓	SS	Soft	WP	BW	1997	18-91	18-113
Crustacean	*Palaemon macrodactylus*	Migrant prawn	 Photo: WoRMS for SMEBD	✓		Unspecified	Soft	WP	BW	1986	18-91	18-113
Crustacean	*Pseudodiaptomus inopinus*	Asian calanoid copepod	 Photo: Melissa Frey	✓		CR	Water column	WP	BW	1991	18-92	18-113
Crustacean	*Rhithropanopeus harrisii*	Harris mud crab	 Photo: Ken-ichi Ueda	✓		CR, CS	Hard	WA	BW, CO, SF	1950	18-92	18-113
Crustacean	*Sphaeroma quoianum*	New Zealand burrowing isopod	 Photo: Dean Janiak	✓	✓	Throughout	Soft	SH	SF	1995	18-92	18-114
Mollusc	*Corbicula fluminea*	Asiatic clam, golden clam	 Photo: wikipedia.org		✓	CR	Soft	WP	IP, CO	UNK	18-93	18-114
Mollusc	*Crassostrea gigas*	Pacific oyster	 Photo: Auguste Le Roux	✓		LB, HI, SS	Hard	WP	CO	1900s	18-93	18-114
Mollusc	*Mya arenaria*	Softshell clam	 Photo: Michal Manas	✓		Throughout	Soft	WA	CO, IP	1880s	18-94	18-114
Mollusc	*Philine auriformis*	New Zealand sea slug	 Photo: David Behrens	✓		Unspecified	Soft	SH	BW	UNK	18-94	18-115
Mollusc	*Potamopyrgus antipodarum*	New Zealand mud snail	 Photo: G. & Ph. Poppe	✓		IS, CR	Hard, Vegetative	SH	UNK	2006	18-94	18-115
Mollusc	*Teredo navalis*	Naval shipworm	 Photo: G. & Ph. Poppe		✓	Unspecified	Hard	UNK	SF	1988	18-94	18-115

Table 1 (continued): Non-native aquatic invertebrates established in the project area that have documented threats to habitat/native species (salmon icon at column head) and/or the local economy (dollar sign icon). Detection date indicates the first known date of project area invasion. Project area subsystem codes (see also Figure 1): CR- Coos River; CS- Catching Slough; HI- Haynes Inlet; IS- Isthmus Slough; LB- Lower Bay; NS- North Slough; PS- Pony Slough; SS- South Slough; UB- Upper Bay

* SH = Southern Hemisphere; WP = West Pacific (e.g., China, Japan); UNK = unknown; PC = Ponto-Caspian; NA = North Atlantic; EA = East Atlantic (e.g., Europe north of Spain); WA = West Atlantic.

** BW = ballast water; SF = ship fouling; CO = commercial oyster culture; IP = intentional plantings; UNK = unknown.

until the 1940s and 1950s (Cohen and Carlton 1995). In a 1988-1990 survey, Hewitt (1993) found *B. violaceus* in South Slough, as well as at sites in the middle and upper Coos estuary (Figure 2)(Table 2). During this two year study recruitment of *B. violaceus* peaked from June to September, but extended into November during one year. Hewitt (1993) also tracked the transport of *B. violaceus* on a floating dock from Joe Ney Slough (part of South Slough) to Isthmus Slough in June of 1990. By September 1990, the total percent coverage of *B. violaceus* on the transplanted dock had grown to 60%. Recruitment of *B. violaceus* to areas adjacent to the dock was also observed and by September 1990, 20% of the adjacent encrusting communities consisted of colonies of this sea squirt. Hewitt (1993) reports the coverage of *B. violaceus* in Isthmus Slough declined in subsequent years to 5-10%, but it had also spread seaward from the upper bay at a rate of 2 km/yr from 1991-1993 to Pony Slough in the middle bay (Figure 2). A decade later, surveys of non-native fouling communities showed *B. violaceus* was present in 2003 at the Charleston Boat Basin Marina, Empire Pier, and near Valino Island in South Slough (Figure 3)(de Rivera et al. 2005). It was also found the following year at the Port of Coos Bay Citrus Dock in the upper Coos estuary (de Rivera et al. 2005).

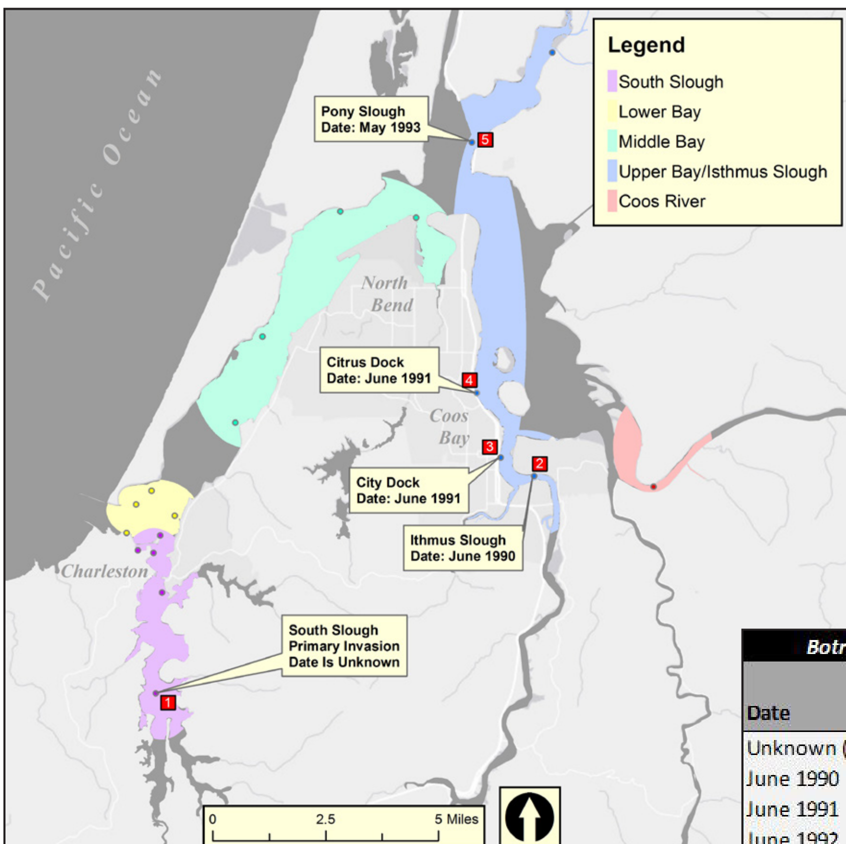


Figure 2: Locations of Hewitt's (1993) study sites (points on map) where he investigated populations of invasive/non-native encrusting organisms. Distinct regions were delineated based on Hewitt's study, and based on similarities of sample sites. Region delineation should not be confused with similarly named project area regions commonly used in this and other chapters.The red squares with callouts on map and adjoining table show the secondary dispersal (within the Coos estuary) of the colonial sea squirt *Botrylloides violaceus*.

*Although originally found in South Slough (site 1 on map), it was manually moved to Isthmus Slough (site 2) and dispersal distances were calculated from that point.

Data Source: Hewitt 1993.

***Botrylloides violaceus* Dispersal**

Date	Distance Spread (km)
Unknown (primary invasion)	
June 1990	0*
June 1991	1.6
June 1992	3.2
May 1993	4.8

Monthly recruitment presence (in green) of introduced fouling species in the lower Coos estuary and Isthmus Slough (from August 1988-December 1990)

Species	Lower Coos Estuary											
	J	F	M	A	M	J	J	A	S	O	N	D
Balanus improvisus												
Tubularia crocea												
Conopeum tenuissimum	■	■	■	■	■	■	■	■	■	■	■	
Schizoporella unicornis	■	■	■	■	■	■	■	■	■	■	■	■
Barentsia benedeni												
Halichondria bowerbanki												
Haliclona sp.												
Botryllus schlosseri	■	■		■	■	■	■	■	■	■	■	■
Botrylloides violaceus	■	■	■	■	■	■	■	■	■	■	■	■
Diplosoma mitsakurii												
Molgula manhattensis								■	■	■		
Bowerbankia gracilis	■	■	■	■	■	■	■	■	■	■	■	

Species	Isthmus Slough (Upper Coos Estuary)											
	J	F	M	A	M	J	J	A	S	O	N	D
Balanus improvisus				■	■	■	■	■	■	■		
Tubularia crocea					■	■	■	■	■	■	■	
Conopeum tenuissimum		■	■	■	■	■	■	■	■	■		
Schizoporella unicornis												
Barentsia benedeni							■	■	■	■		
Halichondria bowerbanki						■	■	■				
Haliclona sp.			■							■		
Botryllus schlosseri												
Botrylloides violaceus						■	■	■	■			
Diplosoma mitsakurii						■	■	■				
Molgula manhattensis					■	■	■	■	■	■	■	
Bowerbankia gracilis				■	■	■	■	■	■			

Table 2: Invasive aquatic invertebrates recruited into the lower Coos and Isthmus Slough between 1988-1990. Data: Source Hewitt 1993

Botryllus schlosseri
Golden star sea squirt

As with *B. violaceus*, the native range and introduction history of this sea squirt are ambiguous, but it is presumed to be a native of European waters. Hewitt (1993) found colonies of *B. schlosseri* in South Slough during monthly surveys from September 1988 to September 1990 (Figure 2)(Table 2). In June of 1990, colonies of *B. schlosseri* were transported to Isthmus Slough from South Slough (at Joe Ney Slough) on a floating dock. Although the colonies survived their initial relocation, by September 1990 coverage of the transplanted dock by *B. schlosseri* colonies had reduced to 5%. During a 2003-2004 survey of fouling communities in the estuary, *B. schlosseri* was only found at one location (the Charleston Boat Basin Marina) in 2003 (Figure 3)(de Rivera et al. 2005). It was not present at any sites in 2004, but the Charleston Marina was not sampled that year. *B. schlosseri* has most likely spread throughout its introduced range by ship hull fouling and with oyster shipments from the Atlantic and Asia (Hewitt 1993).

Bugula neritina
Spiral-tufted bushy bryozoan

This species is found all over the world. Along the Pacific Coast of North America, the native range of *B. neritina* extends from Monterey Bay to the south (Cohen and Carlton 1995). In the 1980s it was reported in the San Francisco estuary and continued to extend its range north into the 1990s (Cohen and Carlton 1995). It was first reported in the Coos estuary by Hewitt (1993) where it was found in South Slough (Figure 2). Throughout its range, *B. neritina* is commonly found in fouling communities and was likely dispersed to new locations on ship hull fouling communities since its planktonic larval stage is relatively brief.

Cliona sp.

