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New Zealand Mud Snails

In the twentieth century, the role of a conservationist takes on a much heftier load than those of the 18th and 19th centuries. In the past, the responsibility of a conservationist was limited to the knowledge of that time. Today, with researchers specializing in various fields including Invasive Species Ecology our comprehension of ecosystems far exceeds historical understanding. Biological Invasions now dominate the field of Conservation presenting a very apparent and present danger to our native ecosystems. Natural Resource Managers are now given this overwhelming challenge with the single goal of advancing knowledge in this field. This includes a better understanding of the effects of invasive species, management of established species and most important, prevention. In this review, we will dive into the characteristics, life history, and invasive traits of one of the fastest spreading and least understood non-native species America has ever seen. The New Zealand Mud Snail presents many challenges to Invasive Species Ecologists. However it is a relatively new threat. With modern technology and the knowledge we have gathered from past invasions, we are given the opportunity to develop a swift management technique to either halt the further spread of this species or completely eradicate this species all together.

Image of (Gray) Potamopyrgus antipodarum
Credit: University of Montana

Nomenclature

This invasive snail has two common names consisting of Jenkin's Spire Shell or more commonly the New Zealand Mudsnail given to this gastropod for its county of origin. For roughly 100 years, this species has been known as Hydrobia jenkinsi mainly in Europe. Not until recently has the genus species changed to the more widely accepted genus species name, Potamopyrgus antipodarum. This species falls under the Order of Mesogastropoda (Some still refer to this Order as Neotaenioglossa though it is no longer accepted as a modern Order under the Class Gastropoda). The Order of Mesogastropoda covers aquatic snails both fresh and saltwater as well as some land snails. Another unique characteristic that will be discussed in more detail is the capability of this snail to flourish in both fresh and brackish water. This in combination with the physical feature of an Operculum places this species under the Amnicolas or Duskysnail Family known as Hydrobiidae.

Scientific Classification

Kingdom:Animalia

Phylum: Mollusca

Class: Gastropoda

Order: Mesogastropoda

Superfamily: Rissooidea

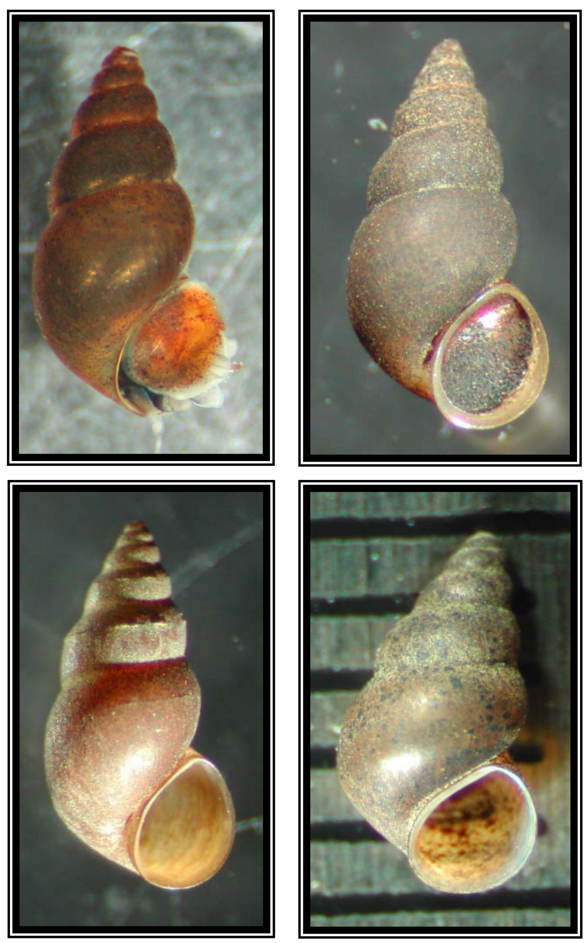
Family: Hydrobiidae

Genus: Potamopyrgus

Species: P. antipodarum

Identification

As seen from the photographs below (Credit: University of Montana), Potamopyrgus antipodarum comes in a variety of color forms, ranging from light yellow to dark brown, as well as slight morphological shell differences. It is important we able to comprehend this and employ various other techniques for the classification of this species. The morphology of this aquatic snail species is absolutely essential for the identification of this species in comparison to other small snail species. First of all and most obvious is the cone of the shell which is made up of five to six whorls depending on location and age. It is also important to note that these whorls are dextral



meaning they open to the right of this animal's opening. This species is also considered an operculate snail which means this species has an operculum. This operculum is sort of a trap door made of keratin and calcium carbonate that it can use to cover the aperture or opening of the shell. In the case of the subspecies that has invaded the United States, samples may contain species with raised shell keels as well.

