National Management and Control Plan for the New Zealand Mudsnail (*Potamopyrgus antipodarum*) DRAFT

Photo by Dan Gustafson, Montana State University

Prepared for the Aquatic Nuisance Species Task Force by the New Zealand Mudsnail Management and Control Plan Working Group

Draft August 2006

New Zealand Mudsnail Management and Control Working Group Members

Tina Proctor, USFWS Region 6 Denver
Billie Kerans, Montana State University
Pat Clancey, Montana Department of Fish, Wildlife and Parks
Eileen Ryce, Montana Department of Fish, Wildlife and Parks
Mark Dybdahl, Washington State University
Dan Gustafson, Montana State University
Robert Hall, University of Wyoming
Frank Pickett, PPL Montana
David Richards, EcoAnalysts, Inc. Center for Aquatic Studies
Robyn Draheim Waldeck, Portland State University
John Chapman, Oregon State University
Robert H. Wiltshire, Federation of Fly Fishers
Dawne Becker, California Department of Fish and Game
Mark Anderson, National Park Service
Bob Pitman, USFWS, Region 2 Albuquerque
Denny Lassuy, USFWS, Region 7 Alaska
Paul Heimowitz, USFWS Region 1 Portland
Pat Dwyer, Fishery Consultant
Ed Levri, Penn State University, Altoona

Executive Summary

The New Zealand mudsnail (*Potamopyrgus antipodarum*) (NZ mudsnail) is indigenous to New Zealand and its adjacent islands. In New Zealand, the snails have been found in nearly every aquatic habitat including large river, forested tributary streams, thermal springs, ponds, glacial lakes and estuaries. Over the past 150 years, NZ mudsnails have spread in three continents.

Three different clones of New Zealand mudsnails have been identified in the United States: one is found in Lakes Ontario, Erie and Superior and is the same as Clone A found in Europe; the second is found in nine western States, having spread out from an initial population in the Snake River in Idaho; and the third has recently been identified in the Snake River, Idaho. It is speculated that the eastern U.S. clone came in ballast water from Europe and the western U.S. clones came from the commercial movement of aquaculture products such as trout eggs or live fish from Australia or New Zealand.

The introduced populations of these tiny snails (up to 6 mm) are mostly all female and the snails are live bearers. Males are present only rarely in North America. Densities of NZ mudsnails fluctuate widely, reaching 500,000 snails/ m^2 in some locations.

A database established on the New Zealand Mudsnail in the Western USA web site (http://www.esg.montana.edu/aim/mollusca/nzms/) is being used to track new populations and keep people informed about the latest research. A map showing affected watersheds is kept current by the Department of Ecology at Montana State University-Bozeman.

In 2003, the Aquatic Nuisance Species Task Force (ANSTF) established the NZ Mudsnail Management Plan Working Group (Working Group) to create a national management and control plan. The Working Group met three times in Bozeman, Montana in August of 2003, 2004 and 2005. The goal of the National Management Plan for NZ mudsnails is to prevent and delay the spread to new areas, reduce the impacts of existing and new populations, and continue developing information to meet this goal. The Working Group developed the following objectives:

1. Identify foci, pathways and vectors
2. Develop methods of detecting new populations
3. Develop strategies and methods to control and manage populations
4. Develop further understanding of ecological and economic impacts
5. Increase public understanding of the need to deal with NZ mudsnails and gain political support for implementing national plan objectives.

Research to better understand the ecological impacts of NZ mudsnails on macroinvertebrates and higher tropic levels is moving forward. Research on possible control and containment methods continues. Because one of the major pathways of spread appears to be anglers, additional effort has concentrated on the best ways to eliminate the snails from fishing gear. It is clear that management decisions need to be made to prevent the spread of this invasive species before we completely understand the impacts.

Table of Contents

List of Figures

List of Tables

I. Purpose and Organization of the New Zealand Mudsnail National Management and Control Plan

The purpose of this National Management and Control Plan (NMP) is to guide the Aquatic Nuisance Species Task Force (ANSTF) and other interested parties in managing the New Zealand mudsnails (*Potamopyrgus antipodarum*) (NZ mudsnail) already present in US waters as well as to prevent and delay the spread of NZ mudsnails to new areas. The ANSTF is an intergovernmental entity established under the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (Act, 6 USC. 4701-4741), as amended by the National Invasive Species Act of 1996 (NISA). The ANSTF is co-chaired by the U.S. Fish and Wildlife Service (FWS) and the National Oceanic and Atmospheric Administration (NOAA). The ANSTF is responsible for coordination of national efforts to prevent the introduction and spread of aquatic invasive species. Among these responsibilities is the development of management plans for specific high-risk invasive species.

