Corbicula fluminea (O. F. Müller, 1774) – Asian Clam

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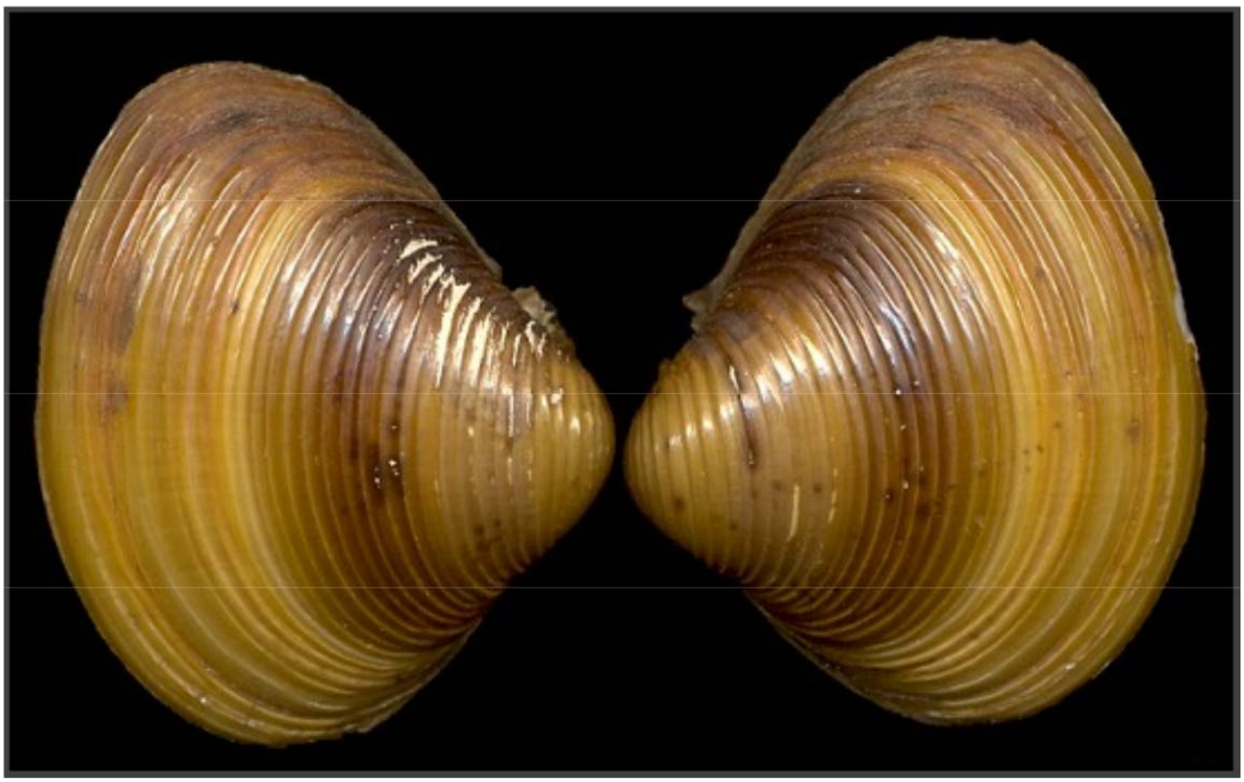