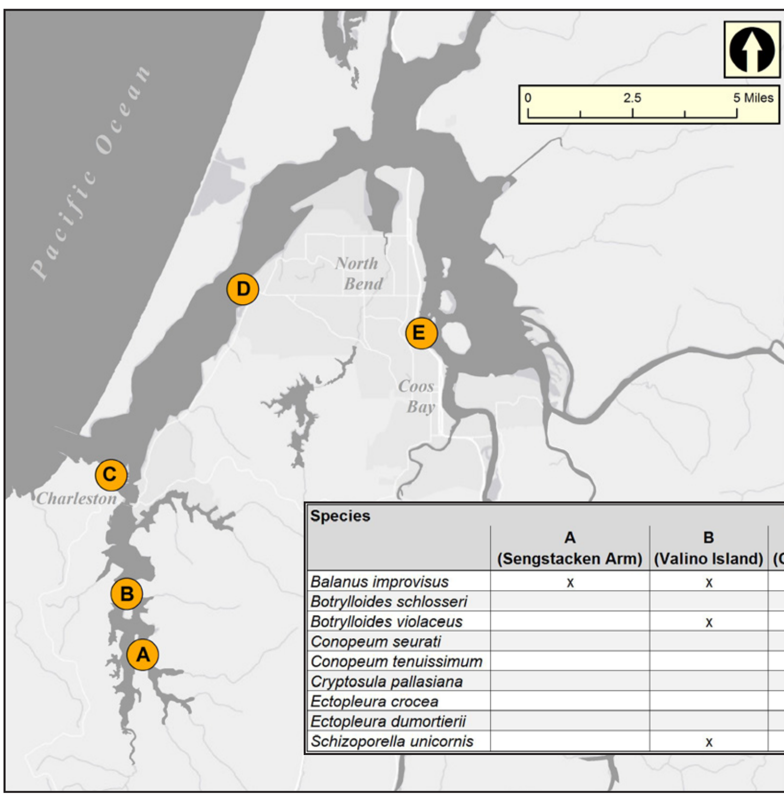
Boring sponges

The native ranges of boring sponges in this genus are not entirely known, but several species are thought to naturally occur in the western Atlantic where they grow on Atlantic oysters. The first record of *Cliona sp*. from the San Francisco estuary is from 1893, after they were likely transported to the Pacific Coast with oyster shipments (Cohen and Carlton 1995). *Cliona sp*. is listed as established in the Coos estuary in Ruiz et al. (2000).

Cordylophora caspia

Freshwater hydroid

Found by Hewitt (1993) in the upper bay and in the Coos River (Figure 2). The species is thought to have been introduced on ship hulls as a fouling organism and through the transport of oysters to the area from both the western Pacific and the Atlantic Ocean (Hewitt 1993).

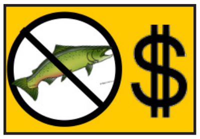


Species	Site				
	A (Sengstacken Arm)	B (Valino Island)	C (Charleston marina)	D (Empire)	E (Citrus Dock)
Balanus improvisus	x	x	x	x	x
Botrylloides schlosseri			x		
Botrylloides violaceus		x	x	x	x
Conopeum seurati			x	x	
Conopeum tenuissimum				x	
Cryptosula pallasiana			x		
Ectopleura crocea					x
Ectopleura dumortierii					x
Schizoporella unicornis		x	x	x	

Figure 3: Deployment locations of settlement plates where invasive aquatic invertebrates were found (2003 and 2004). Plates were deployed on pilings and on marina docks. Species recovered at each location are shown. Data Source: de Rivera et al. 2005

Didemnum vexillum

Carpet sea squirt



This species was first recorded in Oregon in the Umpqua Triangle in 2010 and later that year in the Charleston Boat Basin. Surveys from 2010 to 2013 reported new colonies in the Charleston Boat Basin in 2012-2013, but it hasn't been reported elsewhere in the Coos estuary. *D. vexillum* grows rapidly and reproduces by fragmentation and planktonic larvae. It was likely introduced from fouling communities on ship hulls, or the presence of small colonial fragments in ballast water. *D. vexillum* requires salinities greater than 25 (Daley and Scavia 2008), which suggests it will likely be restricted to the lower portions of the Coos estuary. It can survive temperatures ranging from 2 to 25°C and daily fluctuations as large as 11°C (Valentine et al. 2007). Colonies of this *D. vexillum* produce acidic components that successfully deter predators and facilitate its ability to become established. It is on the Oregon Invasive Species Council list of 100 worst invasive species. (OISC 2013).

***Diplosoma listerianum* (also reported as *Diplosoma mitsakurii*)**

Colonial sea squirt (no common name)

Native to Japan, this sea squirt was likely introduced to the Coos estuary through ballast water of shipping vessels along the Pacific coast of the US. Hewitt (1993) reports this

Major Invasion Vectors

***Hard Ballast** – Beginning in the 16th century the transport of hard ballast on ships (e.g., river cobble) resulted in the earliest invasions of aquatic organisms.*

***Ballast Water** – The use of water for ships' ballast can transport invertebrate larvae, viable fragments of sessile organisms, and small aquatic species between estuaries.*

***Ship fouling** – As early as the 16th century, fouling aquatic species have been transported on the hulls of ships. This remains a particularly effective vector for introductions of aquatic invertebrates to new areas.*

***Shellfish imports** – Historic shipments of Atlantic oyster (Crassostrea virginica) from the US east coast to the west coast transported aquatic species on oyster shells. Similarly, historic imports of Pacific oyster (Crassostrea gigas) from Japan transported many Asian aquatic species to the US. Commercial oyster shipments between estuaries continue to move organisms.*

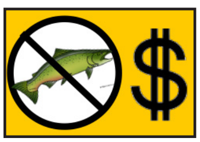
***Intentional Introductions** – Intentional seeding of non-native molluscs (e.g. Manila clams (Vererupis philippinarum)) has occurred along the Oregon Coast.*

***Tsunami Debris/Storms** – Events like the 2011 Japanese tsunami and storms transport aquatic species-carrying debris across oceans.*

***Climate change** – Predicted changes in ocean conditions (e.g., temperature increases) will expand aquatic species ranges, facilitating the movement of non-native species from California to Oregon.*

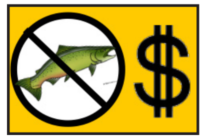
species was absent from surveyed sites in 1988-1991, but it was present in the summer of 1992 in Isthmus Slough (Figure 2)(Table 2). Identification of the species was aided by a survey that detected sea squirt “tadpole” larvae in ballast water from Japanese ships entering the Coos estuary in the summer of 1992 (Carlton and Geller 1993). This species was not found at later survey dates by Hewitt (September and November 1992 or February and April 1993), therefore it appears the invasion was not successful.

***Ectopleura crocea* (also reported as *Tubularia crocea*)**
Pink-mouthed hydroid



Native to the northwestern Atlantic Ocean, this hydroid was likely introduced to the Pacific on ship hulls as a fouling organism and in shipments of Atlantic and Japanese oysters. There are several published reports of this species in the Coos estuary, with the earliest from 1948 (referenced in Carlton 1979). It was later reported in Coos Bay in 1987 on the wooden hull of a ship leaving the estuary, but not on the ship when it arrived from Yaquina Bay (Carlton and Hodder 1995). It was found in upper Coos Bay in the early 1990s by Hewitt (1993)(Figure 2, Table 2). *E. crocea* was also found, along with the non-native *E. dumortierii*, in 2004 at the Port of Coos Bay Citrus Dock in the upper Coos estuary, but neither species was found at 2003 survey locations or any other locations in 2004 (Figure 3)(de Rivera et al. 2005).

Molgula manhattensis
Sea grapes



Native to the North Atlantic, this sea squirt was first reported on the Pacific Coast of the US in 1949 in Tomales Bay, California, and found throughout the San Francisco estuary in the 1950s. By 1974 it had extended north to Coos Bay (Cohen and Carlton 1995). The species is tolerant of low salinities so it’s often found in upper reaches of estuaries. In California, *M. manhattensis* is known to survive periods of low salinity due to high levels of freshwater input (Cohen and Carlton 1995). Hewitt (1993) found this species in South Slough and in the upper Coos estuary (Figure 2)(Table 2). It is often found attached to oyster shells, so it’s possible it originally spread with oyster shipments from the Atlantic Ocean in the 1940s, as well as in ship fouling communities (Hewitt 1993, Cohen and Carlton 1995). It was found on the hull of a wooden ship leaving Coos Bay in 1987 (Carlton and Hodder 1995). In 2015 and 2016, high densities of these sea squirts were found in the upper Coos estuary at Coalbank Slough (B. Yednock pers. comm. 2016).

***Monocorophium acherusicum* (also reported as *Corophium acherusicum*)**
Amphipod (no common name)

Native to the North Atlantic, the first specimen of this species from the Coos estuary was collected in 1905 with oyster shells of the Atlantic oyster (*Crassostrea virginica*). This account, as well as a second one from 1942, is reported by Carlton (1979; reported as *Corophium acherusicum*). It's listed as an established species in the Coos estuary by Ruiz et al. (2000) and Wonham and Carlton (2005) and is known to be common in fouling communities in the Charleston Boat Basin Marina and the Empire Docks. The species likely arrived to the region on fouled ship hulls and in oyster shipments from the Atlantic Ocean.

Styela clava
Club sea squirt

This sea squirt was first reported in the Coos estuary in 1993-94, presumably introduced from Europe, although it's been present in California since the 1930s (Cohen and Carlton 1995). *S. clava* is not reported anywhere else in Oregon. Likely vectors for its invasion include Pacific oyster shipments, ballast water, and hull fouling (Cohen and Carlton 1995; Ruiz et al. 2000). This species is often found attached to artificial structures (e.g. pilings, floats, docks, boat hulls, aquaculture gear) in relatively shallow waters ranging from 11-27°C and salinities between 22-36. Adults cannot survive salinities less than 10.

***Watersipora subtorquata* (also reported as *W. edmonsonii*)**
Bryozoan (no common name)

The native range of this species is unknown, and difficulty in the identification of this species and others in the genus has led to an uncertain introduction history. Representatives of the genus were first seen in Southern California in the 1960s. Specimens identified as *W. subtorquata* were found in the Coos estuary in the early 1990s, as well as in 1998 (Carlton 2000), with the most likely mode of transport being fouling communities on ship hulls.

Another representative of this difficult to identify genus, *W. edmonsonii*(?)(uncertainty indicated by the question mark) was reported by Hewitt (1993). It was collected in South Slough in 1990. Hewitt suggested it was likely introduced from southern California through modern mechanisms, such as ballast water or mariculture transport. He reports the species comprised ~5% of the encrusting community at the Charleston Boat Basin Marina in 1990 (Figure 2). Later surveys showed its percent coverage declined to <1% (Hewitt 1993).

Crustaceans (crabs, shrimp, amphipods, isopods)

Ampithoe valida
Amphipod (no common name)

Native to the northwestern Atlantic Ocean, this species was first collected in the early 1940s in the San Francisco and Tomales estuaries. It was found in the Coos estuary in 1950, then again on the hull of a wooden ship leaving Coos Bay in 1987 (Carlton and Hodder 1995; Carlton 1979). This species lives in eelgrass beds, on algae, and in oyster beds in the Atlantic Ocean, therefore it is possible it was introduced earlier in the 1900s to San Francisco via oyster shipments from the Atlantic and remained undetected until the 1940s. It was likely also transported in ballast water and by ship fouling (Cohen and Carlton 1995).

Caprella mutica
Japanese skeleton shrimp

This species, native to the Sea of Japan, was first collected in the 1970s in California in the San Francisco estuary, Elkhorn Slough, and the Humboldt estuary. It wasn't collected in the Coos estuary until 1983 (Cohen and Carlton 1995). *C. mutica* was possibly brought to the US Pacific Coast with shipments of Japanese oysters (Cohen and Carlton 1995), but it is also known to survive in ships' ballast water (Carlton 1985). In locations where they become established, these skeleton shrimp can become quite abundant.

