Pacific Northwest Aquatic Invasive Species Profile

Japanese Oyster Drill *Ocinebrellus inornatus*

Lee Duckwall
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Figure 1. Photo of *O. inornatus* on the left and American oyster drill (*Urosalpinx cinerea*) on the right.

Diagnostic Information

Common Names: Japanese oyster drill, Asian oyster drill

Other Scientific Names: *Ceratostoma inornatum, Ocenebra japonica, Ocenebra inornata, Ocinebrina inornata, Tritonalia japonica*

Order: Neogastropoda

Family: Muricidae

Genus: *Ocinebrellus*

Species: *inornatus*

Identification

Ocinebrellus inornatus displays a considerable amount of phenotypic variation that has the resulted in some confusion over its classification. It has been classified into the genera *Ocenebra* and *Ceratostoma* as well due to striking differences in shell morphology displayed by different specimens of *Ocinebrellus inornatus*. The genus *Ocinebrellus* is characterized by a ventrally sealed siphonal canal and the tendency towards axial over spiral sculpture on post-nuclear whorls (Amano and Vermeij 1998). The maximum shell height of *O. inornatus* is 47.9 mm, though individuals are generally closer to 40 mm (Amano and Vermeij 1998). *O. inornatus* displays a small degree of sexual dimorphism in which the female is slightly larger than the male (Martel et al 2004). The shell consists of five teloconch whorls with the last whorl containing four to twelve axial ribs (Amano and Vermeij 1998). An important characteristic that is often used to define individuals of the family Muricidae is the presence of a labral tooth. *Ocinebrellus inornatus* is found with and without a labral tooth simultaneously within populations both in its native and introduced range (Amano and Vermeij 1998). This has been a major cause of the confusion over the classification of this species and has resulted in the two conditions being commonly defined as separate species. Color of *O. inornatus* is generally beige or brown but can also be orange or striped.

Another oyster drill that has invaded the Pacific Northwest is the American oyster drill, *Urosalpinx cinerea* (Figure 1). The primary characteristic that distinguishes it from *Ocinebrellus inornatus* is its relatively smaller size, generally only 25 mm and reaching a maximum length of 35 mm. Other than size the two species share a very similar appearance. The shell consists of 5 to 6 whorls with 9 to 12 axial ribs. *Urosalpinx cinerea* has been introduced into Washington as a result of the transportation of eastern oysters (*Crassostrea virginica*) from the east coast of the United States. They have had similar ecological and economic impacts primarily in Willapa Bay where their population is the largest (Boersma et al 2006).

Another similar species is the native dogwhelk (*Nucella lamellosa*), which can be distinguished from both oyster drills by its larger size and thicker shell (Figure 2). Its preferred prey is also barnacles, not oysters (Boersma et al 2006).

Figure 2. Native dogwhelk (*Nucella lamellosa*).

Life History and Basic Ecology

Life Cycle and Reproduction

Ocinebrellus inornatus is gonochoristic, having separate sexes, and eggs are fertilized internally (Martel et al 2004). Eggs are laid from April to June in yellow egg capsules (Figure 3) that are slightly larger than a grain of rice (Buhle et al 2004). Martel et al (2004) discovered that in introduced populations in France, *O. inornatus* also displays a second reproduction period in autumn. This extended reproduction period gives them a higher resistance to seasonal environmental effects. After a development period of three weeks (Martel et al 2004), approximately 10 non-planktotrophic juveniles emerge from each capsule (Buhle et al 2004). Juveniles are about 2 mm upon emergence and show growth rates of at least 2 mm a month (Buhle et al 2004). Individuals may reach reproductive size (27 mm) after only a year. Adult annual survival rates may be as high as 30% but are generally closer to 10% in most areas (Buhle et al 2004).

Feeding Habits

Ocinebrellus inornatus and oyster drills in general are notorious for their destructive predation of commercially important bivalves. They have been known to feed on several species of mussels, oysters, and clams, and have also been observe feeding on other gastropods and barnacles. One of the primary concerns associated with the invasion of *O. inornatus* is the predation on the native Olympia oyster (*Ostrea lurida*). Buhle and Ruesink (2009) discovered that while *O. inornatus* is a predator of *Ostrea lurida,* it actually prefers the non-native Pacific oyster (*Crassostrea gigas*). In experimental trials and field enclosures *O. inornatus* was observed to attack Pacific oysters over Olympia oyster with a ratio in some cases as large as 7:1. This likely represents specialized feeding adaptations, due to the shared native ranges of *O. inornatus* and *Crassostrea gigas*. *O. inornatus* also demonstrated a preference for smaller oysters (Buhle and Ruesink 2009).