Corbicula fluminea **(O. F. Müller, 1774)**

Order: Veneroida

Superfamily: Corbiculoidea

Family: Corbiculidae

Common Names: Asian clam, asiatic clam, prosperity clam, gold clam, pygmy clam

Basic ID

Corbicula fluminea is usually less than an inch in size (25mm) but can reach lengths as large as 2.25 in (50 to 65 mm) (McMahon 2002). The outline of the shell is usually triangular or round and the beak is located centrally along the dorsal side of the clam and is typically inflated (Nedeau *et al.* Undated). These bivalves are typically light-colored and are typified by evenly spaced concentric sulcations (ridges), lateral teeth on their posterior and anterior sides with many fine serrations. There are two morphs of this species (McMahon 1991). One is a yellow-green to light yellowish-brown morph on its periostracum and a white to light blue or purple nacre. The other morph is limited to the southwestern United States (in its US range only) and is dark olive green to black on its periostracum and displays a dark royal blue nacre. *C. fluminea* is a freshwater species, but can be found in brackish water as well. The shell shape alone is unique to this species in the Pacific Northwest (PNW) as are the well-developed concentric sulcations are absent on other genera in the Pacific Northwest (Nedeau *et al.* Undated). Figures 1 & 2 above depict basic bivalve morphology useful for identifying bivalves in general, while Figure 3 &4 are of *C. Fluminea* itself. The USFWS in collaboration with other institutions has put out a guide to PNW bivalves ecology as well as a dichotomous key available online for free at: http://www.fws.gov/columbiariver/mwg/pdfdocs/Pacific_Northwest_Mussel_Guide.pdf

Range

C. fluminea is believed to be native to temperate and tropical regions of the eastern Mediterranean all the way west to southern Asia as well as parts of Africa and even some areas in eastern Australia (Morton 1986). The Asian clam has invaded many regions of the continental U.S., since its first documented discovery in Washington State in 1938 and has continued to spread (Figure 5) (Foster 2008). In the PNW, *C. fluminea*, has invaded several regions (Figure 6) (Foster 2008). The specific locations are from the complied lists on the USGS website for *C. fluminea* (2007). In Washington it has been documented to occur in the Columbia River since 1938 (Burch 1944) as well as the Snake, Chehalis, and Willapa rivers; Hood Canal in Jefferson County; and Aberdeen Lake in Grays Harbor Lake County (Counts 1986, 1991). In Oregon *C. fluminea* has was

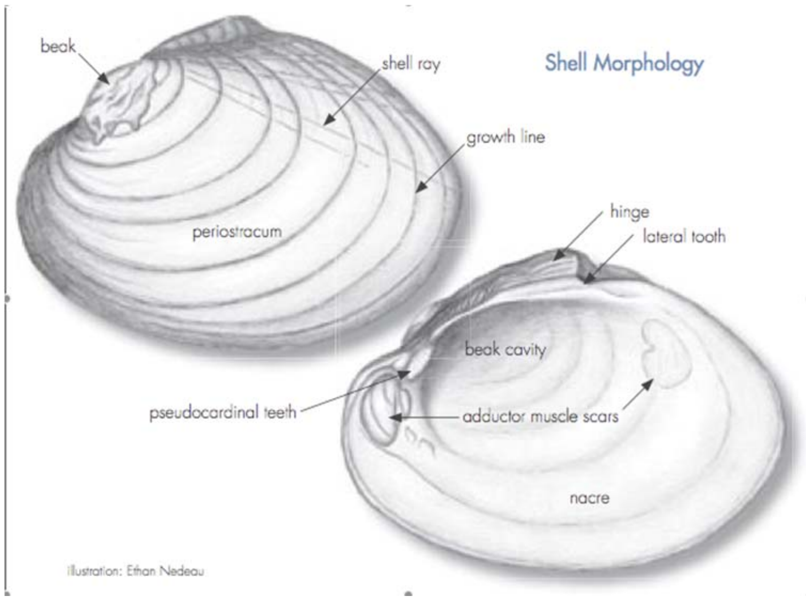

Figure 1. General bivalve shell morphology (Nedeau *et al.* Undated).