The size of these snails is also a very important characteristic that can be used to identify this snail. In relation to the body, it is important to observe the aperture of the snail which will be oval and never as tall as the snail's spire. One of the quickest and easiest ways to identify the New Zealand Mud Snail is to go off the length of the shell. In their native range, snails can reach about 12 mm at maximum size. Here in their non-native range, this species usually varies around 3-5 mm (1/10-2/10 inches) in length but can be as small as a grain of sand and as large as 6mm dependant on external environment and age. In the great lakes, researchers have done extensive size studies finding the average shell length to be around 1/8 of inch (Levri et al. 2007).

Life History and Ecology

The reproduction and life cycle of Potamopyrgus antipodarum is very unique in the animal world and varies according to location. In this species' native habitat of New Zealand we see sexually functional males but only in

Size, color variation, and colonization of *P. antipodarum.* <u>Credit</u>: University of Montana extremely small numbers. Females on the other hand are made up of normal diploid sexual individuals as well parthenogenetically cloned females that are triploid. This cloning is form of asexual reproduction known as parthenogenesis which literally translates to “virgin creation”. In the case of P. antipodarum, females are capable of reproducing offspring from an egg cell that has not been fertilized by a male. In parthenogenesis, this lack of male fertilization causes all offspring produced to consist of females as a result of this species’ normal system utilizing XY sex determination. In the invasion we are seeing within North America, this reproductive phenomenon is the norm as all populations are clonal (Schreiber et. al. 1998). This means each population seen within North America is first and foremost female. Second, these organisms descended asexually from one single female ancestor from each introduction making each morph genetically identical (Hall 2006). Another important reproductive strategy of P. antipodarum is that females are ovoviviparous. This is basically defined as the development of the ova in the female snail’s brood pouch. As the eggs develop, the mother’s body provides necessary nutrients until they are ready to emerge as completely functional snails (State of Wisconsin 2009). This is an excellent reproductive strategy as in ensures future survivorship allowing a single female to instigate an entirely new population.

One very important characteristic that many invasive species possess is that in their new environments, native predation and other natural impediments are absent. In the case of the New Zealand Mud Snail, if conditions are favorable this species can multiple very rapidly without the presence of the trematode parasites and other co-evolved predators found in New Zealand. In the United States, P. antipodarum is capable of reproducing new generations up to six times a year. This is most prominently seen during summer months and may overlap into spring and fall seasons depending on water temperature. Between ten and ninety new young emerge each time a female releases her developed embryo. The growth rates of young snails under laboratory conditions have shown a rate of .1mm per day at 21 degrees Celsius (Richards 2002). With each embryo being female as discussed before, each organism is given the opportunity to reproduce through its lifetime creating exponential growth. These breeding populations establish so quickly because female snails are capable of reaching sexual maturity between the first three to nine

The figure below shows P. antipodarum feeding on algal clumps growing on an aquatic plant. Credit: Justin Morrison.

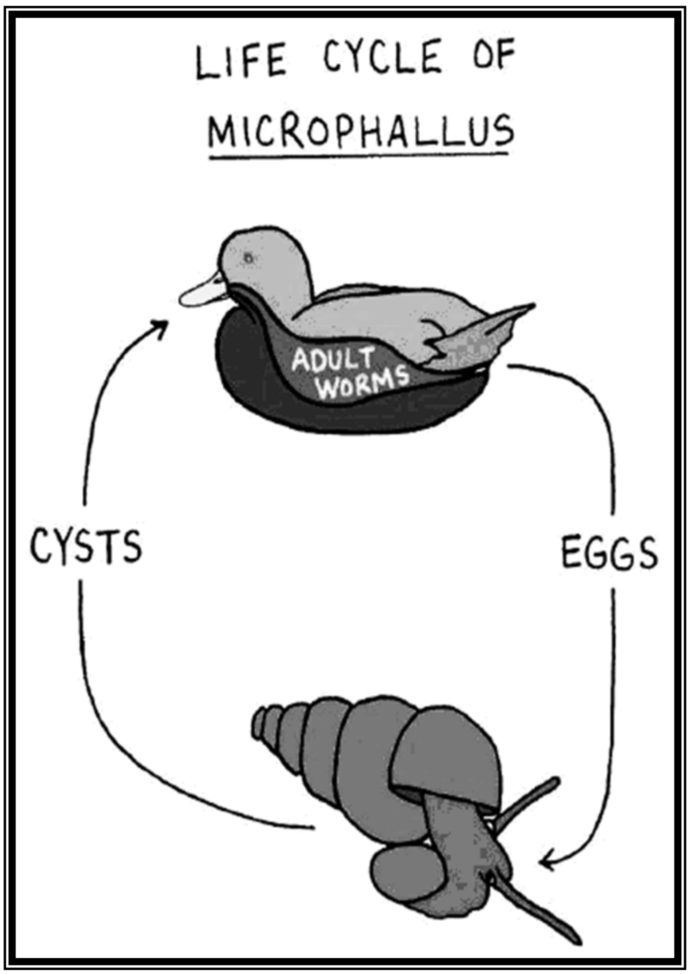
P. antipodarum established on rocky substrate.
Credit: University of California - Riverside