Following an initial NZ mudsnail meeting in Yellowstone National Park in 1998, three biologists sent a report about the research on the species to the ANSTF. They made a recommendation to create a national management plan to include specific research and public education objectives. The response in a November 2, 1998 letter from the ANSTF executive secretary, Robert Peoples, was that "based on available information, the ecological concerns raised in the report do not clearly indicate that the New Zealand mud snail threatens or is likely to threaten the diversity or abundance of native species or the ecological stability of infested waters or human water dependent on those waters." At that time no action was taken by the ANSTF, although research and education activities in agencies and at universities continued.

In 2003, the ANSTF requested that a NZ mudsnail Management Plan Working Group (Working Group) be established to create a national management and control plan. The Working Group met three times in Bozeman, Montana in August of 2003, 2004 and 2005. In 2003 and 2005, the Working Group met immediately following the annual NZ Mudsnail in the Western USA conferences.

The Working Group, composed of people from universities, state and federal agencies, private industries and non-profits, worked together to research available information regarding biology, distribution, and ecological impacts of the mudsnails. The goal of the NZ mudsnail NMP is to prevent and delay the spread of NZ mudsnails to new areas, reduce the impacts of existing and new populations, and continue developing information to meet this goal. The Working Group developed the following objectives for the Plan:

1. Identify foci, pathways and vectors
2. Develop methods of detecting new populations
3. Develop strategies and methods to control and manage populations
4. Develop further understanding of ecological and economic impacts

5. Increase public understanding of the need to deal with NZ mudsnails and gain political support for implementing national plan objectives.

The plan has four sections. Section I is the Introduction, which describes the NZ mudsnail clones and summarizes their biology and ecology. The last part of the Introduction includes a summary of state and federal regulations and state invasive species plans that affect what can be done or must be done regarding NZ mudsnails.

Section II includes a broad discussion of the five objectives expanding on prevention, detection, impacts, eradication and control. Education and outreach, implementation tasks and research needs are integrated into the discussion of each objective.

Section III summarizes and prioritizes management actions, education and outreach, research needs and funding that have been covered in the previous sections.

The Appendices give more extensive information about NZ mudsnail distribution, life history, biology and ecological impacts, further details on state and federal regulations regarding NZ mudsnails, an example of a risk assessment for a federal fish hatchery, and instructions for cleaning wading and other gear. The last appendix is a bibliography.

II. Introduction

The New Zealand mudsnail (*Potamopyrgus antipodarum*) (NZ mudsnail) is spreading rapidly in the western United States with several new populations being discovered every year. The snails first appeared near Hagerman Idaho, and were documented by S.W. Taylor in 1987 (Bowler 1991). A separate population was first discovered in Lake Ontario in 1991. The western and eastern clones are different and probably arrived in the U.S. through different pathways. This species, which is indigenous to New Zealand and its adjacent islands (Winterbourn 1970b), is now found in Australia and is widespread in Europe where it was misidentified for many decades. This species is found in the literature under the various names of *Potamopyrgus antipodarum, P. jenkensi, P. niger* and *Hydrobia jenkensi.*

A. Description

The NZ mudsnail shell is normally horn-colored, but ranges from light to dark brown (similar to most freshwater snails). The shell is rather elongate compared to many western North American species. Like most snails, its whorls are dextral (opening to the animal's right). The shell of a full-grown NZ mudsnail normally has 5 or 6 whorls, a higher number than most western North American snail species. Almost all western populations reach a maximal size very near 5 mm. One population in Idaho (Cassia Creek of the Raft River) regularly reaches 6 mm. Other populations which are not monitored as closely may achieve similar sizes.

Figure 1. Like all prosobranchs, the NZ mudsnail has an operculum or covering to block the shell opening when the animal is withdrawn into its shell. (Photo from Dan GUStafson)

Preliminary identification of introduced populations is facilitated by noting that NZ mudsnail populations are mostly all female and the snails are live bearers. In populations that have been examined, males are present only rarely in western North America. The developing young are easily observed within a brood pouch inside the first whorl of the shell of most adult snails. The embryos are normally well-developed in the summer and fall.