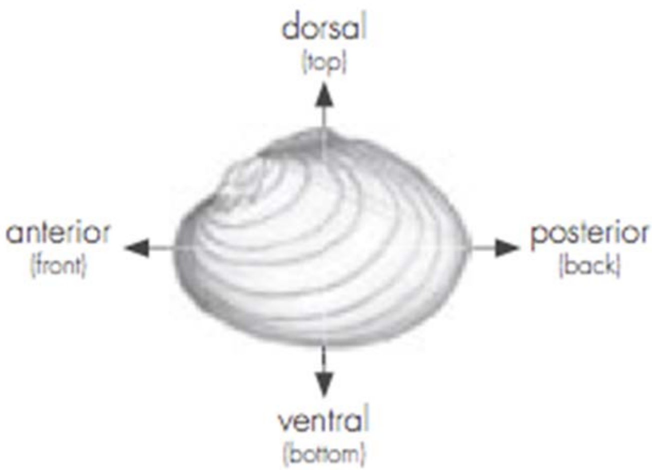

Figure 2. The four sides of the clam, which are useful in identification of bivalves (Nedeau *et al*. Undated),

Figure 3. Typical shell shape of *C. fluminea* (Nedeau *et al.* Undated).

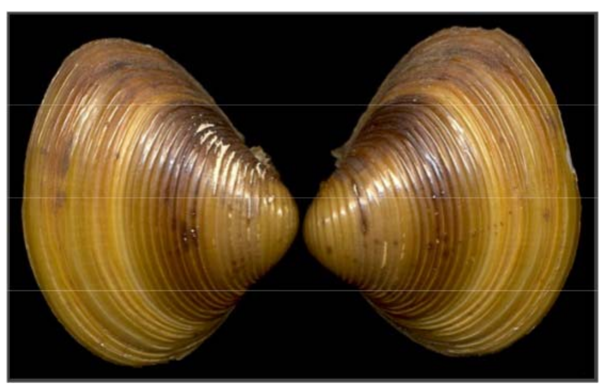

Figure 4. Photo of an adult yellow morph of *C. fluminea* (at:http://www.jaxshells.org/821aa.jpg).

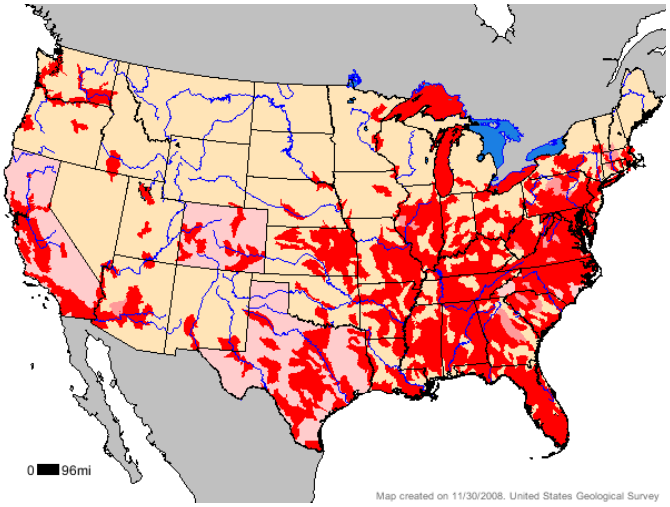

Figure 5. Distribution of C. Fluminea in the continental U.S. Hawaii is not shown but is invaded as well. Red areas are more heavily infested than pink areas. (Foster 2008).

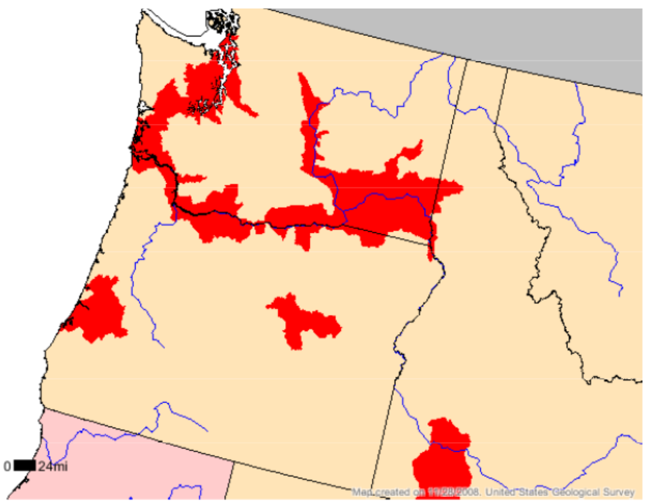

Figure 6. Distribution of C. fluminea in PNW (Foster 2008).