months of life depending on the surround water temperatures (State of Wisconsin 2009). This is why in many regions where P. antipodarum exists, this species was completely undetectable than rose to 10,000 to 500,000 snails per meter squared in a decade. This is exact event happened in Yellowstone National Park where this species has now established in very dense numbers throughout the park (Knox 2009).

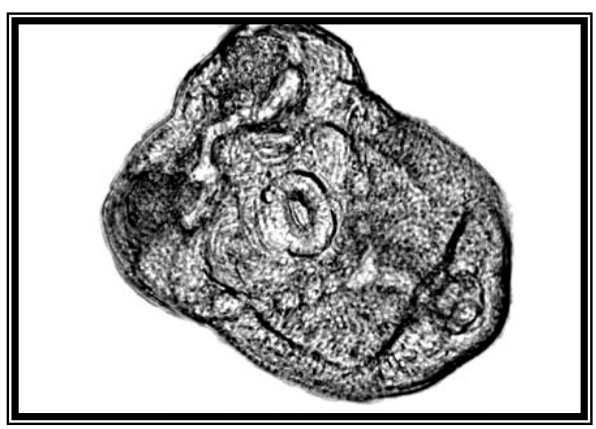
Like many other aquatic snails, the New Zealand Mud Snail is not considered to be a picky eater even when it comes to food that is contaminated with high sedimentation. In this case it is capable of consuming sediment and scraping off the algal growths following by spewing out the sediment. Potamopyrgus antipodarum is primarily a nocturnal grazer believed to be an effort to avoid diurnal predation. Most of this species diet consists of both epiphytic and periphytic algal species as well as several varieties of aquatic plant. Like other snails, this snail also scavenges for detritus which is basically any dead organic tissue from plants or animals. In laboratory experiments it was seen that this species also was capable of consuming sedimentation and diatoms (MacFarland 2008). The elements and silica gained from ingesting these two items is believed to help with various metabolic processes and the growth of various structural regions of the snail's body.

Concerning the optimal environment for normal growth and reproduction, the New Zealand Mud Snail is extremely tolerant to a wide range of conditions making this a very valid species for wide spread invasion. P. antipodarum is capable of inhabiting both fresh and brackish water bodies which can include estuaries and lakes as well rivers and streams. It is also not picky on water type living in clear or turbid water and water bodies with high or low calcium levels (Holomuzki and Biggs 2000). The highest productivity for these snails is seen in high nutrient eutrophic water bodies. One of the most astonishing qualities of this snail is the ability it has to live in an extremely wide array of thermal limits ranging from just above 32 degrees F all the way to 83 degrees F (Cox and Rutherford 2000). As mentioned previously, this species is euryhaline meaning it is capable of adapting to a wide range of salinities. This includes living in saline water conditions of up to 26% salt content for temporary amounts of time and is capable of normal physiological functions in brackish water (Leppäkoski and

Olenin 2000). On top of all of these listed sustainable conditions, P. antipodarum is also capable of functioning on just about any type of substrate from muddy and eutrophic to rock or concrete and even dense planted regions (MacFarland 2008). Similar to many invasive species, the quick and rapid spread of the New Zealand Mud Snail is partially related to the lack of pathogens, parasites and predators that are found in the species' native habitat. It is believed by many that the specific clone morph that has begun its plague of North America is resistant to many of the parasites that do exist both here and in New Zealand. In the native habitat of P. antipodarum, the most common parasite to this snail is a trematode from the genus Microphallus (Dybdahl and Krist 2004). This genus of trematode has been found in past studies to exist in over 50% of the native population of New Zealand Mud Snail (Jokela & Lively 1995). Research has begun to look for possible parasites in this North American morph but has so far been unable to locate anything of significance (Adema et. al. 2009). As a result of this absence, we will continue to see rapid and effective spread of this organism.