Carcinus maenas
European green crab

This species is native to the eastern Atlantic Ocean from Africa to Norway and Iceland, but it has been a successful invader along the northeastern coast of North America (in the US and Canada), the southern hemisphere, and the US Pacific Coast. It was first seen on the US Pacific Coast in the San Francisco estuary in 1989. Genetic evidence links that introduction to populations from the Atlantic Coast (Darling et al. 2008). Large numbers of juvenile green crabs were later found recruiting to Oregon estuaries in 1997/1998 (including the Coos estuary) from late-August to early October, following a very strong El Niño year when northward flowing currents presumably facilitated the dispersal of larvae north from California (Yamada and Gillespie 2008)(see Invasive and Non-native Species Climate Change Summary). Recruitment of juvenile green crabs in the Coos estuary was studied from 1997 through 2006 by Yamada and Gillespie (2008). Juvenile green crabs were observed every year, although abundance varied considerably; only four were collected in 2005 compared to 65 in 1998. Higher numbers were found to be linked to warmer winters (Yamada and Gillespie 2008). *C. maenas* appears to be restricted to lower salinities in Oregon estuaries due to predation pressure by native crabs (Hunt and Yamada 2003). As recently as 2017, juvenile and adult *C. maenas* have been collected throughout South Slough (B. Yednock pers. comm. 2016).

Jassa marmorata

Amphipod (no common name)

Native to the Atlantic Ocean, this species has been collected along the Pacific Coast of North America in Alaska, British Columbia, and from Coos Bay south to Mexico (Cohen and Carlton 1995). It was first collected in the Coos estuary in 1954 (referenced in Carlton 1979). This species lives in fouling communities often found on ship hulls and with oysters, and was found in ballast tanks entering the Coos estuary from Japan (having survived a 15 day voyage)(Cohen and Carlton 1995). Specimens were also found on the wooden hull of a ship that arrived to Coos Bay in 1987 from Yaquina Bay (Carlton and Hodder 1995).

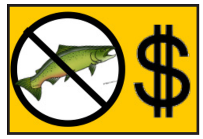
Limnoria tripunctata

Gribble, wood boring isopod

The native range of this small wood-boring isopod is unknown, but the first records of its appearance on the Pacific Coast are from the 1870s (referenced in Cohen and Carlton 1995). It was likely introduced to the region with the arrival of wooden-hulled ships and quickly became established in wood pilings and docks. *L. tripunctata* was found on a wooden ship traveling from Yaquina Bay to Coos Bay in 1987 and present throughout the remainder of the journey to the Humboldt and San Francisco estuaries (Carlton and Hodder 1995).

Orthione griffenis

Bopyrid isopod parasite



This species is was first documented in 1988 on the US west coast in Willapa Bay where it was collected with the native mud shrimp *Upogebia pugettensis* (Dumbauld et al. 2011). It was later found in the Coos estuary in 1997 and in the Yaquina estuary in 1999 (Markham 2005, Chapman et al. 2012). Larvae were likely introduced and spread through shipping activity via ballast water (Chapman et al. 2012). *O. griffenis* is now well established along the US west coast in mud shrimp populations from Canada to Mexico (Chapman et al. 2012).

Palaemon macrodactylus

Migrant prawn

Native to the western Pacific, this species first arrived in the eastern Pacific in the 1950s in the San Francisco estuary (Cohen and Carlton 1995). It most likely arrived in ballast water or in the fouled sea water system of ships traveling to the area from Asia (Cohen and Carlton 1995). *P. macrodactylus* spread north and south from the San Francisco Bay Area in the 1970s and was first collected in the Coos estuary in 1986 (Cohen and Carlton 1995). Tolerant of a wide variety of environmental conditions, this species can be found in near fresh water (1-2) and in areas of low water quality.

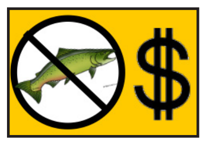
Pseudodiaptomus inopinus
Asian calanoid copepod

This Asian copepod was first reported in the Pacific Northwest in the Columbia River in 1990 where, based on abundance, it had already become well-established (Cordell et al. 1992). Because this species spends its entire life cycle in the plankton, it was likely introduced to the Columbia River in ballast water of shipping vessels. In a survey of Pacific Northwest estuaries from British Columbia to Oregon, *P. inopinus* was found in samples collected from the Coos River in September and October of 1991 (Cordell and Morrison 1996). Although barnacle, bivalve, and brachyuran crab larvae dominated these plankton samples, *P. inopinus* comprised 10.2% of numerical abundance in the Coos River samples, compared to a maximum of 28.9% in the Yaquina River and minimum of 0 in the Chehalis River (Washington)(Cordell and Morrison 1996).

Rhithropanopeus harrisii
Harris mud crab

Native to the Atlantic Ocean, this species was first documented along the Pacific Coast in the Oakland estuary in 1937, possibly having arrived with shipments of Atlantic oysters. In Oregon, it was first found in the Coos estuary in 1950, then later found in the Netarts estuary in 1976 and in the Yaquina and Umpqua estuaries in 1978 (Cohen and Carlton 1995). Its northward range expansion was presumably facilitated by periodic El Niño-Southern Oscillation events when northward flowing currents are strongest (Petersen 2006)(see Invasive and Non-native Species Climate Change Summary). *R. harrisii* is often found in low salinity waters and, in the Coos estuary, is also largely restricted to the upper reaches of the estuary by the presence of the native bay shore crab (*Hemigrapsus oregonensis*), a direct competitor found in the middle and lower reaches of the estuary (Jordan 1989).

Sphaeroma quoianum
New Zealand burrowing isopod



Native to Australia (esp. Tasmania) and New Zealand, this isopod was first reported in the northeastern Pacific in the San Francisco estuary in 1893. It spread throughout California from the 1920s to the 1950s and was first found in the Coos estuary in 1995 on floating docks in Isthmus Slough (Cohen and Carlton 1995). The species is highly abundant throughout the Coos estuary where suitable substrate exists (Figure 4)(Davidson 2006 and 2008).

Molluscs (snails, clams, mussels, oysters)

Corbicula fluminea

Asiatic clam, golden clam

Native to tropical SE Asia, this clam was originally introduced to the US as a food source by Chinese immigrants and more recently may have been unintentionally introduced to new areas with Pacific oyster and bait imports (Foster 2015). It was first reported in Oregon in 1948 in the Columbia River and has since been found in the John Day, Smith, Siuslaw, and Willamette Rivers (Foster 2015). Listed as an established species in Coos Bay by Ruiz et al. (2000), no additional published accounts of the species in Coos Bay could be found.

Crassostrea gigas

Pacific oyster

Native to Japan, these oysters were intentionally introduced for commercial oyster production around the world and are extensively cultivated along the US Pacific Coast, including the Coos estuary. Oysters were transported from Japan to Washington as early as 1875 and to Oregon in the early 1900s (Carlton 1979). Commercial aquaculture operations in Coos estuary are located in South Slough, Haynes Inlet, and the upper Coos estuary. Small numbers of live Japanese oysters have been observed outside of these aquaculture areas. Hewitt (1993) found *C. gigas* recruits in South Slough and at sites in the

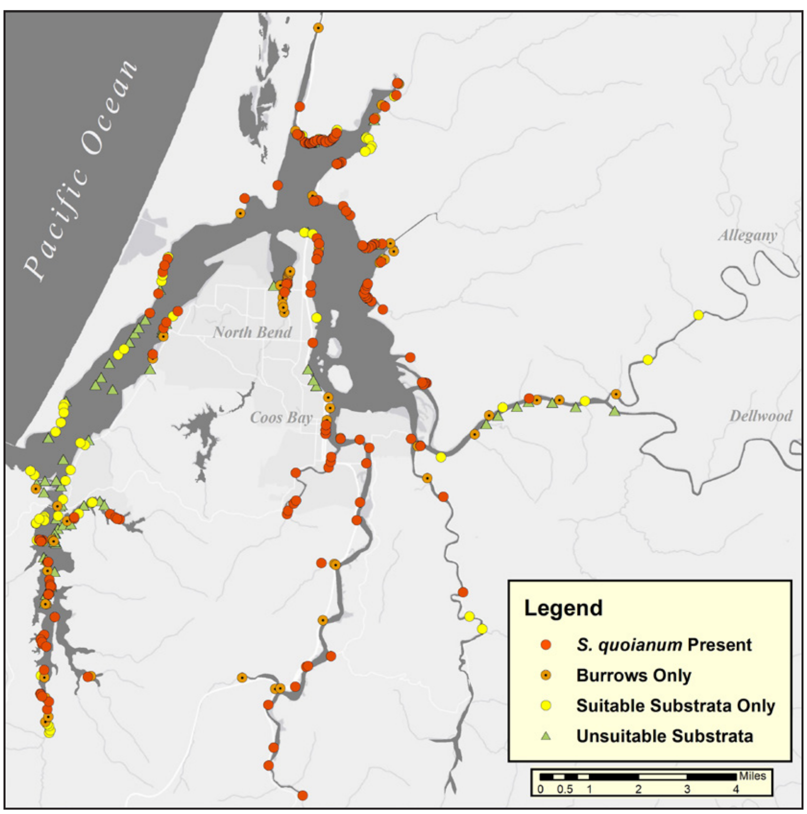


Figure 4: Distribution of the burrowing isopod, *Sphaeroma quoianum*, found in the Coos estuary in 2005/2006. Locations where burrows or suitable substrate were found and *S. quoianum* were not observed are also shown. Data Source: Davidson 2006.

middle and upper Coos estuary. Rimler (2014) also observed recruits of *C. gigas* on settlement plates in the Coos estuary in August of 2012.

Mya arenaria
Softshell clam

The softshell clam is native to the north Pacific (from Alaska to the Aleutian Peninsula) and along the Atlantic Coast of the US. Because they grow fairly large and are edible, softshell clams were intentionally introduced to Coos Bay and other locations along the Pacific Coast of the US by 1880 (Carlton 1979). Although they have failed to become established at other introduction sites in the Pacific, they are commonly found today throughout Coos Bay, including in the higher reaches of the estuary (as far as 30 miles from the ocean)(ODFW 2014). Softshell clams are popular among recreational and commercial clammers.

Philine auriformis
New Zealand sea slug

This sea slug is native to New Zealand, but has colonized the US Pacific Coast. It's become established in the Coos estuary (Ruiz et al. 2000, Wonham and Carlton 2005) and is on the Oregon Invasive Species Council's 100 Worst Invaders List (OISC 2013). Its status in Oregon, however, is considered contained.

Potamopyrgus antipodarum
New Zealand mud snail

This snail is native to New Zealand, but is a known invader across the globe. It was first discovered in the Coos estuary in 2006, likely introduced by ballast water or with fishing gear. Its small size (5-6 mm) and ability to thrive in fresh and brackish water makes it an easy species to spread accidentally via recreational fishing and boating. *P. antipodarum* has been found in several estuaries and rivers along the Oregon Coast, from the Columbia River to the Rogue River (Davidson et al. 2008a).

Teredo navalis
Naval shipworm

The native range of this wood-boring bivalve is not known, but it is considered to be an introduced species to the US Pacific Coast, with its earliest documented occurrence (1913) in the San Francisco estuary (Carlton 1979). The first reports of the *T. navalis* in the Coos estuary are from 1988 (Fofonoff et al. 2003). Nearly a century earlier, a report from the United States War Department describes infestations of *T. navalis* in the lower Coos estuary (USWD 1879). However, since *T. navalis* is found only in the upper portions of estuaries, it's more likely the species described in the 1879 report was the native shipworm, *Bankia setacea* (J. Carlton pers. comm. 2015).