first discovered and documented in the Columbia drainage in 1948 (Ingram 1948). Since then its documented spread includes the John Day River; the Smith River near Scottsburg, at the mouth of the Siuslaw and Willamette rivers (counts 1991), and in Coos Bay (Ruiz 2000). Idaho has been invaded as well along the Idaho-Washington State line in the Snake River since 1959 (Ingram 1959).

Ecology and Life History

The Asian clam, *C. fluminea*, is a freshwater clam but has been known to occur in brackish waters as well (salinity levels up to 13ppt for short periods of time) (Nedeau *et al.* Undated, Morton and Tong 1985, Evans *et al.* 1979). It primarily occurs in estuarine, lake, and river habitats of all sizes and can survive in a multitude of substrates including sand, silt, clay, and gravel but prefers fine, clean sand, clay, and coarse sand substrates (Foster 2008). It requires well-oxygenated waters and temperatures between 2-36 degrees Celsius; temperatures above and below this range are lethal. (Balcom 1994). *C. fluminea* can tolerate this wide range of temperatures, however, it requires temperatures above 16 degrees Celsius in order to reproduce and has reduced metabolism and respiration above 30.

They are filter feeders that remove particles from the water column and feed primarily on phytoplankton as well as particulate organic matter (POM) (Foster 2008, Hill & Knight 1981, Foe & Knight 1986). Various studies of the clams feeding selectivity have demonstrated that it is an extremely efficient filter feeder, with higher filtration and assimilation rates than other freshwater clams, and feeds on various species of alga and POM rather indiscriminately (Boltovskoy *et al.* 1995, McMahon 1999). These invasive clams have the highest net production efficiencies than any other freshwater clam that has been studied (McMahon 1999). In addition to filter feeding C. fluminea is also capable of deposit feeding wherein the clam transports sediments across its labial palps by ciliary tracts on its foot (Hornbeach & Way unpublished, cited by Way *et al*. 1990). It is hypothesized that the Asian clam is primarily a filter feeder and uses deposit feeding to supplement its diet when food resources are scarce or particle size limits filter feeding efficiency (Boltovskoy *et al.* 1995, Way *et al.* 1990, Hakenkamp *et al.* 2001). The higher metabolic rate is likely the mechanism by which C fluminea is able to achieve higher filtration, assimilation and growth rates than other unionoideans (McMahon 1999). They are found at the surface of sediment or slightly buried, usually no more than 10cm below the surface. These clams can be found in densities as great as 20,000 per meter squared (McMahon 1999).

C. fluminea is a simultaneous hermaphrodite and has the ability to self-fertilize as well as broadcast its sperm through the water column (Kraemer *et al.* 1986). The clams release sperm into the water column (or to themselves), and once they find another clam they fertilize and brood the larvae within the branchial gills of the adult clam. Fecundity in the Asian clam is high, estimated at 68,678 juveniles per adult per year (Aldridge & McMahon 1978). The juveniles are very small, but have a well-developed bivalve shell, adductor foot, statocysts, gills, and digestive system. They are released via the excurrent siphon on the adult into the surrounding water. The juveniles either anchor themselves to sediment or other hard surface substrates by creating a mucilaginous byssal thread or use the thread to be carried through the water column by fluvial or tidal currents and dispersed long distance This thread can also attach to the body of avian species associated with the water capable of transporting the juvenile clams to other bodies of water. Juveniles reach maturation within 3-6 months and are generally 6-10 mm and live for 1-4 years on average. In North America two annual reproductive periods have been documented, one that runs from spring through early summer and another that runs from late summer to early fall. The short maturation time and bivoltine reproductive periods means that spring born individuals can reproduce within the same year that they are born. Mortality rates of juveniles and adults are high (74-98% in year 1, 59-69% in year 2, 93-97% in year three) (Sickel 1986). This life history characteristic has lead to populations, which are dominated by juveniles and immature individuals. (McMahon 1999)