Oyster drills feed by drilling a hole through the shell of their prey. This process is aided by sulfuric acid secretions used to soften the shell and allow the radula to more easily drill through the shell. After the hole is drilled, the oyster

Figure 3. Photo from USGS Non-indigenous aquatic species website showing mating *O. inornatus* with egg capsules.

drill excretes digestive enzymes into the body of its prey. The oyster drill is then able to extract the digested tissues. This process can take as long as a week depending on the size of the oyster (Boersma et al 2006). *O. inornatus* generally targets smaller oysters, which they are capable of consuming at a rate of three per week (Boersma et al 2006). Because an oyster drill's ability to feed is determined by its ability to drill a hole through the shell of its prey, it is limited to prey with shells that can be easily drilled through. The shell thickness of the prey is the main deterrent of oyster drill success. They are limited to preying upon individuals with shell thickness less than the length of their radula. For this reason the oyster drills, including *Ocinebrellus inornatus,* feeds primarily on the spat of oysters. This may also cause adults of the native Olympia oyster to be more susceptible than Pacific oyster to predation due to their smaller size and slower growth rate.

Environmental Optima and Tolerances

Ocinebrellus inornatus is native to warm and cool temperate seas of northeastern Asia (Amano and Vermeij 1998). Warmer temperatures are more desirable for growth and reproduction. Martel et al (2004) showed that *O. inornatus* had higher growth rates during the summer months when water temperatures are warmer. This same correlation was also observed by Buhle and Ruesink (2009) when observing growth rates of newly hatched juveniles. Reproduction in the late spring is most likely a response to the higher growth rates possible in summer months. Although warmer temperatures are preferred, *O. inornatus* has been observed to have a very high tolerance of cold temperatures. Faase and Ligthart (2009) reported *O. inornatus* surviving temperatures of 0-1 ºC during in a cold spell in the Netherlands.

Like many other oyster drills *Ocinebrellus inornatus* does not have a high tolerance for low salinity and are uncommon in areas with high freshwater input. It is believed that oysters may have evolved a tolerance for lower salinity in response to predation by oyster drills. In Willapa Bay, Washington neither *O. inornatus* nor the invasive American oyster drill, *Urosalpinx cinerea*, are found in the northern portion of the bay where there is higher river flow (Figure 4) (Buhle and Ruesink 2009).

The preferred habitat of *O. inornatus* is hard substrate, in particular the reefs built by Pacific oysters. This provides them with a food source, protection from predators, and an excellent place to deposit eggs. Oyster drills are found in higher abundance in naturally formed Pacific oyster reefs over cultured beds (Buhle and Ruesink 2009). *O. inornatus* can also be found in very low densities on the bare tide flat between reefs (Buhle and Ruesink 2009)

Biotic Associations

Research relating to parasites, pathogens, and commensals of *Ocinebrellus inornatus* appears to be lacking. A common reason for the success of an invasive species is the release from predation or parasites when introduced to a new environment. It has been mentioned that this may be a possible reason for the success of *O. inornatus* in its non-native habitat (Faase and Ligthart 2009). It is not uncommon for members of the family Muricidae to be hosts for parasites (Oliva et al 1999) so it is very likely that *O. inornatus* contains parasites in at least its native range.

Current Geographic Distribution

The native range of *Ocinebrellus inornatus* is between the Sakhalin and Kurile Islands and Japan. It is also found in the region between Northern China and South Korea (Martel et al 2004). The first record of *Ocinebrellus inornatus* from outside its native range was the West coast of the United States in Puget Sound Washington in 1924 (Martel et al 2004). Since then they have spread throughout Puget Sound and to other parts of the Pacific Northwest. *O. inornatus* currently has established populations as far north as British Columbia, including the Straight of Georgia and the west coast of Vancouver Island. They have also spread south along the coastline of Washington and into Willapa Bay where they have been a serious problem to shellfish growers. Established populations of *O. inornatus* have been found further south in Netarts Bay, Oregon. Live specimens have been collected as far south as Tomales Bay and Morro Bay in California (Carlton 1979). There has been an established population on the Atlantic coast of France since 1995 (Martel et al 2004).