Many clones of *Potamopyrgus antipodarum* are known from New Zealand. Prior to September 2005, all western U.S. NZ mudsnails were thought to be identical, representing a single introduction from New Zealand or Australia. A second clone of the NZ mudsnail is now known from a short section of the Snake River of Idaho. A third clone is known from the eastern U.S.

This second clone probably represents a second introduction, but very little is known at this time. The snail has been in the area from several years at least. Preliminary genetic work by Mark Dybdahl verifies that it is a separate genotype, but he did not find a match to any other known invasive genotype from around the world (pers. comm.). Work continues in this area. Ecologically, the 2 clones look like 2 species. They overlap in range and where they co-occur, the second clone dominates the typical clone.

Figure 2. Two western U.S. NZ mudsnail clones. The right picture is the second clone discovered in 2005 in the Snake River, Idaho. (Photo from Dan Gustafson)

The two western North American NZ mudsnails clones are about the same size (5-6 mm). The second clone (right) is distinctly broader than the typical western U.S. clone. It also has a relatively larger last whorl. The aperture is also relatively larger and the basal lip is more extended. The second clone is normally paler in shell color and therefore more transparent to internal structures. In mixed samples (and all samples with the second clone are mixed), the two clones are easily separated as there are no intermediates.

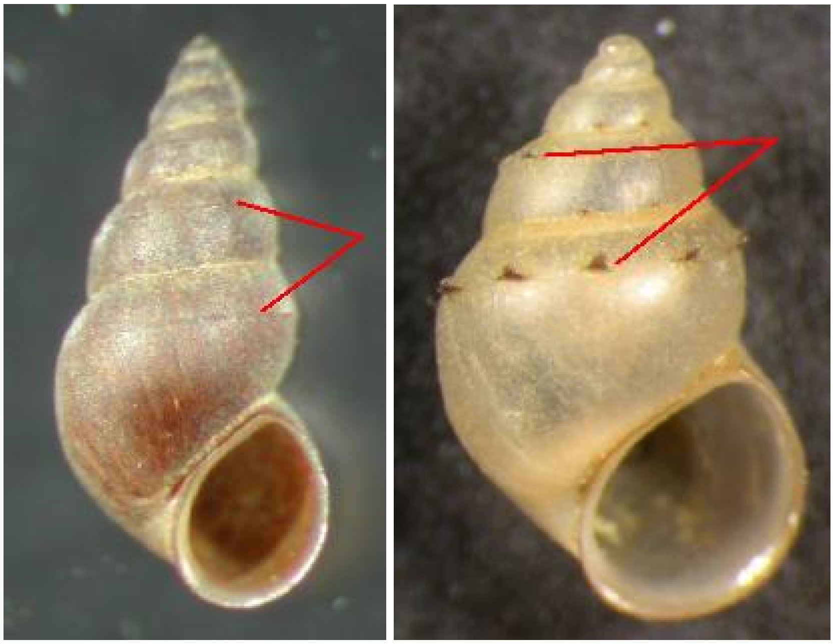

Figure 3. Shell carina. Note the difference in raised carinas in the two clones. (Photo from Dan Gustafson)

On the typical western U.S. mudsnail (left), there is a slightly raised carina on the shell of some individuals in some populations. In the second western U.S. NZ mudsnail clone (right), the carina, if present, is much raised and broken into isolated scales, like the triangular points on a simple crown. In the second clone, the carina is present in some individuals at all known collection sites. The location of the carina is about the same in both clones. All native western U.S. hydrobiids lack such a carina entirely.

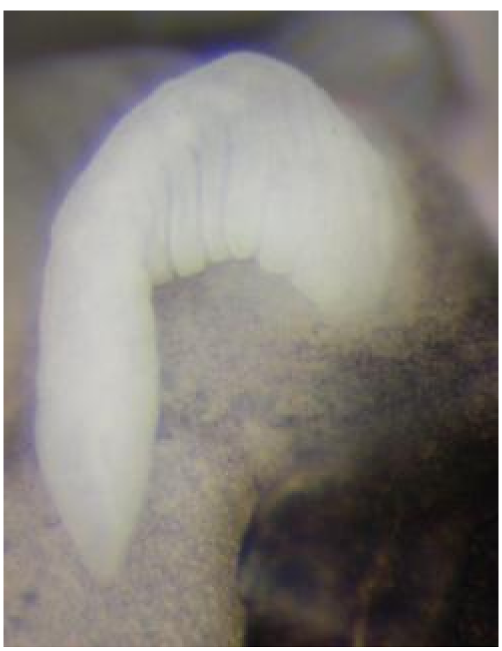

Figure 4. Penis of male NZ mudsnail. The origin and role of the males is not known, but normal sexual reproduction seems unlikely. The penis is about the same in both morphs of the western clone. (Photo from Dan Gustafson)