Many of the life history traits discussed above, short life span, early maturity, high fecundity bivoltine reproduction, high growth rates, small juvenile size, and ability to disperse downstream permits for *C. fluminea* to be highly invasive and adapted to unstable habitats where unpredictable disturbances can severely reduce or eliminate populations (McMahon 1999). These characteristics render *C. fluminea* capable of recovering high population densities after severe population declines or upon reaching new habitat. In addition, *C. fluminea* tolerant of turbidity (Way *et al.* 1990) and has higher than average filtration, assimilation, metabolic rates and therefore growth rates (when compared to other freshwater bivalves) (Alimov 1975, McMahon 1999). The higher metabolic rate enhances the clam's ability to reburrow rabidly when it is dislocated from substrates due to high currents protecting the clam from damage or predation (McMahon 1999). These too increase the clam's ability to invade unstable habitats, which have higher flow rates and greater suspended solids and sediments. Their adaptations to unstable habitat are one of the reasons they are able to out compete many native aquatic species, especially mussels. Many native species require a much longer period of time to recover from sudden population declines than *C. fluminea* (McMahon 1999, McMahon 2002).

Even though many of *C. fluminea*'s life history traits allow for it to be a successful invader, there are several ecological constraints on the species, which can potentially limit its ability to establish. *C. fluminea*, when compared to other unoidean species, is less tolerant of elevated and quick changes in temperature (McMahon 1996, 1999), hypoxia (Johnson & McMahon 1998, McMahon & Bogan 2001), emersion (McMahon 1999), low pH, and low calcium concentrations, all of which can limit the clam's distribution (McMahon 1999, McMahon & Bogan 2001). Although *C. fluminea* is a highly invasive and successful invader it does have some limitations on its range. This species exhibits both some of the characteristics that predispose it to being a successful invader but is missing others. Many native freshwater bivalve are much more tolerant to these physical characteristics of the environment than *C. fluminea*. Invasion ecology suggests that a successful invader will be more tolerant than native species (McMahon 2002). Although these ecological constraints can place restrictions on *C. fluminea's* expansion, it has continued to spread voraciously. It is thought that *C. fluminea* will continue to spread until it reaches its lower temperature boundary (Foster 2008).

History of invasion:

Pathways, vectors and routes of introduction

The first documented collection of *C. fluminea* in the US occurred in 1938 in Washington State along the shores of the Columbia River near the town of Knappton (Foster 2008). The original vector is unknown however many researchers believe it to have been introduced by Chinese immigrants to use as a food source or it may have been introduced accidentally via the seafood trade when the Giant Pacific Oyster was brought to the US to cultivate (Foster 2008). Similarly, the mechanism for historical dispersal within the US is unknown. However we do know that C. fluminea is highly associated with human activity and could have continued to be introduced to new locations by humans for food sources (Devick 1991), as an accidental hitchhiker in the seafood trade, sold through the aquarium trade, dispersed by recreational boaters, transported via ballast water (Counts 1986), and is used as live bait to this day (Counts 1986). In addition, *C. fluminea* has the ability to disperse via juveniles in the water column or to be carried by birds associated with water (McMahon 1999) although some believe that this is not a primary vector (Counts 1986, Isom 1986). Its natural dispersal is likely an important factor in its secondary spread, once humans have introduced it to a new area. *C. fluminea* has most likely utilized a combination both its natural dispersal and human-mediated dispersal mechanisms to invade large portions of the US, and more recently South America (first discovered in the 1970's) (Ituarte 1994) and Europe (first documented in 1980 by Mouthon (1981)). In addition, its life history traits make it a good invader.