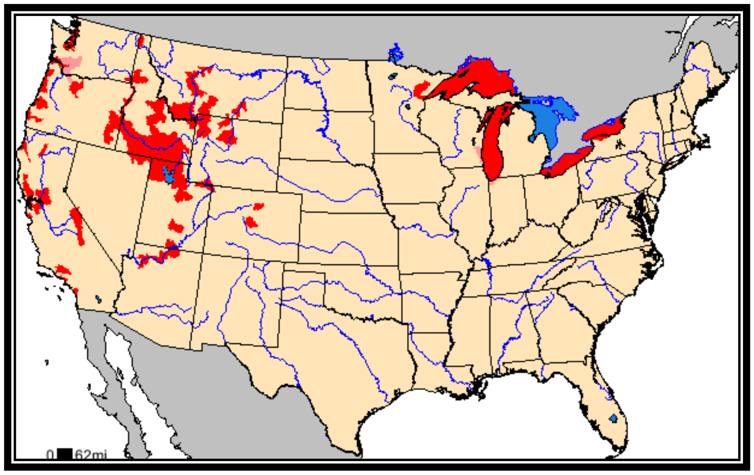
The figure to the left shows the life cycles of the Microphallus trematode that infects P. antipodarum. To summarize, adult worms live within a ducks intestines where they lay eggs. The eggs are consumed by P. antipodarum and hundreds to thousands of metacercaria are produced. These cysts hatch and are returned to the start of the cycle where they are consumed by the duck. The most important part of this process is that the snail is sterilized following this infection. The figure below shows an adult parasitic trematode worm belonging to the Microphallus family. Credit: University of Indiana.



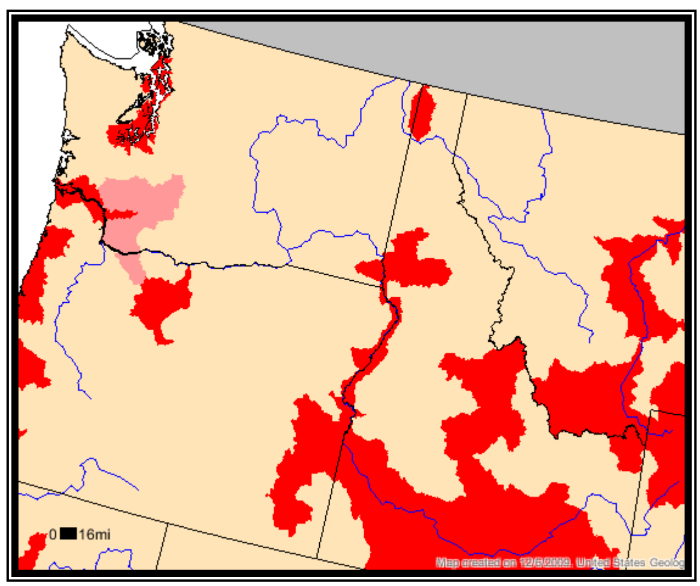
Current Geographic Distribution

On a global scale, the New Zealand Mud Snail is completely naturalized throughout Europe as well as New Zealand's close neighbor Australia. In the United States this is a relatively new invader but even within the last twenty years, this species has become very wide spread throughout the United States, seen in the Western States as well as all States bordering the Laurentian Great Lakes.