***Section 2. Established Non-Native Species with Unknown Threats* (Table 3)**

Biofoulers (sponges, hydroids, anemones, bryozoans, and sea squirts)

***Amphibalanus improvisus* (also reported as *Balanus improvisus*)**
Bay barnacle
Native to the North Atlantic Ocean, the first *A. improvisus* specimen found on the Pacific Coast was collected in the San Francisco estuary in 1853 and was likely introduced as a fouling organism on ship hulls. Later, from the 1900s to the 1960s, shipments of Atlantic oysters to the Pacific resulted in many more Pacific Coast introductions of this species. It was first reported in the Coos estuary in 1978 (Cohen and Carlton 1995) and is now commonly found in lower salinity regions of the upper estuary. Hewitt (1993) found this species in the middle and upper reaches of the Coos estuary and in the Coos River (Figure 2)(Table 2). During a survey of non-native fouling organisms, *B. improvisus* was found in 2003 at the Charleston Marina, Empire Pier, and in South Slough in both the Sengstacken and Winchester arms and near Valino Island (Figure 3)(de Rivera et al. 2005). In 2004, it was found again in Winchester arm of South Slough and at the Port of Coos Bay Citrus Dock near downtown Coos Bay (de Rivera et al. 2005).

Barentsia benedeni
No common name
The native range of this colonial invertebrate is not well characterized, but its first appearance on the US Pacific Coast occurred in the San Francisco estuary in 1929. This species does not have a planktonic larval stage, therefore it is unlikely to have dispersed to the area naturally as larvae or in ballast water. It was most likely introduced to the region on fouled ship hulls, or as part of the fouling communities that were inadvertently introduced with oyster shipments from Japan (Hewitt 1993, Cohen and Carlton 1995). It's been collected in the Coos estuary since 1988, where it was found in the upper estuary and Coos River (Figure 2)(Table 2)(Hewitt 1993).

Bowerbankia gracilis
Creeping bryozoan
This species' presence is reported from all over the world, but its native range is likely limited to both hemispheres of the western Atlantic Ocean. Identification of *B. gracilis* is difficult so incorrect identification has likely complicated accurate delineation of its native and introduced ranges. *B. gracilis* has been found in the Coos estuary since 1970 (Cohen and Carlton 1995, Hewitt 1993) and other areas of the US Pacific Coast since the 1920s. It was likely introduced with oyster and bait shipments or fouling communities on ship hulls. Without a planktonic stage in its life cycle, *B. gracilis* is not likely to spread by ballast water. Hewitt (1993) found this species throughout Coos estuary (lower, middle, and upper bay sites), South Slough, and the Coos River (Figure 2)(Table 2). Recruitment is highest for this species from March through August, with a notable peak in July (Hewitt 1993).

Established Non-Native Aquatic Invertebrates With Unknown Impacts

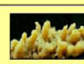
Defining Group	Scientific Name	Common Name	Photo	Distribution in Project Area	Substrate	Native Location*	Vector**	Detection Date	Information (pg)
Biofouler	*Amphibalanus improvisus*	Bay barnacle	 Photo: Christiane Maria	LB, HI, IS, CR, UB, SS	Hard	NA	CO, SF	1978	18-95
Biofouler	*Barentsia benedeni*	No common name	 Photo: Allie T.	HI, IS, CR	Hard	NA	BW/CO	1988	18-95
Biofouler	*Bowerbankia gracilis*	Creeping bryozoan	 Photo: Fausse and De Blauwe	LB, HI, IS, CR, SS	Hard	UNK	CO/SF	1970	18-95
Biofouler	*Conopeum seurati*	Bryozoan	 Photo: Nat. Hist. Mus. London	LB, SS	Hard	NA	CO/SF	2003	18-98
Biofouler	*Conopeum tenuissimum*	Lacy crust bryozoan	 Photo: USGS	LB, HI, IS, CR, SS, UB	Hard	WA	CO/SF	1970	18-98
Biofouler	*Cryptosula pallasiana*	Bryozoan	 Photo: Andrew N. Cohen	LB, SS	Hard	UNK	CO/SF	1988	18-98
Biofouler	*Diadumene leucolena*	White anemone	 Photo: Benthic Ecology Lab	Unspecified	Hard	NA	CO/SF	1967	18-98
Biofouler	*Diadumene lineata*	Orange-striped sea anenome	 Photo: R. Manuel	IS	Hard	WP	CO/SF	1978	18-99
Biofouler	*Gonothyraea clarki*	Hydroid		Unspecified	Hard	NA	UNK	1995	18-99
Biofouler	*Halichondria bowerbanki*	Sponge	 Photo: Khoyatan Marine Lab	LB, IS, SS	Hard	WA	CO/SF	1988-1990	18-99
Biofouler	*Haliclona loosanoff*	Sponge		IS, SS	Hard	WA	CO/SF	UNK	18-99
Biofouler	*Monocorophium insidiosum*	Amphipod	 Photo: M. Frey	Unspecified	Hard	NA	BW, CO, SF	UNK	18-99
Biofouler	*Schizoporella unicornis*	Single horn bryozoan	 Photo: Andy Cowley	SS, LB	Hard	WP	CO/SF	1986	18-100
Biofouler	*Triticella sp.*	Bryozoan	 Photo: Bert Pijs	IS	Hard	WP	BW	1988-1990	18-100
Crustacean	*Eobrolgus spinosus*	Amphipod	 Photo: Cent. Coast. Studies	SS, LB	Soft	WA	CO/BW	UNK	18-100
Crustacean	*Grandidierella japonica*	Amphipod	 Photo: CA Academy of Sciences	Unspecified	Hard	WP	BW, CO	1977	18-100
Crustacean	*Iais californica*	Isopod	 Photo: Denis Riek	Unspecified	Soft	SH	SF	UNK	18-100

Table 3 (continued on next page): Non-native aquatic invertebrates established in the project area that are not documented threats to habitat/native species or the local economy. Detection date indicates the first known date of project area invasion. Project area subsystem codes (see also Figure 1): CR- Coos River; CS- Catching Slough; HI- Haynes Inlet; IS- Isthmus Slough; LB- Lower Bay; NS- North Slough; PS- Pony Slough; SS- South Slough; UB- Upper Bay

* SH = Southern Hemisphere; WP = West Pacific (e.g., China, Japan); UNK = unknown; NA = North Atlantic; EA = East Atlantic (e.g., Europe north of Spain); WA = West Atlantic.

** BW = ballast water; DB = dry ballast; SF = ship fouling; CO = commercial oyster culture; UNK = unknown.

Established Non-Native Aquatic Invertebrates With Unknown Impacts (continued)

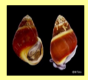
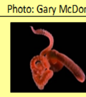
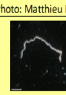
Defining Group	Scientific Name	Common Name	Photo	Distribution in Project Area	Substrate	Native Location*	Vector**	Detection Date	Information (pg)
Crustacean	*Incisocalliope derzhavini*	Amphipod		UB	Hard	WP	SF	1986	18-101
Crustacean	*Melita nitida*	Amphipod	 Photo: Bathyporeia	UB	Hard	WA	BW, CO, SF	1986	18-101
Crustacean	*Nippoleucon hinumensis*	Asian cumacean	 Photo: Wikicommons	Unspecified	Soft	WP	BW/CO	1979	18-101
Crustacean	*Sinelobus stanfordi*	Tanaid crustacean	 Photo: M. Taru	Unspecified	Hard, Soft	UNK	BW/CO/SF	UNK	18-101
Mollusc	*Assiminea parasitologica*	Asian marsh snail	 Photo: M. Taru	Throughout	Vegetative	WP	BW	2007	18-102
Mollusc	*Myosotella myosotis*	Mouse ear snail, salt marsh snail	 Photo: Nat. Hist. Mus. Rotterdam	SS, LB, UB, NS, PS, HI, IS	Soft, Vegetative	EA	CO/SF	1969	18-103
Mollusc	*Nuttallia obscurata*	Purple varnish clam	 Photo: L. Schroeder	SS, LB	Soft	WP	BW	2003	18-103
Mollusc	*Tenellia adspersa*	Minature aeolis	 Photo: Gary McDonald	UB	Hard	NA	BW,CO,SF	UNK	18-104
Worm	*Heteromastus filiformis*	Bristle worm	 Photo: wikipedia	Unspecified	Soft	WA	BW/CO	1970	18-104
Worm	*Mysta tchangsii*	Polychete worm		Unspecified	Soft	WP	CO/BW	UNK	18-104
Worm	*Nereis succinea*	*Euryhaline "pile" worm*	 Photo: Hans Hillewaert	Unspecified	Soft	NA	CO/SF	1986	18-104
Worm	*Polydora cornuta*	Polychaete mud worm	 Photo: G. Read	UB, IS	Soft	NA	CO, SF	1950	18-104
Worm	*Pseudopolydora kempi*	Spinoid Worm	 Photo: M. Taru	UB, IS	Soft	WP	BW/CO/SF	1977	18-104
Worm	*Streblospio benedicti*	Polychaete Worm	 Photo: David S. Johnson	UB, IS	Soft	WA	CO/SF	1977	18-105
Worm	*Tubificoides brownae*	Marine oligochaete worm	 Photo: Matthieu Leray	Unspecified	Soft	NA	BW/CO	1986	18-105
Worm	*Tubificoides diazi*	Marine oligochaete worm	 Photo: Matthieu Leray	Unspecified	Soft	NA	BW/CO	1979	18-105

Table 3 (continued): Non-native aquatic invertebrates established in the project area that are not documented threats to habitat/native species or the local economy. Detection date indicates the first known date of project area invasion. Project area subsystem codes (see also Figure 1): CR- Coos River; CS- Catching Slough; HI- Haynes Inlet; IS- Isthmus Slough; LB- Lower Bay; NS- North Slough; PS- Pony Slough; SS- South Slough; UB- Upper Bay

* SH = Southern Hemisphere; WP = West Pacific (e.g., China, Japan); UNK = unknown; NA = North Atlantic; EA = East Atlantic (e.g., Europe north of Spain); WA = West Atlantic.

** BW = ballast water; DB = dry ballast; SF = ship fouling; CO = commercial oyster culture; UNK = unknown.

Conopeum seurati
Bryozoan (no common name)
This species was found in the Coos estuary in 2003 on settlement plates deployed in the Charleston Boat Basin Marina and at the Empire Pier as part of a broad-scale survey of non-native species on the US West Coast (Figure 3)(de Rivera et al. 2005). It was not found the following year in 2004 at the Empire Pier; the Charleston Boat Basin Marina site was not sampled for a second year. *C. seurati* was not found in any other surveyed locations in the Coos estuary in 2003 and 2004. Its presence at two locations in 2003 may have been an isolated event.

Conopeum tenuissimum
Lacy crust bryozoan
Native to the Atlantic and Gulf of Mexico Coasts of North America, this bryozoan was first reported on the Pacific Coast in the early 1950s in the San Francisco estuary (Carlton 1979) and has been collected in the Coos estuary since 1970 (Cohen and Carlton 1995). Likely modes of introduction include ballast water, fouling communities on ship hulls, and/or shipments of Atlantic oysters to the West Coast (Cohen and Carlton 1995). It was found on the hull of a ship leaving Coos Bay in 1987 (Carlton and Hodder 1995) and collected at every location surveyed by Hewitt (1993) from 1988-1990 (Figure 2)(Table 2). Surveys included South Slough, the lower, middle, and upper Coos estuary, and the Coos River. Peak recruitment for this species occurs from June to September, but can continue later in the year (Hewitt 1993). This species was observed in 2003 on settlement plates at Empire Pier during a survey of fouling communities, but it was not present at any other locations surveyed in 2003 or in 2004 (Figure 3)(de Rivera et al. 2005).