Factors influencing establishment and spread

It is thought that *C. fluminea* will continue to spread throughout the continental U.S. until it reaches its lower temperature restriction, 2 degrees C (Foster 2008). This is due to the fact that because of its natural and human mediated dispersal there are few geographic barriers that will prevent its spread, leaving only physiological and environmental constraints to stop the spread of *C. fluminea*. *C. fluminea* has many r-selected traits (McMahon 2002). Its ability to disperse long distances, reproduce hermaphroditically, release close to 70,000 juveniles in the same year, half of which can reproduce with in 3-6 months contribute to its establishment and spread. The Asian clam is capable of quickly establishing large populations in a short amount of time. Thus, propagule size is not likely to play a large role in controlling the establishment and spread of this species.

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Economic impacts

Economic impacts of *C. fluminea* have been documented since its initial invasion in the US. The main cause of economic damage created by C. fluminea is as a biofouler (Isom *et al.* 1986; Williams & McMahon 1986). It causes millions of dollars worth of damage to intake pipes, irrigation canals, or other infrastructure of energy, water, agriculture and other industries across the entire country. In 1986, the cost of correcting and controlling problems and damage associated with *C. fluminea* was estimated at one billion dollars annually (Isom 1986). No current estimates exist. However, since *C. fluminea* has only continued to spread and considering inflation, the cost of control has probably risen sharply. *C. fluminea* enters pipes as they draw water from rivers and reservoirs to use for cooling purposes. The larvae of C. fluminea are also drawn into the pipes in this manner and once inside the plant it can clog condenser tunes, raw service water pipes, fire fighting equipment, among others. Once pulled inside they are able to attach and breed. The intake pipes as well as other infrastructure become clogged with live clams, empty shells and dead body tissue. The buildup of these clams in the infrastructure can cause decreased efficiency of power generation, damage and clog irrigation canals and pipes used for agriculture (Prokopovich & Hebert 1965; Devick 1991), drinking water (Smith *et al.* 1979). In addition, *C. fluminea* can cause problems for the sand and gravel industry (McMahon 1983).

Ecological impacts

Non-native bivalves have been shown to change community structure and ecosystem processes in the areas they invade (Stewart *et al.* 1998, Strayer *et al.* 1999). The reported ecological impacts of *C. fluminea* have largely been negative. Documented negative impacts to ecosystems include the displacement or extirpation of native mollusc populations, modification of water flow, sedimentation and other physical processes (e.g. McMahon 1983, Hakenkamp and Palmer 1999), limitation of pelagic food sources (Cohen *et al.* 1984, Lauritsen 1986), changes in invertebrate community structure (Beaver *et al.*1991, Hakenkamp *et al.* 2001, Werner and Rothhaupt 2007), as well as ecosystem level change (Phelps 1994). Invasive species have been shown to have both potentially beneficial and detrimental effects.

Invasion of *C. fluminea* has also been associated with positive benefits such as the improvement of water clarity and reduce eutrophication because it is such an efficient filterer (Phelps 1994) and its ability to serve a biological monitor of pollution due to its tolerance of pollutants (Doherty 1990). However, its role in filtration to provide better water quality and reduce eutrophication can also be considered a negative effect and is discussed below. It is also possible that *C. fluminea* could provide shelter and substrates for other species (Gutierrez *et al.* 2003) or be a prey item other pelagic and benthic species (Foster 2008). However, these potentially positive effects have not been well studied and warrant further studies order to be called a positive benefit of this species.