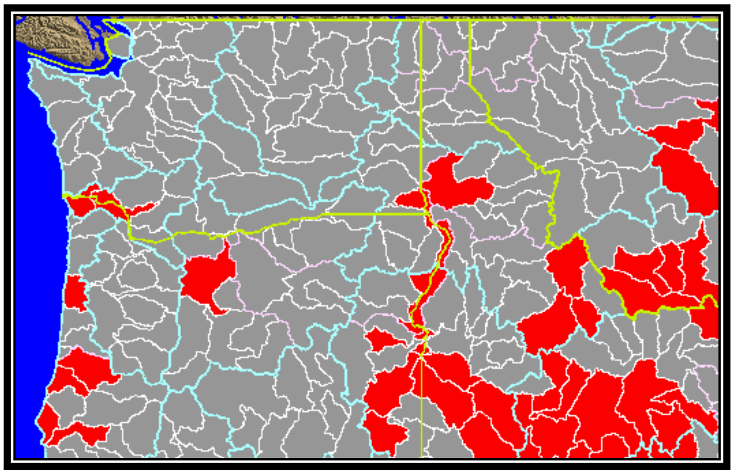
The first time this species was ever recorded in the United States was in the Pacific Northwest so it is vital to study this region. In Idaho, the species was first found in the Snake River which extends through Idaho, Oregon and Washington. It is now seen throughout the Snake River Basin in Idaho and has been discovered in Northern Idaho within the last several years. Oregon also has been hit very hard by this invader and its continual spread. In 2005, this species was found in Central Oregon in localized regions along the Deschutes River. In Eastern Oregon the species can be found in the Snake, Malheur and the Owyhee River. It has also been recorded to have established in many regions along the coast near the mouths of several rivers including the Columbia and the Rogue River. Washington has the most recent findings where this species has been located in the southeastern portion of the state in the Snake River. In 2002, this species was located in the Lower Columbia River Basin where it has begun a quick dispersal. The most recent New Zealand Mud Snail news was in Washington where it was discovered in Olympia's Capitol Lake on November 16, 2009. This jump dispersal from the Columbia River 100 miles north to Capitol Lake has researchers on edge with the possibility of several established populations between these two locations.



The figure below shows the current national distribution of P. antipodarum Credit: USGS – Nonindigenous Aquatic Species



Current distribution of *Potamopyrgus antipodarum* throughout the Pacific Northwest. The image on the left shows the most current analysis but has not been updated with the most recent findings in Olympia, Washington. Credit: USGS – Nonindigenous Aquatic Species.



Various infected water ways in the Pacific Northwest but has not been updated with the most recent findings in Olympia, Washington. Credit: University of Montana.

History of Invasiveness

Globally, the New Zealand Mud Snail has had a documented record of invasive history for almost two hundred years now. Originating in New Zealand, this snail's first introduction into non-native regions consisted of a short jump to Australia and Tasmania. This species was first found in Australia but incorrectly identified in the year 1835 (Ponder 1988). It is believed that the jump was made by a traveling bird and it is proven in many experiments that P. antipodarum is capable of passing through the gastrointestinal tract of fish and birds (Aamio and Bonsdorff 1997). The next step in this species invasive history was the introduction into Europe at the end of the 19th century (Hubendick 1950). This pathway was human related, most likely through the shipment of drinking water barrels in shipping vessels from Australia. The first record of this species establishment in Europe was in the United Kingdom in the year 1859 (Ponder 1988). For over 100 years now this species has flourished colonizing a majority of both Europe and Australia.

North America's first taste of Potamopyrgus antipodarum was mid-way up the Snake River in Idaho in the year 1987. The exact mechanism of this species' arrival into North America is unknown, but it is believed to have traveled in with Rainbow Trout eggs shipped from New Zealand (Bowler 1991). The next discovery was in 1991 within the Laurentian Great Lakes where this snail was found in Lake Ontario near the St. Lawrence River (Levri 2007). Originally thought to be from the same morph as the Idaho introduced P. antipodarum, this is now believed to be a separate introduction via ballast water from Europe. Recent studies have shown minor differences between these populations including a raised keel and coloration distinctions. For the last twenty years, this species continues to spread throughout North America with Canada seeing their first introduction in British Columbia in 2007 (Davidson et al. 2008).