Cryptosula pallasiana
Bryozoan (no common name)
Native to the North and Western Atlantic, this species appeared throughout the western and northern Pacific from the 1950s to the 1970s (Cohen and Carlton 1995). It was first reported in the Coos estuary in 1988, where it was found in South Slough and the Lower Coos estuary (Figure 2)(Hewitt 1993). The planktonic life stage of this species is short, therefore it was likely spread by ship hulls' fouling communities or on Atlantic and Japanese oysters (Hewitt 1993), on which it's usually found in the Atlantic (Cohen and Carlton 1995). Recruitment in the Coos estuary appears to be extended throughout the year from around March to November, with peaks observed in July and September (Hewitt 1993). *C. pallasiana* was collected in 2003 from settlement plates at the Charleston Boat Basin Marina during a survey of non-native species (Figure 3)(de Rivera et al. 2005). It was not collected at any other site in the estuary in 2003 or 2004 (however, the marina was not sampled in 2004).

Diadumene leucolena
White Anemone
This anemone has been abundant in the Oakland estuary (California) since the 19th century, where it is common among fouling communities and on oyster shells (Cohen and Carlton 1995). It may have arrived in the

Pacific from its native range along the Atlantic Coast of the US via ballast water, as a fouling organism, or with oyster shipments (Cohen and Carlton 1995). Since its arrival to the Pacific, *D. leucolena* has since extended its range north and south from the Oakland and San Francisco Bay area. It was first reported in Coos Bay in 1967 (Carlton 1979).

Diadumene lineata **(also reported as *Haliplanella lineata* and *H. luciae*)**
Orange-striped sea anemone
First reported in the Coos estuary in 1978 (Carlton 1979) but anecdotal reports indicate it was found earlier than this first report. Native to Asia, it was likely introduced to Coos Bay by ship fouling and through oyster shipments. Found by Hewitt (1993) in upper Coos Bay (Figure 2).

Gonothyraea clarki
Hydroid (no common name)
This fouling hydroid is native to the North Atlantic Ocean. It was first found in the San Francisco estuary in 1985 and was collected from floats in Coos Bay in Isthmus Slough in 1995 (Cohen and Carlton 1995).

Halichondria bowerbanki
Deadman's finger sponge
This sponge was first found on the Pacific Coast in the 1950s in the San Francisco estuary (Carlton 1979) and was later found in Coos Bay surveys conducted from 1988-1990 (Hewitt 1993). It likely spread to the Pacific from its native range in the Atlantic Ocean with the importation of Atlantic oysters for aquaculture, but may also have arrived on ship hulls as a fouling organism (Hewitt 1993, Cohen and Carlton 1995). Hewitt (1993) reports the presence of *H. bowerbanki* in South Slough and the upper bay (Figure 2)(Table 2).

Haliclona loosanoffi **(also reported as *Haliclona sp.*)**
Loosanoff's Haliclona
Native to the Atlantic Ocean, this sponge was introduced to the Pacific as early as the 1950s, however difficulty in distinguishing this species from other Haliclona sponge species makes it hard to confirm the exact introduction date. As with *H. bowerbanki*, it could have spread from the Atlantic with shipments of Atlantic oysters and/or as a fouling species (Hewitt 1993, Cohen and Carlton 1995). Hewitt (1993) reports a Haliclona species from the upper Coos estuary, which likely refers to *H. loosanoffi*, as well as a possible native Haliclona species in South Slough and the lower Coos estuary sites (Figure 2)(Table 2).

Monocorophium insidiosum **(also reported as *Corophium insidiosum*)**
Amphipod (no common name)
The exact date of introduction to the Coos estuary for this species is unknown, but it was likely transported to the Pacific Coast from its native range in the North Atlantic on ship hulls as a fouling organism and with shipments of Atlantic oysters. This amphipod is listed as an established introduced species in the Coos estuary by Ruiz et al. (2000) and Wonham and Carlton 2005.

***Schizoporella unicornis* (also reported as *S. japonica*)**
Single horn bryozoan
This bryozoan is native to the western Pacific and likely transported to the eastern Pacific on fouled ship hulls and shipments of Japanese oysters. It was first reported in California in 1938, in British Columbia in 1966, and in Oregon (Coos estuary) in 1986 (Cohen and Carlton 1995). *S. unicornis* is reported in Hewitt (1993) from South Slough, presumably introduced with local cultivation of Japanese oysters. Recruitment of this species to sampling locations from 1998 to 1990 was observed in all months, with a peak from June to August (Table 2)(Hewitt 1993). Hewitt (1993) also tracked the transport of this species to Isthmus Slough from South Slough (at Joe Ney Slough) on a floating dock that was moved in June 1990. After 15 days the *S. unicornis* colonies on the dock were still alive, but by September 1990 they had turned white and were presumed dead. During a survey of non-native fouling invertebrates, S. unicornis was collected in 2003 on fouling plates that had been deployed at the Charleston Boat Basin Marina, the Empire Pier, and a piling near Valino Island in South Slough (Figure 3) (de Rivera et al. 2005). It was not collected at any other sites the following year, although the marina was not sampled in 2004.

Triticella sp.
Bryozoan (no common name)
Found by Hewitt (1993) in the upper Coos estuary. He also identified possible native species of the same genus in South Slough and at sites in the lower estuary (Figure 2). The native range of this species is likely limited to Japanese waters, and it is thought to have been introduced by shipments of Japanese oysters, ballast water, and/or interstate shipping along the US Pacific Coast (Hewitt 1993).

<u>Crustaceans (crabs, shrimp, amphipods, isopods)</u>

Eobrolgus spinosus
Amphipod (no common name)
This amphipod species is native to the US Atlantic Coast, but has been found in isolated areas on the US Pacific Coast. It's listed as an established introduced species in the Coos estuary by Ruiz et al. (2000), and was found in South Slough as recently as February 2012 (GISIN 2017).

Grandidierella japonica
Amphipod (no common name)
Native to Japan, this amphipod spread to the US Pacific Coast in the 1960s and 1970s, likely with oyster shipments, ship fouling communities and/or ballast water. It was reported in the Coos estuary (and collected since) in 1977 (Cohen and Carlton 1995). It's become established on the US Pacific Coast and is highly abundant in several California estuaries.

Iais californica
Isopod (no common name)
This small isopod is often found living attached to the ventral surface of the introduced burrowing isopod, *Sphaeroma quoianum* (see summary in Section 1). It was first described on the US Pacific Coast in the San Francisco estuary in 1904, where it likely ar-

rived on a ship hull with *S. quoianum* (Cohen and Carlton 1995). It has since been found in the Coos estuary on *S. quoianum* living on floating docks in Isthmus Slough (Cohen and Carlton 1995). *I. californica* has also been found living on the native isopod, *Gnorimosphaeroma oregonensis*.

***Incisocalliope derzhavini* (also reported as *Parapleustes derzhavini*)**
Amphipod (no common name)
This amphipod is thought to originate from the west Pacific. *I. derzhavini* was first documented on the US Pacific Coast in 1904 in the San Francisco estuary. It spread to other coastal locations in California in the 1970s, then to Oregon in the 1980s, arriving in the Coos estuary in 1986 (Cohen and Carlton 1995). This species was most likely introduced on ship hull fouling communities. *I. derzhavini* can be found in a wide range of salinities (from 6 to 32) and often grows in high abundances with hydroids, but rarely on algae (Cohen and Carlton 1995). Chapman (1988) found this amphipod in small numbers among other non-native species (*Ampithoe valida, Corophium acherusicum, Neanthes succinea, and Limnoria sp.* isopods) on wooden floats near Citrus Dock in Coos Bay.

Melita nitida
Amphipod (no common name)
Native to the northwestern Atlantic Ocean, this amphipod was first reported in the Pacific in the San Francisco estuary in 1938, then later in British Columbia and California in the 1970s. It was first collected in Oregon in 1986-87 in Yaquina, Coos, and Alsea estuaries (Chapman 1988). *M. nitida* live in salinities ranging from 0 to 25 and are common in fouling communities, in the intertidal zone under rocks and debris, and on mudflats in algae mats (Chapman 1988). Initial introductions to the Pacific may have been the result of oyster shipments from the Atlantic, on ship hulls among fouling organisms, or the transport of solid ballast or ballast water (Cohen and Carlton 1995).

Nippoleucon hinumensis
Asian cumacean shrimp
Native to Japan, this small shrimp was introduced via ballast water to the northeastern Pacific Ocean (Cohen and Carlton 1995). Since 1986, it's been collected in large densities in California where it's often one of the top three dominant species (Cohen and Carlton 1995). It was first collected in the Coos estuary in 1979 and in other Oregon estuaries <10 years later (Umpqua (1983) and Yaquina (1988))(Cohen and Carlton 1995).

Sinelobus stanfordi
Tanaid crustacean
This shrimp-like crustacean is currently found nearly worldwide, but its native range is unknown. The first record of the species found on the US Pacific Coast is from the 1960s in the San Francisco estuary (described in Cohen and Carlton 1995), but it is now found along the entire US Pacific Coast from San Diego to Canada (Davidson et al. 2007) and is listed as an established species in the Coos estuary in Ruiz et al. (2000) and Wonham and Carlton (2005).

Molluscs (snails, clams, mussels, oysters)

Assiminea parasitologica
Asian marsh snail

Several populations of *A. parasitologica* were first documented in the upper reaches of the Coos estuary in 2007. This was the first known occurrence of the species in North America and it was assumed that it was introduced to the area from the ballast water of commercial ships from Asia. During a survey of Oregon and Washington in 2008, this snail was also found in the Umpqua and Yaquina estuaries and was assumed to have been accidentally transferred to these systems by humans (e.g. recreational fishing, boating, scientific field sampling)(Laferriere et al. 2010).

A systematic survey of Coos Bay in 2009 found *A. parasitologica* to be the most abundant snail in Isthmus Slough, Coos River and Haynes Inlet (west), and one of the two most abundant snails in Kentuck Inlet, Haynes Inlet (east), and South Slough (Figure 5)(Laferriere et al. 2010). In addition to the Coos estuary, ten other estuaries in the Pacific Northwest were surveyed in 2009, and *A. parasitologica* was found in the Coquille, Umpqua, Alsea, and Newport systems. It was absent in Willapa, Columbia, Nehalem, Tillamook, Lincoln City, and Siuslaw.