C. fluminea's ability to filter at rates much higher than many native mussels can potentially change the physical processes, water quality, and the biotic community. The Asian clam has been shown to remove large amounts of suspended materials from the water column thereby potentially increasing water quality. In the Potomac River in Washington D.C., increases in the population of *C. fluminea* is associated with a substantial decrease in phytoplankton and water turbidity, leading to a substantial increase in submerged aquatic vegetation (Phelps 1994). In this case *C. fluminea* acted as an ecosystem engineer changing the landscape of the Potomac River. It could also limit seston available to other filter feeding species and change the structure of the planktonic community (Beaver *et al.* 1991, Hakenkamp and Palmer 1999). The clam's ability to filter at such high rates as well as high densities allow it to consume large quantities of phytoplankton affecting the zooplankton community (Beaver *et al.* 1991). *C. fluminea* could also have an effect on the recruitment of other aquatic species, which use the water column to reproduce and disperse by filtering out their sperm, glochida, and juveniles from the water column (Sousa *et al.* 2005, McMahon 1991, Strayer 1999). It's high filtration rates and densities could also mean that the clam is out competing other bivalves and filterers for food (McMahon 1999). Lastly their high filtration and assimilation rates of phytoplankton could result in the diversion of primary productivity away from higher trophic levels of the food chain (Lucas *et al.* 2002, McMahon 1999). Some researchers have speculated that this could lead to a decline in commercial and game fisheries stocks (Robinson and Wellborn 1988 as cited in McMahon 1999).

The Asian clam can also affect its surrounding benthic substrate and community in other ways due to its high metabolism and respiration, pedal feeding, and accumulation of clamshells after massive die-offs. *C. fluminea* can affect the nitrogen cycling rates (mainly through excretion of faeces and pseudofaeses) of the water column and of phytoplankton productivity (Asmus & Asmus 1991). Due to the clams high metabolism and respiration it release large quantities of nitrogen that affects both of these processes (Beaver *et al.* 1991). *C. fluminea* could considerably increase the amount of carbon released into the surrounding environment because of its high respiration rates (Hakenkamp and Palmer 1999). Pedal feeding by C. fluminea could also affect other benthic invertebrates by disturbing the substrate and reducing available food and POM for other organisms (Hakenkamp and Palmer 1999). Pedal feeding of the Asian clam has been shown to decrease the abundance of benthic flagellates, bacteria, and diatoms (Hakenkamp *et al*. 2001). *C. fluminea* is often present in large densities and often makes up greater than 99% (dry biomass)of the benthic invertebrate community (McMahon 1991). In addition, it is adapted to unstable habitats and is extremely successful in them. This means that when disturbance events occur and massive die-offs of *C. fluminea* occur (either annually through winter water temperature changes or desiccation events). The accumulation of their shells can lead to changing the substrate from soft sediments to a hard one that can lead to colonization by different plants and animals (McMahon 1999). In addition the massive die-offs can lead to the build up of shells that alter and block flows, release chemicals into the water like ammonia, all of which make the habitat that much harder for it to be recolonized by native species after a disturbance (McMahon 1999).

The majority of the negative affects associated with the invasion of C. fluminea are speculative (e.g. assuming that *C. fluminea's* ability to filter and assimilate so much of the surrounding phytoplankton and POM that it must somehow alter and affect native species). Most of the studies to date have researched the capacity of *C. fluminea* to change the conditions of an invaded ecosystem (Sousa *et al.* 2008). There are few studies that actually directly look at the ecological effects that *C. fluminea* has rendered on its invaded territory. Of the few studies done there have been mixed results with respect to its effects on native biota. Some of the studies discussed above have shown differences (Hakenkamp *et al.* 2001, Beaver *et al.* 1991) while others have seen no difference whatsoever (Werner & Rothhaupt 2007). More research needs to be conducted and is discussed in a subsequent section.

Management Strategies

The majority of management strategies that exist for *C. fluminea* are solely for the economic damage done to the infrastructure of power plants, water utility companies, irrigation canals, etc. Populations of *C. fluminea* are controlled by a variety of methods. Thermal regulation, by way of heating water in the pipes to temperatures that exceed 37 degrees Celsius is can be employed (Balcom 1994). However, this method is not possible in many existing water systems. Instead mechanical methods, such as screens and traps, can sometimes effectively eliminate older clams and remove body tissue and shells (Balcom 1994). Chemicals methods, such as releasing small concentrations of chlorine or bromine, can be used to kill both juveniles and adults of *C.fluminea* (Balcom 1994 and reviewed in McMahon 1999). This method can be very effective, but many regulations are in place that prevents the use and release of these chemicals in to waterways. In addition, these chemicals can have some collateral damage to other organisms. Another management strategy that has been suggested is dredging since the clam typically only lives in the top 10 cm of sediments (Foster 2008). However, this method can be quite costly, if it is able to be performed at all, and because the clam can so readily reestablish from a few individual left behind, or disperse from upstream this method cannot be considered a long term solution. Dredging can also pose collateral damage to an ecosystem.