Invasion Vectors and Factors Influencing Establishment

As this is a relatively new invasive species to the United States, we have a somewhat foreign understanding of the routes of introduction. In addition, we only have possible theories for prominent population establishment (invasion) and are unaware of the exact invasion methods utilized by *P. antipodarum*. A majority of these theories show human interactions to be responsible for many of the historically prominent introductions. In the case of the first recorded introduction into the United States, it is believed that the New Zealand Mud Snail traveled from its Native habitat into the states hitchhiking on a shipment of *Oncorhynchus mykiss* eggs (Bowler 1991). This falls under the category of fish aquaculture operations or the stocking of non-native fish into various water bodies for recreational fishing. Human disturbances are also believed to be responsible for the introduction of this snail into the Great Lakes Region as mentioned above. Snails are capable of hull fouling as well as travel through the ballast water of larger shipping vessels. Following introduction, both have active and passive means of transport to blame for further spread of this invasive species. At this point in the snail's invasion potential, officials are most concerned with recreation fowling through human interaction (Knox 2009). This method utilizes the ability of the New Zealand Mud Snail to hitchhike on the recreational aquatic gear of humans. The body size and hardiness of this species allows the snail to be undetected and endure conditions outside of its environment optima. If kept moist, the New Zealand Mud Snail is capable of living outside of water for up to two months (Dunker 2009). Fowling may include boats, any type of fishing equipment that comes into contact with an infected water body, and even our pets. Beyond this, there are several natural methods for this species distribution. *P. antipodarum* is on the dinner menu for many species of birds and fish including the migrating *Oncorhynchus tshawytscha* or Chinook salmon (Bersine et al. 2008). With many mud snails capable of surviving the travel through the alimentary canal of both fish and birds, an opportunity is presented to travel great distances (Haynes et al 1985). In the case of salmon, this is a very rapid method for traveling up streams and rivers. If ingested by a migratory bird such as a duck species, this snail has the ability to travel extensive distances with probable water body dispersal. This species is also considered to be a rapid traveling snail with the ability to move up a stream at a rate of 1 meter per hour (Richards 2002). With the capacity to release itself from substrate, it is also very capable of traveling downstream with current, especially while it is a juvenile (Vareille-Morel 1983). Once a snail has been introduced to a tolerable environment, the fact that this species can asexually produce means that one snail can start an entirely new population. As mentioned above, the body size of the New Zealand Mud Snail is an added advantage for dispersal and resilience. To the naked eye, a juvenile mud snail is almost undetectable posing a significant threat. Unfortunately once this species does establish a viable population, we have no capability of removing the snail with current technology. In estuaries, they exist on plant and rocky surfaces as well as within mud and various other substrates making it impossible to filter out this pest.

The cartoon showing the hardiness of the P. antipodarum. Credit: Sea Grant Nonindigenous Species Site.

Potential Ecological and Economic Impacts

One of the most unique aspects of studying the invasive ecology of this species is that there are no known or prominent economic or ecological impacts in this stage of invasion (USGS 2009). This may be partially related to lack of study but also that this is a relatively recent introduction into our national waters. The potential threats have been studied with capability for both economic and ecological damage. With many rapid producing mollusks, the threat of bio-fouling is a very imperative issue. This has been seen with zebra mussels throughout the great lakes region causing billions of dollars of damage throughout the last ten years via bio-fouling (Roberts 1990). It is believed that if this species continues to spread it will begin to propagate in the water intake lines of city water companies and other industrial businesses. The start of this has been seen in Australia with the New Zealand Mud Snail emerging from domestic water taps (Ponder 1988). This species is also believed by many state governments to have the possibility of causing millions of dollars of economic damage to the fishing market if it affects salmonid species. This economic damage is related to the ecological impact of *P. antipodarum* on the food web and the ability of this snail to create a personal niche for itself. In the case where the New Zealand Mud Snail is able to flourish, there is likely reduction in native invertebrates and other native mollusks. This is a result of this snail's ability to make up over 75% of a streams biomass (Kerans et al. 2005). The reason this occurs is two fold: First there is a competition for territory between aquatic mollusks and second there is a competition for vital nutrients affecting both nitrogen and carbon cycles in the invaded ecosystem (Hall et. al. 2003). For example, in the Snake River where P. antipodarum was first discovered it is assumed but not proven that the New Zealand Mud Snail is partially to blame for the population reduction of five native endangered mollusks (Smith 1992). With the capability of affecting both native mollusks and invertebrates, effects are seen on up through the food web in fish. This is a major concern if this snail spreads further in the Great Lakes Basin where it could wipe out many native mollusk species and in turn impact fish populations (Levri et al. 2007). This is also a concern in the Columbia River Basin where Salmon growth could be greatly affected. All of these unfavorable impacts relate to this species on the lower ranks of the food web which are relied upon by higher level organisms.