History of Invasiveness

The primary pathway for the introduction and spread of *Ocinebrellus inornatus* has been the transportation of the Pacific oyster, *Crassostrea gigas.* Even before Pacific oysters were transported to the United States, the destructive nature of *Ocinebrellus inornatus* was already known, as it had been serious problem for oyster aquaculture in Japan. Precautions were taken to prevent the spread of this invasive species to the oyster beds on the West Coast. Despite this, *O. inornatus* was still introduced to the United States, and in 1924 established populations were discovered in Puget Sound. Since then it has spread throughout Puget Sound and the Washington coastline. It was introduced into Willapa Bay sometime before 1965 (Carlton 1979). In 1995 *Ocinebrellus inornatus* was found established on the Atlantic coast of France in Marennes-Oléron bay as a result of shipments of Pacific oysters from the United States (Martel et al 2004). It has continued to spread throughout the Atlantic coastline of France and has also been found in the Netherlands (Faase and Ligthart 2009).

Invasion Process

Pathways, Vectors, and Routes of Introduction

During the 1800's and early 1900's the Olympia oyster was over harvested throughout its native range. With the demand for oysters still high, Pacific oyster seed was transported from its native range in Japan to the West coast of the United States. Pacific oysters were first transported to Puget Sound for commercial use. Originally adults were introduced but failed to establish a population. Soon it was discovered that oyster seed could easily be transported and grown to adult size in Washington. Extensive trade for Pacific oyster seed between Japan, California, and Washington led to massive amounts of oyster shell being transported throughout the West coast with very limited regulations aimed to prevent the spread of invasive species. The transportation of oyster shell has resulted in one of the most important pathways for the introduction of invasive species (Carlton 1992). The number of species that have been introduced as a result of oyster transportation is comparable to that of ballast water, and hull fouling (Wolff and Reise 2002). The large masses of shell being imported into Washington provided a vector for a number of invasive species including *Ocinebrellus inornatus*. *O. inornatus* has been established in Washington since nearly the beginning of the Pacific oyster industry. As the industry expanded to other parts of Puget Sound and throughout Washington, *O. inornatus* was transported as well. Any attempts to regulate the spread of invasive species due to oyster transportation were easily overwhelmed by the number of oysters being transported. Often there have been years in which millions, even tens of millions, of individuals were imported (Wolff and Reise 2002).

Factors Influencing Establishment and Spread

By far the most important factor that has limited the spread of *Ocinebrellus inornatus* is the fact that it does not have a planktonic stage at any point in its life cycle (Martel et al 2004). Without a planktotrophic larval stage, natural dispersion is very limited. This restricts the mechanisms for spreading to human controlled pathways, primarily the transportation of oyster shell and live adults.

A major factor that influences the establishment of *Ocinebrellus inornatus* is the presence of large numbers of oysters. Buhle and Ruesink (2009) discovered that densities of *O. inornatus* were highest in areas with naturally formed Pacific oyster reefs. Areas with no hard substrate contained very few individuals. Cultured oyster beds also contained high densities of *O. inornatus*; however, abundance was still lower than naturally formed reefs. This is likely due to the requirement of complex substrate for shelter and reproductive purposes as well as more variations in food sources available on natural reefs.

The success of establishment is also highly regulated by environmental factors. The limited tolerance for low salinity and preference for higher temperature restricts the geographic distribution of *O. inornatus.* Buhle and Ruesink (2009) observed that the distribution of oyster drills in Willapa Bay was restricted to areas further from the rivers (Figure 4).

Another interesting factor effecting establishment is biotic resistance from crab predation. In the experiments by Buhle and Ruesink (2009) juvenile Dungeness crabs were often observed in the enclosed field experiments, and many of the dead individuals of *O. inornatus* showed signs of crab predation. Red rock crabs (*Cancer productus*) have also been known to prey upon *O. inornatus.*

Ecological and Economic Impacts

Oyster drills historically have had devastating impacts on the commercial shellfish industry. In some cases their predation has been severe enough to cause shellfish growers to abandon infested beds (Buhle and Ruesink 2009). Oyster drills are capable of consuming small oysters, around 2 cm, at a rate of 3/week and have often been found in densities of 100/m^2 (Buhle and Ruesink 2009, Boersma et al 2006). They have been known to inflict as high as 50% mortality on oyster spat.