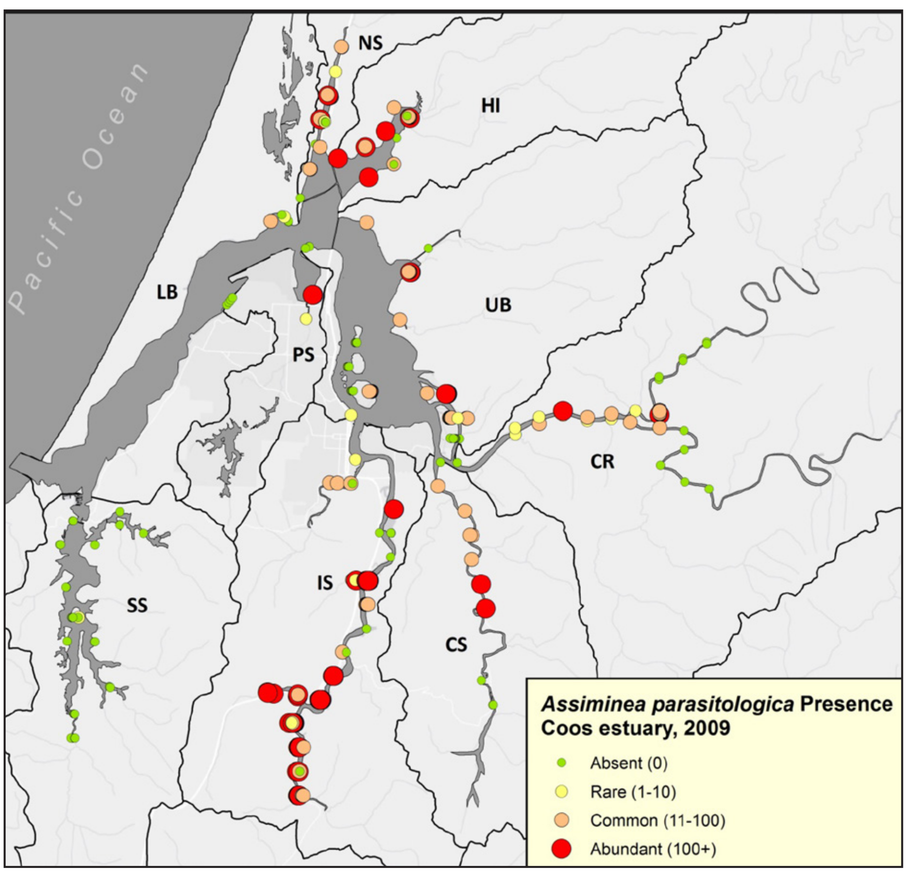


Figure 5: Relative abundance and distribution of the invasive Asian marsh snail *Assiminea parasitologica* from 2009 surveys. Data Source: Laferriere et al. 2010

Myosotella myosotis **(also reported as *Ovatella myosotis*)**

Mouse ear snail/salt marsh snail

Found throughout the eastern and western Atlantic, this snail was first identified in the San Francisco estuary in 1871 and was likely introduced to the bay through shipments of Atlantic oysters (Cohen and Carlton 1995). Because this species lacks a planktonic larval phase, its spread would have resulted from the movement of adults and/or eggs. The first record of *M. myosotis* in Coos Bay is from 1969 (referenced in Carlton 1979) and it is now common in high salt marshes of the bay (Figure 6)(Berman and Carlton 1991). It is a euryhaline species, which means it's found in estuarine habitats subject to a wide range of salinities. Work by Berman and Carlton (1991) shows the abundance and success of *M. myosotis* in Coos Bay relates more to the species' ability to occupy a semi-terrestrial environment than its ability to outcompete native snails for resources.

Nuttallia obscurata

Purple varnish clam

The purple varnish clam is native to the western Pacific, with its natural range encompassing Russia, China, and Japan. It was first found in the Pacific Northwest in 1991 in Blaine, Washington, most likely introduced in ballast water from ships entering the Port of Vancouver. It has since expanded its range to the north and south and was first reported in Coos Bay in 2003 (Fofonoff et al. 2003). These clams have relatively high survivorship in higher temperatures and lower salinities than other bivalves along the West Coast, which may explain their success as invaders to the region (Siegrist 2010).

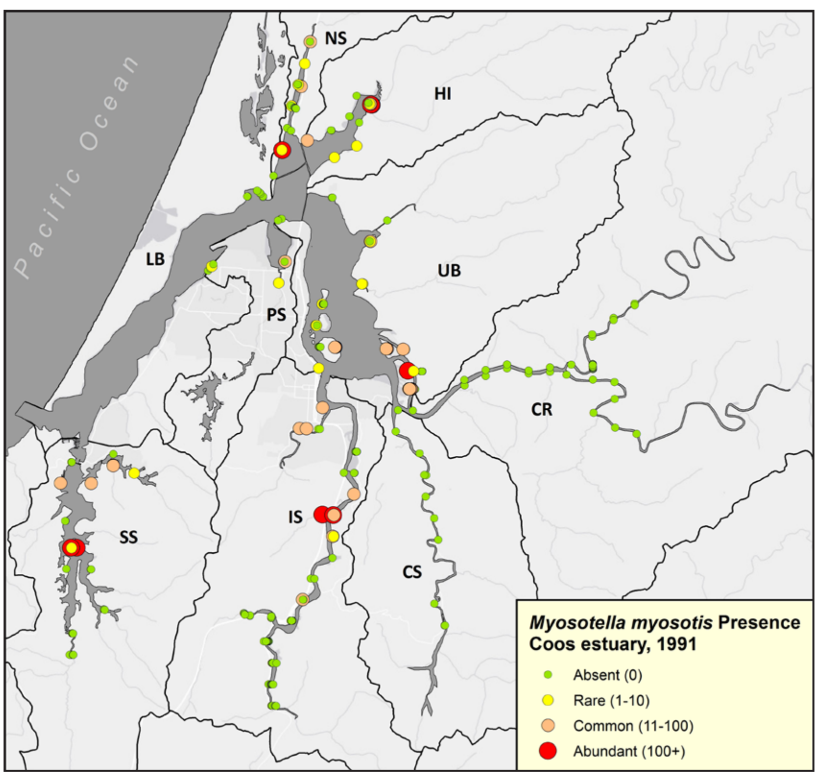


Figure 6: Relative abundance and distribution of the invasive mouse ear snail *Myosotella myosotis* (also known as *Ovatella myosotis*) from 1991 surveys. Data Source: Laferriere et al. 2010

Tenellia adspersa
Miniature aeolis
This snail is native to European and Mediterranean waters, but has spread to the western Atlantic and to the Pacific including the Coos estuary (Cohen and Carlton 1995). Although no date could be found for its introduction to the Coos estuary, the species most likely spread from its native range on ships in ballast water, or possibly its eggs were spread via attachment to ship fouling communities. *T. adspersa* adults and eggs were found on a vessel leaving Coos Bay in 1987 that were not on the vessel when it arrived to bay from Yaquina Bay (Carlton and Hodder 1995). *T. adspersa* is found in a wide range of salinities and also occurs in freshwater.

<u>Worms</u>
Heteromastus filiformis
Bristle worm
Native to the US Atlantic Coast, but it has been reported in the North Sea, Mediterranean, Morocco, South Africa, Persian Gulf, New Zealand, Japan, and the Bering and Chukchi Seas (Cohen and Carlton 1995). *H. filiformis* was first collected in the San Francisco estuary in 1936 (but was likely introduced earlier and unidentified until the 1930s), at Vancouver Island, BC in 1962, and in Coos Bay in 1970 (Cohen and Carlton 1995). In its native range it co-occurs with oysters, therefore it likely was introduced with Atlantic oysters and possibly ballast water (Cohen and Carlton 1995).

***Mysta tchangsii* (also reported as *Eteone sp*.)**
Polychaete worm (no common name)
This species is native to the Yellow Sea. It is reported as an established species in Coos Bay in Ruiz et al. (2000), but no other published records of its presence in Coos Bay could be found.

***Nereis succinea* (also reported as *Neanthes succinea*)**
Pile worm
Reported in locations across the globe, but first collected in Oregon in Netarts Bay in 1976 (Carlton 1979). *N. succinea* was later observed in Coos Bay in 1986 (Cohen and Carlton 1995) and is listed as an established introduced species in Coos Bay in Ruiz et al. (2000) and Wonham and Carlton (2005).

***Polydora cornuta* (also reported as *P. ligni*)**
Polychaete worm (no common name)
Native to the North Atlantic, this worm was introduced to the US Pacific coast with shipments of Atlantic oysters. Although it was most likely first introduced in the 1870s, it was first documented on the US west coast in 1932 in British Columbia (Carlton 1979). It was likely transported along the Pacific Coast following additional introductions from the Atlantic. *P. cornuta* was first reported in Coos Bay in 1950 (Carlton 1979) and was found in Isthmus Slough in the 1970s during a dredging study (McCauley et al. 1977).

Pseudopolydora kempi
Spinoid worm (no common name)
Native to the western Pacific, this species was first reported in the eastern Pacific in 1951 at Nanaimo, British Columbia. It was first reported in Oregon in 1974 at Yaquina Bay, then at Netarts Bay in 1976 and Coos Bay, where it was collected from Isthmus Slough, in 1977 (Carlton 1979, McCauley et al. 1977).

P. kempi has been introduced to locations with shipments of Pacific oysters (*Crassostrea gigas*), but may have also be transported in ballast water or on ship hulls among fouling organisms.

Streblospio benedicti

Polychaete worm (no common name)

This worm is native to the western Atlantic Ocean and was likely introduced to the Pacific Coast in the 1870s with Atlantic oyster shipments, although it remained undetected in the Pacific until 1932 when it was reported in the San Francisco estuary (Carlton 1979). The first record of the species in Coos Bay is from 1977, where it was found in Isthmus Slough during a dredging study (McCauley et al. 1977). This species, along with the polychaete mud worm *P. cornuta*, is highly tolerant of pollution and is therefore often an indicator of poor water quality.

Tubificoides brownae

Oligochaete worm (no common name)

This worm is native to the Atlantic Ocean and considered a cryptogenic species (of uncertain origin) in the south San Francisco estuary. However, Cohen and Carlton (1995) consider it introduced to the Pacific based on its limited distribution along the Pacific Coast compared to its broad continuous distribution on the Atlantic Coast. *T. brownae* was first reported in Coos Bay in 1986 (Brinkhurst 1986) and is now listed as an established introduced species in Coos Bay in Ruiz et al. (2000) and Wonham and Carlton (2005). It was likely introduced to the region by ballast water or with shipments of commercial oysters (Cohen and Carlton 1995).

Tubificoides diazi

Oligochaete worm (no common name)

This species has been collected along the eastern coast of the US, in northern European waters (Scotland and France), and Australia. It is thought to also be introduced to the eastern Pacific Ocean, where it was collected in the Coos estuary and in British Columbia in 1979 (Brinkhurst 1986). It's listed as an established introduced species in Coos Bay in Ruiz et al. (2000) and Wonham and Carlton (2005), where it was likely introduced by ballast water or with shipments of commercial oysters.

Online Resources for Non-native Aquatic Invasive Invertebrates

Global Invasive Species Database: http://www.issg.org/database/welcome/

National Exotic Marine and Estuarine Species Information System (NEMESIS): http://invasions.si.edu/nemesis/index.jsp

The Exotics Guide: http://www.exoticsguide.org/

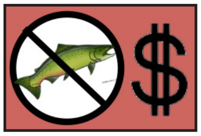
World Register of Marine Species: http://www.marinespecies.org/

The Atlas of Nonindigenous Marine and Estuarine Species in the North Pacific and PICES Nonindigenous Species Information System: http://www.epa.gov/wed/pages/nonindigenous_species/

***Section 3. Predicted Threats* (Table 4)**

Ciona savignyi

Transparent sea squirt



This sea squirt is native to Japan, but has become introduced to several locations on the Pacific Coast of the US. It is currently found at over 19 locations in Puget Sound, Washington, and at multiple locations in California. It grows on docks, pilings, and boat hulls, making it likely to be transported to Oregon on ship hull fouling communities.

Megabalanus rosa

Acorn barnacle

This barnacle is native to the northwestern Pacific Ocean, but has become established in Australia. It is not known to occur in the eastern Pacific Ocean, but it is listed as a key species to watch for on tsunami debris from Japan (Lam et al. 2013).