Management Tactics

The most important step that needs to happen upon the discovery of Potamopyrgus antipodarum is a rapid response. Identification should be confirmed followed by a communal decision to determine whether it is realistic to eradicate the snail or use other methods to control further spread. Following this, a public announcement should be made. This will cause two things to occur: Awareness that will educate the public on the species so as to prevent future spread and the possibility for participation involving control or eradication. Unfortunately, if a population is established it becomes extremely difficult to completely remove this pest. It only takes one snail to re-establish a new population of New Zealand Mud Snails. If eradication is plausible, there are a few possible methods to remove this snail. This is also dependant on environment. In a stream it is impossible to contain P. antipodarum while in a small lake or pond the possibility of eradication is much more likely. The only proven chemical method used thus far consisted of concoction know as Bayluscide which resulted in a 100% mortality rate for this snail (Francis-Floyd et al. 1997). Other methods of eradication beyond chemical treatments include temperature treatments and desiccation. Reduction of humidity can be done by the draining of the infected water body with exposure to sunlight causing 100% mortality in dehydrated conditions (Dwyer et. al. 2003). In case of extreme temperature, the sun can help achieve this as well as the utilization of a flame thrower (Richardson et al. 2004). In the case that eradication is not logical, containing and controlling this invasion is the next best step. One of the first steps taken by most officials is to completely lock down the lake to any recreational use. Further steps to isolate lakes are also necessary where each known applicable vector is taken into account and avoided. In this situation, again various chemicals can be utilized, but this only slows down further spread. One likely method for controlling this species is looking at the way they are controlled in New Zealand. Most promising is the use of a parasitic trematode native to New Zealand and releasing this into invaded regions. Only laboratory test work has been done this far but results look very promising for controlling this pest (Dybdahl et al. 2005). Issues arise outside of the laboratory with the possibility of releasing this parasite into actual invaded regions. As a society, we have failed many times with introduction of a new non-native species to control an already established non-native species. In the case of the trematode, there could be extreme repercussions on native organisms that were over looked not to mention the significant amount of money it would take to enact this bio-control. In the case of preventing spread through recreational vectors, there are various steps one can take to remove any possible hitchhikers from gear. First of all, foreign debris should be removed from gear with a scrub brush and cleaned thoroughly. One method includes soaking gear in chemicals for five minutes such as commercial grade 409 detergent, bleach, isopropyl alcohol, ammonia, etc. If possible it is also proven that freezing gear for 6-8 hours will also cause a one hundred percent mortality rate in this species (Richards et al. 2004). Opposite to this is the proven method of heating and drying gear once it has been scrubbed and cleaned. This should be done for either two hours at 104 degrees F or for a twenty four hour period at 84 degrees F or higher (Richards et al. 2004). There are many prevention techniques but public education is absolutely vital to endorse many of these processes.

Current News, Research, and Management

There are hundreds of scientific publications on this species of invasive snail yet at this point, our knowledge of the New Zealand Mud Snail still cannot be considered sufficient for understanding the effects this species has ecologically and economically as well as our ability to control this species. Research in the last year continues on trying to understand this snail's ecology and various ways of eliminating or controlling this species based on what we already know from past research. Researchers in California are looking at various habitat conditions necessary for invasion in response to our slim knowledge of this topic. This was done by quantifying both survival and growth rates under various conditions (Herbst et al 2008). The target of most research these days consists of testing out various methods for controlling this species. The previously mentioned trematode is still being researched due to its ability to sterilize the host snail (Koskell et al. 2009). Researchers hope to co-evolve this parasite with the growing number of New Zealand Mud Snail in hopes of halting further spread. Many chemical methods are also being looked into including the use of Epsom salt for controlling reproduction (Oplinger et al. 2009). The effects of another chemical known as fluoxetine also target the reproductive life cycle of the New Zealand Mud Snail (Buronfosse et al. 2009). Many researchers have very high hopes for prevention methods especially in a time when it is vital that the spread of this species is stopped.

The most recent news in the Pacific Northwest concerning the New Zealand Mud Snail was here in Washington less than a month ago. On November 16, Bert Barleson, resident of Olympia and President of the Pacific Northwest Shell Club stumbled across the first signs of the snail on Capitol Lake, Olympia. On November 24, these findings were published confirming the establishment of this species in the lake as well a cry out for the public's help in restraining any further spread of this species. Employees of Washington State Fish and Wildlife hope for a rapid response in either the containment or extermination of the snail in this lake depending on the status of this invasion. In the next week or so we should begin to see a response once the best way to deal with this new invasion has been decided (Washington Department of Fish and Wildlife).

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