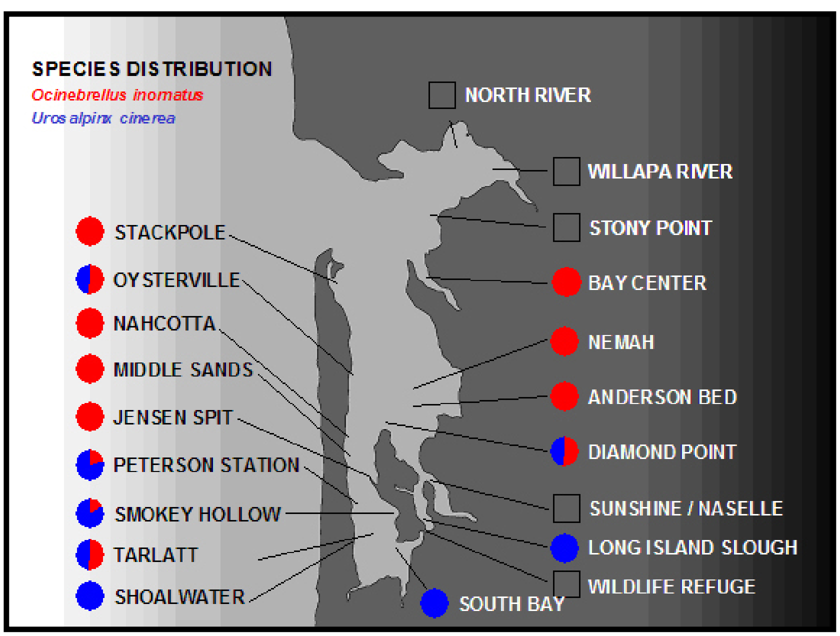

Figure 4. Map of Willapa Bay, Washington showing the distribution of the Japanese oyster drill (red) and the American oyster drill (blue). Note the complete absence of both species in the north where river input is high. Difference in distribution of the two species is likely due to transportation by humans and environmental preferences. From Ruesink Lab

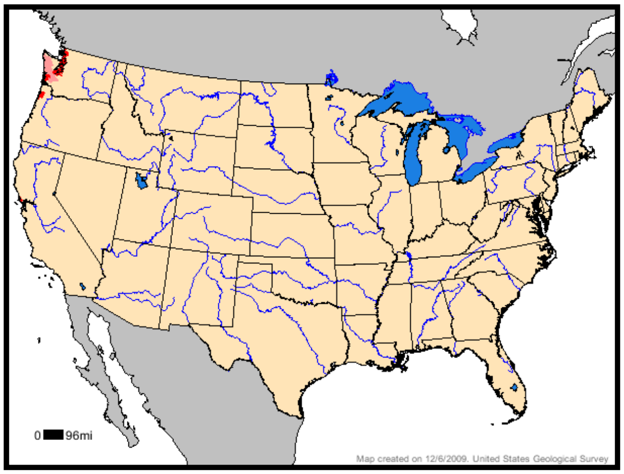

Figure 5. Map from USGS Non-indigenous aquatic species profile of *Ocinebrellus inornatus* showing the distribution in the United States. The densest populations occur in Puget Sound and Willapa Bay, Washington. Populations also exist in Netarts Bay, Oregon and Tomales Bay in northern California.

The primary ecological impact of *Ocinebrellus inornatus* has been on the native Olympia oyster (*Ostrea lurida*). Historically Olympia oysters were widespread throughout the west coast from Alaska to Baja California. During the gold rush they were quickly over harvested in San Francisco. Harvesting increased in the Puget Sound area and throughout Washington and oysters were shipped to California to meet the demand. In Puget Sound exploitation peaked from 1900 to 1928 when 120 million oysters were removed annually (White et al 2009). This resulted in the extensive depletion of Olympia oysters throughout the West coast. Since their depletion, Olympia oysters have struggled to make a comeback largely in part due to invasive oyster drills. *O. inornatus* has been known to cause high localized mortality in Puget Sound (Chapman and Banner 1949).

Buhle and Ruesink (2009) conducted a study examining the impacts of oyster drills on the recovery of Olympia oysters in Willapa Bay, Washington (Figure 6). They discovered that both *Ocinebrellus inornatus* and *Urosalpinx cinerea* actively preyed upon Olympia oysters; however, intensity of predation varied. Both species showed a preference for the introduced Pacific oyster over the native Olympia oysters. It was established that the extent of the impacts of oyster drills on Olympia oysters were very much regulated by Pacific oysters, which provide important habitat and an abundant food source. The presence of Pacific oysters was shown to increase the population of oyster drills,