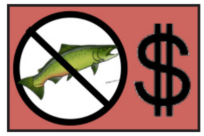
Caprella cristibrachium

Skeleton shrimp

Skeleton shrimp specimens were found washed ashore at Agate Beach, Oregon, on debris from the 2011 Japanese tsunami. It is listed as a key species to watch for on the Oregon Coast (Lam et al. 2013). Little else is reported on this species as an invader elsewhere around the world.

Eriocheir sinensis

Chinese mitten crab



Mitten crabs are known to be aggressive invaders throughout Europe and on both coasts of the US. However, as of 2008, Chinese mitten crabs had not been reported in the Coos estuary and only one adult crab was collected in the Columbia River – the only specimen found in Oregon. A risk assessment prepared by Draheim (2008) declared the Coos estuary to have a moderate risk of introduction by this species. Since mitten crabs are catadromous (i.e., reproduce in brackish waters and spend the majority of their lives in freshwater), their distributions are restricted by salinity. The findings of the risk assessment suggest the Coos estuary is the only estuary in Oregon with the appropriate combination of salinity (~25) and flushing time to allow proper egg and larval development (Anger 1991, Hanson and Sytsma 2008), and therefore the only estuary of concern in Oregon for a mitten crab invasion. The highest risk pathway for introduction to the Coos estuary was identified as ballast water since Coos Bay is an active international and domestic shipping port and planktonic mitten crab larvae can survive in ballast water for extended periods of time. Mitten crabs are a known host for the Oriental lung fluke. There is already a large population of non-native snails (*A. parasitologica*) that can carry and transmit the parasite, making both species a potential vector for a parasite with high risk to human health (see Section 4: Threats to Human Health below).

Predicted Threats

Defining Group	Scientific Name	Common Name	Photo		$	Native Location*	Potential Vector**	Information (pg)
Biofouler	*Ciona savignyi*	Pacific transparent sea squirt	 Photo: CA Academy of Sciences	✓	✓	WP	SF	18-106
Biofouler	*Megabalanus rosa*	Acorn barnacle	 Photo: Jo O'Keefe	✓	✓	SH	SF, BW	18-106
Crustacean	*Caprella cristibrachium*	Skeleton shrimp	 Photo: John Chapman	✓	✓	NP	BF	18-106
Crustacean	*Eriocheir sinensis*	Chinese mitten crab	 Photo: Linda Rohleder	✓	✓	WP	BW	18-106
Crustacean	*Hemigrapsus sanguineus*	Asian shore crab	 Photo: clark.edu	✓	✓	WP	BW	18-107
Enchinoderm	*Asteria amurensis*	Northern Pacific seastar	 Photo: CSIRO	✓	✓	WP	SF, BW	18-107
Mollusc	*Mytilus galloprovincialis*	European blue mussel	 Photo: BE Picton & CC Morrow	✓	✓	EA	SF, BW	18-108
Mollusc	*Potamocorbula amurensis*	Asian clam	 Photo: Luis A. Solorzano	✓	✓	WP	BW	18-108
Mollusc	*Vererupis philippinarum*	Manila clam	 Photo: Peter J. Bryant	✓	✓	WP	CO, IP, BW	18-108

Table 4: Predicted invasive aquatic species threats.

* WP = Western Pacific (e.g., Japan); NP = North Pacific (e.g., Alaska); EA = Eastern Atlantic (e.g., Europe); SH = Southern Hemisphere.

** BW = Ballast water; SF = ship fouling; CO = commercial oyster culture; IP = intentional plantings.

Hemigrapsus sanguineus

Asian/Japanese shore crab

$

Native to the western Pacific Ocean, this crab is a known invader to Europe and the East Coast of the US where it has caused significant ecological impacts. It is a likely potential invader to the Oregon Coast on tsunami debris from Japan (Lam et al. 2013).

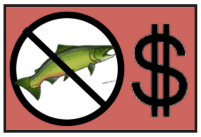
Asterias amurensis

Northern Pacific seastar

$

This seastar is native to the western Pacific Ocean in Japan, North China, Korea, Russia, as well as the North Pacific. It's a known invader to Australia, Tasmania, and Victoria, where populations as large as 12 million were reported within two years of its arrival. *A. amurensis* eats a wide range of mussels and clams, causing significant ecological and economic damage to introduced areas and earning it a place on the 100 World's Worst Invader List (ISSG 2015). It is listed as a key species to watch for on tsunami debris arriving to the Oregon Coast from Japan (Lam et al. 2013).

Mytilus galloprovincialis
Mediterranean mussel

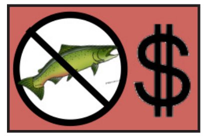


This cosmopolitan mussel is found throughout the western Pacific Ocean, Mediterranean Sea, northern Europe, eastern North America, Australia, New Zealand, Tasmania, Africa, and California (Cohen and Carlton 1995). Although adults of this species have not been reported in the Coos estuary, genetic research from the 1990s identified large numbers of viable *M. galloprovincialis* larvae in ballast water being discharged into the Coos estuary from Japanese ships (Geller et al. 1994). Detection of *M. galloprovincialis* will likely be complicated by its similar appearance to the native mussel *M. trossulus*.

Potamocorbula amurensis **(also reported as *Corbula amurensis*)**
Asian clam

This clam is native to the western Pacific Ocean from southern China to Siberia, Japan and Korea. It first arrived in the San Francisco Bay area in 1986 and was presumed to have been transported by ballast water of shipping vessels (Cohen and Carlton 1995). After its arrival, populations of *P. amurensis* grew quickly throughout the San Francisco estuary and major ecological changes were observed; *P. amurensis* was found to outcompete other species and completely changed the diversity of benthic communities wherever it became introduced (Cohen and Carlton 1995).

Venerupis philippinarum
Japanese littleneck clam, Manila clam



Native to the western Pacific, this clam was inadvertently introduced to multiple locations on the Pacific Coast of North America in the 1920s and 1930s with shipments of Japanese oysters from Asia. Manila clams have since spread via larval transport and with the movement of oysters between locations in Washington, Oregon, and California. From 1943 to 1966, there were several reports of the clam along the US Pacific Coast from Puget Sound to multiple locations in northern California. Most efforts in the 1950s and 1960s to intentionally introduce the clam to additional locations in Canada and Oregon failed. However, introductions to the Netarts estuary in the 1970s were successful and populations of Manila clams remain established there (Carlton 1979, Wonham and Carlton 2005). In many of the locations where Manila clams have become established, they have become the “numerically dominant clam”, with numbers reaching as high as 2,000/m^2 in the San Francisco estuary (Cohen and Carlton 1995). *V. philippinarum* is typically found in higher regions of the intertidal zone, which has been thought to limit competition with native clams, but recent evidence shows introductions of *V. philippinarum* in British Columbia have caused declines in native species (Bendell 2014).

Section 4. Threats to Human Health

Only a few species listed in this data summary are considered potential threats to human health. The purple varnish clam, *Nuttallia obscurata*, is often most abundant at freshwater seeps in estuaries. During periods of high freshwater runoff, these clams could sequester harmful chemicals, bacteria, and viruses that can be found in stormwater runoff (WDFW 2015), possibly affecting the health of humans when they consume purple varnish clams.

Invasive species can also harbor pathogens or parasites that affect humans. The salt marsh snail, *Assiminea parasitologica*, and the Chinese mitten crab, *Eriocheir sinensis*, are both known hosts of the parasitic Oriental lung fluke, *Paragonimus westermani*, which is known to produce symptoms similar to that of tuberculosis in humans (Draheim 2008; CDC 2013). However, humans may become infected only by consuming raw or inadequately cooked crabs and snails.

Section 5. Background on Species with Known Impacts

Biofoulers (sponges, hydroids, anemones, tube-building amphipods, bryozoans, and sea squirts)

Blackfordia virginica
Hydroid (no common name)
Large blooms of *B. virginica* can significantly impact plankton community structure through predation (Marques et al. 2015), but no local impacts have been reported for this species.

Botrylloides violaceus
Orange sheath sea squirt
This sea squirt is known to displace and out-compete other fouling organisms. For example, a study in California found *B. violaceus* achieved 100% coverage of the surveyed fouling community at two different locations (Lambert and Lambert 2003). Another study in California found this sea squirt showed increased growth and survival at warmer than ambient water temperatures compared to native species, which suggests its potential to persist during climate change (Sorte et al. 2010). In Nova Scotia, *B. violaceus* and other sea squirts have also been found to foul native eelgrass plants, causing increased mortality and decreasing the productivity of eelgrass beds (Wong and Vercaemer 2012).

Botryllus schlosseri
Golden star sea squirt
Local impacts of this species have not been documented, but in Bodega Bay, California, it was reported to be one of the eight most abundant fouling species during two separate

survey periods (1969-1971 and 2005-2009) (Sorte and Stachowicz 2011). While several studies in other parts of the species' introduced range also report that *B. schlosseri* can become the dominant species of a fouling community, the extent of its impact appears to be variable. For example, one study of fouling communities in Monterey Bay, California, found *B. schlosseri* grew quickly and initially out-competed other organisms for space, but did not have lasting effects on community structure (Sams and Keough 2012). In Nova Scotia, *B. schlosseri* and other sea squirts have also been found to foul native eelgrass plants, causing increased mortality and decreasing the productivity of eelgrass beds (Wong and Vercaemer 2012).

Bugula neritina
Spiral-tufted bushy bryozoan
No local impacts are reported for this species, but studies in California report it as a dominant species in fouling communities, with the ability to out-compete and out-perform native species (Sorte and Stachowicz 2011). Additionally, *B. neritina* (along with some other non-native species) showed increased growth rates and survival compared to native species when challenged by warmer temperatures, suggesting ecological impacts of this species may intensify with climate change (Sorte et al. 2010). In other parts of its range, *B. neritina* is also known to dominate fouling communities and can cause severe fouling of fishing gear (Hodson et al. 1997). It also has a high tolerance to copper-based anti-fouling paint, which makes it difficult to prevent its establishment and transport on ship hulls (Piola and Johnston 2006).

Cliona sp.
Boring Sponge
These sponges bore cavities in the calcium carbonate shells of shellfish that weaken the shell and make the organisms more susceptible to predation. While some species of boring sponges are native to the Coos estuary, one or more additional non-native species have been introduced, including the Atlantic boring sponge. One study in North Carolina found Atlantic boring sponges can significantly reduce growth rates and overall health condition of eastern oysters (Carroll et al. 2015).

Cordylophora caspia
Freshwater hydroid
No local impacts have been documented for this species, but as with other invasive fouling species, these hydroids have the potential to achieve high densities and out crowd native fouling organisms or cause economic impacts. For example, dense overgrowth of *C. caspia* colonies has been reported to clog intake pipes of power plants, causing the plants to be shut down for cleaning (Folino-Rorem and Indelicato 2005). Although largely ignored by native fish, *C. caspia* was found to be the main prey item of non-native Shimofuri gobis in a recently invaded California marsh (Matern and Brown 2005). This suggests *C. caspia* may have helped facilitate the invasion of another non-native species.