Outside of managing the species as an economic pest few strategies, if any exist (Sousa *et al.* 2008). Like many other species the best management strategy available is to prevent the spread of the species into areas for which it has not yet invaded. Early detection, education, and legislation are some of the best options available to managers wishing to prevent the invasion of *C. fluminea* into new areas. Some states have already passed legislation that prohibits the introduction of *C. fluminea* into their waters (Balcom 1994).

In the PNW, *C. fluminea* is listed as Management Class 3 species. This management class “Includes nonnative species that are established throughout Washington and that have an impact, but for which there are no available or appropriate management techniques.

These species warrant further evaluation and research to ascertain the potential for impact and control, and to prevent establishment in new water bodies (WDFW 2001)." A copy of this report can be downloaded at http://wdfw.wa.gov/fish/nuisxsum.htm. As of yet, there is no management strategy in place for *C. fluminea* in the state of Washington. However, it is mentioned that in virtually every survey conduced to detect the arrival of the zebra mussels (*Dreissena polymorpha)*, *C. fluminea* was found. *C. fluminea* is not yet listed as an invasive species of concern in Oregon and as such there is no management or monitoring plan in place.

Future Research

Very little research concerning the effects of *C. fluminea* on its surrounding ecosystem have been conducted (McMahon 1999, Sousa *et al*. 2008). Much of the research to date has concentrated on managing the effects of *C. fluminea* in relation to the direct economic damage it does to facilities and its infrastructure. Of the research that has been conducted the vast majority of it has been done on the east coast of the US. Only a handful of studies have been published in relation to *C. fluminea* on the west coast and virtually none have been done in the PNW. Virtually any mention of C. fluminea in the literature for the PNW is as a by-product of a primary study (e.g. counts of *C. fluminea* reported from benthic cores taken to assess potential fish diet sources) and does not discuss the influence or ecology of *C. fluminea* in their report.

As mentioned before most of the ecological effects of *C. fluminea* are speculative (McMahon 1999, Sousa *et al.* 2008). More research needs to be conduced to better understand the interactions between *C. fluminea* and its invaded ecosystem (Sousa *et al.* 2008). Manipulative studies would be particularly helpful in better clarifying these interactions. In addition many studies have been done after invasion (McMahon 1999). Useful information could be gained from studies that are able to compare an ecosystem before and after invasion. Large-scale studies that elicit the relationship between the distribution of the Asian clam in relation to physical characteristics of the habitat should also be conducted (Sousa *et al.* 2008). These studies would allow researchers to potentially predict the spread of *C. fluminea* and focus prevention efforts.

Conclusion

Corbicula fluminea is one of the most successful aquatic invaders ever. It causes at least a billion dollars worth of damage every year not even considering its impact to ecosystems or native biota. However, this species is largely unstudied and unmanaged when compared to the zebra mussel. Some researchers speculate that this is because *C. fluminea* has been around for a much longer time than zebra mussels so control procedures for this species is now considered routine and is therefore not as widely publicized (McMahon 1999). Regardless, this species has been shown to have many of the characteristics that make it an ecosystem engineer capable of causing not only the documented damage to human structures but damage that will forever alter our native ecosystems. Yet, it has gone virtually unnoticed by government agencies and the public. The first step in learning about this invader is for federal and state agencies to recognize it as a threat at the very least. This may potentially spur the funding necessary to learn about this species and the changes it brings as well as prevent and mange its spread.

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