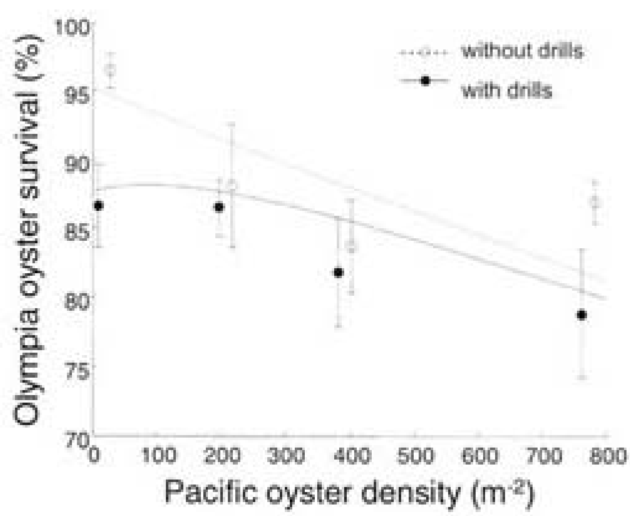

Figure 6. The relationship between Pacific oyster density and Olympia oyster survival. Olympia oysters display a lower survival rate in the presence of Pacific oysters especially when oyster drills are also present (Buhle and Ruesink 2009).

which in turn had negative impacts on recruitment of Olympia oysters. Oyster shell provides necessary substrate for spat of both oyster species to settle. In areas such as naturally formed Pacific oyster reefs, Olympia oysters are unable to settle due to high populations of oyster drills. This significantly limits the distribution available for settlement of Olympia oysters to areas that are missing both Pacific oysters and oyster drills.

Management Strategies and Control Methods

Fortunately *Ocinebrellus inornatus* does not have a planktonic stage at any point in its life cycle. This has limited the factors influencing spread to human controlled vectors. The primary vector for spread has been as a hitchhiker on oyster shell that is commonly transported as settlement substrate. In order to limit further spread, the Washington Department of Fish and Wildlife restricts the transports of shellfish or shell from an infested area to an uninfested area (Boersma et al 2006). Permits to transfer shellfish from infested areas are attainable if shellfish pass an inspection process. In the past chemicals were tested in order to find a means of eradication, but no safe chemicals were found to be effective. When collected from public beaches it is required to shuck oysters and leave the shells on the beach. This is for oyster conservation purposes as well as preventing the spread of oyster drills.

Once established, oyster drills pose a great concern for shellfish growers. Eradication attempts have been unsuccessful, and currently only control measures are used to limit their impact. Oyster drills and their eggs are removed manually from shellfish beds. Buhle et al (2004) found that the removal of eggs has a much larger effect on controlling the population than removing adults. Oyster drills are species with only two life stages. Control measures can be applied at either of these life stages, either targeting fecundity or adult mortality. Since oyster drills already have high adult mortality (about 10% annual survival) control measures targeted at this stage would likely be insignificant in increasing adult mortality. A much more effective management strategy would be removing the eggs oyster drills.

Transportation of oysters has been recognized as a major pathway for the introduction of invasive species and pathogens. Many control measures are taken in order to limit the spread of many different diseases and organisms. Some of the measures aimed to prevent the spread of one organism are also very useful in preventing the spread of *Ocinebrellus inornatus*. A common practice is to immerse oysters in freshwater. Mueller and Hoffmann (1999) found that immersion in freshwater causes *O. inornatus* to detach from oysters. In order to prevent the spread of the green crab, *Carcinus maenus*, oyster shell is required to be baked when transported from California to Washington. This process is also successful in eliminating any live oyster drills as well.

A strategy that has been used to combat invasive species is the use of ant-fouling paint. Tributyltin (TBT) is a component of ant-fouling paint that has been observed to be very toxic to many muricid species. TBT was used in the Netherlands until populations of native whelks experienced dramatic declines (Faase and Ligthart 2007). After the ban of TBT in the Netherlands, both *Urosalpinx cinerea* and *Ocinebrellus inornatus* established populations. The use of TBT in the United Kingdom nearly led to the eradication of *Urosalpinx cinerea* (Faase and Ligthart 2007). This toxic chemical, although effective against oyster drills, has also led to dramatic declines in native muricid species (Faase and Ligthart 2007).

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Other Resources

Washington State University Extension Island County Beach Watchers. Intertidal Organisms http://www.beachwatchers.wsu.edu/ezidweb/animals/Nucellalamellosa.htm

Global Invasive Species Database. http://www.issg.org/database/species/impact_info.asp?si=1383&fr=1&sts=&lang=EN

Ruesink Lab Oyster Drills, University of Washington. http://depts.washington.edu/jlrlab/oysterdrills.php

USGS Non indigenous aquatic species. http://nas3.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=1015

Experts in the Pacific Northwest

Jennifer Ruesink
University of Washington, Department of Biology
ruesink@u.washington.edu

Eric Buhle
University of Washington, Department of Biology
buhle@u.washington.edu