In the typical western NZ mudsnail, males are very rare. Many populations seem to lack males entirely. In the second clone, males are much more common. Finding a dozen or more is normal at all locations. Within the range of the second clone, no males of the typical clone have been seen. Preliminary results by Mark Dybdahl suggest that the second clone is triploid, just like the typical western NZ mudsnail.

The Eastern U.S. clone of New Zealand mudsnails is the same as European clone A (Dybdahl pers.comm.). The clone has been found in three of the Laurentian Great Lakes as well as in parts of the St. Lawrence River. Morphologically, the clone is very similar to the typical western U.S. clone (Figure 5). The average length of adults is about 4.4 mm in one location (Wilson, NY) in Lake Ontario (Levri, unpublished data). About 10% of individuals collected at one site (Wilson, NY) in Lake Ontario show short spines (Levri unpublished data).

Figure 5. NZ mudsnail clone from the Great Lakes. (Photo from Ed Levri)

B. Summary of Biology and Ecology

In New Zealand the NZ mudsnail is dioecious (separate male and female sexes) and bears live young (Winterbourn 1970a, b, Wallace 1978). Ova develop within the female's brood pouch and emerge into the environment as fully functional snails. Female mudsnails in New Zealand may be either sexual or asexual. Asexual females develop eggs that can grow without fertilization and produce cloned genetically identical offspring. Therefore, one female is sufficient to initiate a new population. Although NZ mudsnails reproduce both sexually and asexually in New Zealand, exotic populations are entirely clonal (Zaranko et al 1997, M. Dybdahl unpublished data).

II. Introduction

Figure 6. Female NZ mudsnail with brood. (Photo from Dan Gustafson)

NZ mudsnails have great potential for wide-spread colonization because they have a broad environmental tolerance. Although the species occurs in a wide range of aquatic habitat types, including diverse ranges of temperature, osmotic concentrations, flows, substrates and disturbance regimes, clonal lineages may have either narrow or broad ecological tolerances. In New Zealand, narrow preferences often result in distinctive habitat utilization among clones (Dybdahl and Lively 1995a, Fox et al. 1996, Jokela et al. 1999, Jokela et al. 2003), while one of the clones that is widely spread in Europe is broadly tolerant (Jacobson and Forbes 1997). Thus, the invasiveness and success of this species is likely to be a function of the clone present and local environmental conditions.

Densities of NZ mudsnails can fluctuate widely. In Australia, densities ranged between highs of 50,000 snails/m^2 during the summer and lows of 1,800 snails/m^2 during the winter (Ponder 1988, Schreiber et al. 1998). Similarly, densities often undergo broad fluctuations in Europe (Siegesmund and Hylleberg 1987, Dorgelo 1987, van den Berg 1997, Savage 1996) where water bodies freeze in winter and are re-colonized the following spring. In the Greater Yellowstone Ecosystem, NZ mudsnails reach densities approaching 300,000 snails/m^2 at some locations (Kerans et al. 2005) and as high as 500,000 snails/m^2 in others (Hall et al. 2003), but fluctuate seasonally, reaching highest densities in July or September, and very low levels in March (Kerans et al. 2005). This fluctuation of density also occurs in the Owens Valley of California, and most likely any invaded areas where winter freezing occurs.

In the wild, NZ mudsnails are sometimes ingested by mountain whitefish (*Prosopium williamsoni*) (W. Dwyer, USFWS, personal observation), sculpin (*Cottus sp*.) and brown trout (*Salmo trutta*) (Cada 2004). Laboratory studies show that rainbow trout and steelhead will volitionally feed on NZ mudsnails regardless if fish are starved for a period of time or maintained on feed. However, in both cases, rainbow trout appear to exhibit a more aggressive behavior ingesting more snails than steelhead (Moffitt, personal communication). Unfortunately, studies have shown fish derive little or no energy value from eating snails because the snails are capable of passing through the fish's digestive system alive and intact. (Bondesen and Kaiser 1949, Haynes et al. 1985, Vinson, personal communication, Moffitt, personal communcation). In addition, energy contents of the NZ mudsnail was determined to be extremely low and variable by seasons (Ryan 1982). NZ mudsnails are grazers of attached periphyton and consumers of decaying plant and animal material (Haynes and Taylor 1984).