Didemnum vexillum
Carpet sea squirt
The temperature and salinity conditions of the lower Coos estuary are ideal for growth and reproduction of *D. vexillum* (McCarthy

et al. 2007, Valentine et al. 2007, Daley and Scavia 2008). Colonies of this sea squirt also produce acidic components that deter predators, allowing colonies to grow unchecked. There are no documented effects of *D. vexillum* in the Pacific Northwest, but several studies from the eastern US have found *D. vexillum* can out-compete, overgrow, smother, prevent recruitment of, and kill native organisms, and cause significant declines in biodiversity (Bullard et al. 2007, Mercer et al. 2009, Morris et al. 2009). Due to the high potential for impacts, it is listed on the Oregon Invasive Species Council list of 100 Worst Invasive Species (OISC 2013).

Diplosoma listeranium
Colonial sea squirt
No local impacts have been documented, but this species in known to overcrowd native fouling communities and negatively impact aquaculture operations in other parts of its introduced range (Fitridge et al. 2012). In Bodega Bay, California, *D. listeranium* increased from relatively low abundance in a 1969-1971 survey period to high abundance in a 2005-2009 survey (Sorte and Stachowicz 2011). The ability to thrive in warmer temperatures compared to native fouling species favors the survival and potential range expansion of *D. listeranium* during climate change (Sorte et al. 2010).

Ectopleura crocea
Pink-mouthed hydroid
No local impacts have been reported, but this non-native species is known to foul aquaculture operations in other parts of its introduced range, with negative impacts to the aquacultured species (citations in Fitridge et al. 2012).

Molgula manhattensis
Sea grapes
No local impacts have been documented for this species, but high densities of *M. manhattensis* have been observed covering nearly 100% of the spatial area of settlement plates in the Coos estuary (B. Yednock, pers. comm. 2016).

***Monocorophium acherusicum* (also reported as *Corophium acherusicum*)**
Tube-dwelling amphipod (no common name)
No local impacts have been documented for this species, but one study in California suggests high densities of filter-feeding crustaceans, including *M. acherusicum*, can cause significant declines in plankton biomass (Nichols and Thompson 1985).

Styela clava
Club sea squirt
As with other non-native sea squirts, *S. clava* can successfully out-compete native species and significantly decrease species diversity in fouling communities. It's often found in fouling communities of locally cultivated oysters (Japanese oysters, *Crassostrea gigas*), although detailed information on the distribution and abundance of *S. clava* is not reported for Coos Bay. A study in Southern California found *S. clava* at every location that was surveyed, with spatial coverage as high as 100% across large portions of fouling substrate (Lambert and Lambert 2003). In addition to ecological effects, *S. clava* commonly fouls aquaculture gear and, together with other

non-native fouling species, has been reported to reduce mussel harvests by as much as 50% in Canada (Locke 2009; Arsenault et al. 2009).

Watersipora subtorquata
Bryozoan (no common name)
No local impacts have been reported for this species, but studies in California show its abundance has increased in Bodega Bay from low to high numbers from 1971 to 2005 (Sorte and Stachowicz 2011) and, given its ability to live in warmer temperatures compared to native fouling species, *W. subtorquata* will likely survive and expand its range with climate change (Sorte et al. 2010). *W. subtorquata* is resistant to antifouling paints, making it difficult to deter from boat hulls and a viable vector for transporting other more sensitive non-native species that grow on top of it (Floerl et al. 2004). Other studies show this species can out compete other fouling organisms for space and have persistent effects on the presence and abundance of other species in biofouling communities (Sams and Keough 2012).

<u>Crustaceans (Crabs, shrimp, amphipods, isopods)</u>
Amphithoe valida
Amphipod (no common name)
No local impacts have been reported, but this species has the potential to significantly impact the production of eelgrass beds. In San Francisco Bay, these amphipods were found to preferentially feed on seeds of *Zostera marina* and, based on grazing rates and densities observed in eelgrass beds, could effectively remove all of the seeds in an eelgrass bed within weeks (Reynolds et al. 2012; Lewis and Boyer 2014).

Caprella mutica
Japanese skeleton shrimp
No local impacts have been documented for this species; however in other areas of its introduced range, this skeleton shrimp can become very abundant and live in extremely high densities. *C. mutica* were found to completely displace native skeleton shrimp in Scotland, even when initial densities of the non-native species were quite low (Shucksmith et al. 2009). Despite the potential for negative effects on native species, *C. mutica* invasions have yielded ecological benefits. For example, in Bodega Bay, California, *C. mutica* was found to prey on newly settled juveniles of the invasive sea squirt *Ciona intestinalis* (Rius et al. 2014). Despite its presence in estuaries in California and Washington, *C. intestinalis* has not been found in the Coos estuary; therefore it's possible *C. mutica* may help prevent or minimize the effects of a future local invasion.

Carcinus maenas
European green crab
This species has successfully and aggressively invaded every continent except Antarctica, earning it a place on the World Conservation Union's (IUCN) 100 Worst Invasive Species list. While studies have yet to measure the local impacts of green crabs on native species in the project area, one laboratory-based experiment conducted with green crabs that were collected from the Oregon Coast found them to be more efficient predators of native Olympia oysters (*Ostrea lurida*) than native Dungeness crabs (Yamada et al. 2010). This is of particular concern for projects aimed at restoring and conserving native oyster populations in

Coos Bay where green crab abundance and densities are increasing in areas with suitable oyster habitat. Also of concern are the many documented negative impacts of green crabs in other areas of the West Coast. In California, green crabs have been found to significantly alter the size, abundance and behavior of native shore crabs (de Rivera et al. 2011), as well as significantly modify benthic communities (Grosholz et al. 2000), reduce food availability for shorebirds (Estelle and Grosholz 2012), and deplete Olympia oyster populations (Kimbro et al. 2009). Green crabs have also been found to directly out-compete commercially and recreationally important Dungeness crabs of similar size for food and valuable shelter (McDonald et al. 2001). Intense predation pressure of green crabs on a native clam has also been documented in New Zealand and threatens the success and viability of this fishery (Walton et al. 2002). Foraging activity by green crabs is also suggested to be destructive to eelgrass beds (Davis et al. 1998), which could impact the function of this important habitat for other species, including commercially important fish and invertebrates.

Jassa marmorata
Amphipod (no common name)
No recent or local impacts have been reported for this species. Literature from California in the 1950s indicates this amphipod can grow in dense colonies that inhibit the recruitment of native fouling organisms (Barnard 1958, cited by Fofonoff et al. 2003).

Limnoria tripunctata
Isopod (no common name)
No local impacts have been reported, but this wood boring isopod has been reported to cause extensive damage to wooden piling and structures in San Francisco, British Columbia, and elsewhere in its introduced range (Cohen and Carlton 1995; Quayle 1992).

Orthione griffenis
Parasitic isopod (no common name)
This bopyrid isopod parasite is responsible for drastic declines in populations of the native mudshrimp, *Upogebia pugettensis*, along the western coast of the United States (Dumbauld et al. 2011). While the parasite doesn't directly kill mudshrimp, it causes significant blood loss, resulting in the castration of its host, resulting in a reduced overall reproductive rate of a population to below sustainable levels.

Palaemon macrodactylus
Migrant prawn
No local impacts have been reported for this species, but these shrimp are known to compete with native shrimp for food resources in San Francisco Bay (Sitts and Knight 1979).

Pseudodiaptomus inopinus
Asian calanoid isopod
No quantifiable impacts of this species have been documented, but it's become the dominant copepod of many estuaries in Washington, British Columbia, and Oregon – although it was not especially abundant in the Coos – and has the potential to significantly impact primary production by overgrazing phytoplankton (Cordell and Morrison 1996; Grosholz 2002).

Rhithropanopeus harrisii
Harris mud crab
In the Coos estuary, these crabs are restricted

to low salinity regions of the estuary due to competition and direct predation pressure by native *Hemigrapsus oregonensis* (Jordan 1989). No local impacts have been reported, but Harris mud crabs are successful invaders in several places across the globe and have led to trophic cascades in intertidal communities (Jormalainen et al. 2016).

Sphaeroma quoianum
New Zealand burrowing isopod
These burrowing isopods are found throughout the Coos estuary and South Slough (Davidson 2008). They create vast networks of cylindrical burrows (2-10 mm in diameter) in marsh banks, earthen dikes, wood, friable rock, hard rock, concrete, and Styrofoam that can support thousands of individuals per 0.25 m^3 (Davidson 2006; Davidson et al. 2008b). Their burrowing activity is known to weaken shoreline substrates and has increased salt marsh bank erosion at sites in California by as much as 240% (Talley et al. 2001). Extensive damage to docks and marine structures by *S. quoianum* has also been reported (see references in Davidson 2008). In Coos Bay, 100,000 *S. quoianum* is estimated to remove as much as 6 ft^3 of marsh bank, 4 ft^3 of Styrofoam, 3 ft^3 of sandstone, or nearly 1 ft^3 of wood in a two month period (Davidson and de Rivera 2012).

<u>**Molluscs (snails, clams, mussels, oysters)**</u>

Corbicula fluminea
Asiatic clam, golden clam
No local impacts have been reported for the Asiatic clam, but large populations in San Francisco Bay have been linked to significant sediment and hydrologic changes in the Sacramento-San Joaquin River Delta (including extensive impacts to irrigation systems) and declines in phytoplankton biomass (Cohen and Carlton 1995; Lopez et al. 2006).

Crassostrea gigas
Japanese oysters
Japanese oysters occur at high densities in aquaculture operations, but are also known to escape these operations and establish feral populations. No impacts have been reported specifically for the Coos estuary, but negative impacts of Japanese oysters are well-documented in other locations. For example, in Willapa Bay, Washington, Japanese oysters were found to reduce the density and growth of native eelgrass (*Zostera marina*) through direct competition for space (Wagner et al. 2012). They are also know to significantly alter intertidal habitats – specifically by converting soft-bottom habitats to hard-bottom shell reefs, which can promote the settlement of native oysters, but reduces their survival since native oysters have higher survival rates in subtidal locations (Ruesink et al. 2005). The movement of Japanese oysters among locations for aquaculture has been a well-documented vector by which other non-native species and parasites have spread, causing further impacts to native communities and habitats.

Mya arenaria
Softshell clam
This is a popular species for recreational clamming in Oregon estuaries, including the Coos. No negative impacts have been recorded locally, but large populations of these clams have replaced native clams in San Francisco

Bay (Cohen and Carlton 1995). A positive impact has been documented in Washington, where high densities of juvenile Dungeness crabs were found in large deposits of *M. arenaria* shells in Grays Harbor compared to adjacent mudflat areas (Palacios et al. 2000). In California, *M. arenaria* is an important prey item for native water birds, fish and crabs (Cloern et al. 2007).

Philine auriformis
New Zealand sea slug
As a specialist predator of small bivalves, this sea slug has the potential to impact native clams. No local impacts have been documented, but declines in bivalve populations in California have been associated with invasions of *P. auriformis* (Cadien and Ranasinghe 2001).

Potamopygrus antipodarum
New Zealand mud snail
There are no reports of abundances or direct impacts to the native community by *Potamopygrus antipodarum* for the project area. However, in other parts of their introduced range in the western United States these snails have been found at densities as high as 300,000/m^2 and have caused significant trophic level effects, reduced growth rates of native invertebrates due to competition for food resources, and in some cases have even been associated with declines in other invertebrate species (Hall et al. 2003; Kerans et al. 2005; Hall et al. 2006;).

Teredo navalis
Naval shipworm
Local impacts of these bivalves have not been quantitatively studied, but they have been found boring into wood structures and pilings around the Coos estuary. In California, they have been responsible for billions of dollars in damage to maritime infrastructure throughout San Francisco Bay (Carlton 1979; Cohen and Carlton 1995).

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