More detailed information on the biology and ecology of NZ mudsnails can be found in Appendix A.

C. Summary of Applicable State and Federal Policies and Regulations

This summary addresses federal and state laws, regulations, plans, and policies that directly relate to NZ mudsnails, either specifically or generally. It does not include other ANS prevention requirements, such as ballast water regulations, that relate to NZ mudsnails indirectly. More specific information on state provisions can be found in Appendix B.

At this time, NZ mudsnails are not listed as "injurious wildlife" in the federal Lacey Act regulations under 50 CFR Part 16. However, under certain conditions, transport of NZ mudsnails between states that restrict possession of this species can constitute a Lacey Act violation. The other key federal provision that has been applied to NZ mudsnail invasions is Executive Order 13112, signed by President Clinton in 1999. This policy prevents federal agencies from authorizing, funding, or carrying out actions that are "likely to cause or promote the introduction or spread of invasive species" (except under certain conditions). It has been the basis for NZ mudsnail prevention and control programs at federal fish hatcheries, federally-funded state fish hatcheries, and other facilities.

In the western U.S., California, Colorado, Kansas, Montana, Utah, Washington, and Wyoming are among those states that specifically prohibit importation, possession and transport of NZ mudsnails. Alaska, Hawaii, Idaho, Nevada, and Oregon are among those states that do not specifically list NZ mudsnails as prohibited, but nonetheless do not allow this species to be imported, possessed, or transported without prior authorization through a state permit system. States such as Colorado and California have used quarantine and fishing access closure authority to deal with NZ mudsnail infestations. NZ mudsnails are also specifically addressed in state aquatic nuisance species management plans developed by Alaska, Hawai'i, Indiana, Kansas, Montana, Oregon, and Washington.

In the eastern U.S., neither New York nor Pennsylvania has specific laws or regulations pertaining to NZ mudsnails. Both States have general provisions for a permit system controlling species that are transported into their waters.

III. Objectives

A. Objective 1: Identify Foci, Pathways and Vectors

1. Introductions and Dispersal of NZ mudsnails in North America

The NZ mudsnail is indigenous to New Zealand and its adjacent islands (Stewart and Chatham Islands, Winterbourn 1970b, Ponder 1988). In New Zealand, the snails have been found in nearly every aquatic habitat including large rivers, forested tributary streams, thermal springs, ponds, glacial lakes, and estuaries (Winterbourn 1970b, 1978, Towns 1979, 1981b, Rounick and Winterbourn 1982, Talbot and Ward 1987, Winterbourn and Ryan 1994, Scott et al. 1994). Two other species of *Potamopyrgus* (*P. estuarinus* and *P. pupoides*) are also known from New Zealand, however these are confined to brackish waters (Winterbourn 1970b).

Over the past 150 years, NZ mudsnails have spread in 3 continents (Figure 7). During the nineteenth century, NZ mudsnails were introduced to Europe. The first recorded occurrence in Europe dates to 1859 in Great Britain (Bondesen and Kaiser 1949, Ponder 1988). Ponder speculates that they may have gotten to Europe in fresh drinking water carried by ships. Bondesen and Kaiser (1949) provide a detailed account of the species' discovery in Great Britain and Western Europe. Initial reports of the snail in Europe attribute it to an entirely distinct species, *Potamopyrgus jenkinsi*, which was thought to be a European native species closely related to *P. antipodarum.* It was not until the later part of the twentieth century that morphometric and molecular analysis confirmed that *P. jenkinsi* was in fact *P. antipodarum* (Winterbourn 1970b, Winterbourn 1972). These populations probably originated from either the North Island of New Zealand (Stadler et al. 2005), or from Australia.

Potamopyrgus antipodarum was reported from Tasmania in 1872 and Victoria, Australia, in 1895. Initially, as was the case in Europe, the species was described as a synonymous species, *P. niger,* by early workers (Ponder 1988). The snail spread throughout the state of Victoria, streams around Sydney in New South Wales, and Tasmania (Ponder 1988). Populations in Australia are genetically polymorphic (comprised of numerous clones), but DNA sequence data suggests all these populations originated from New Zealand's North Island (Dybdahl, personal communication).

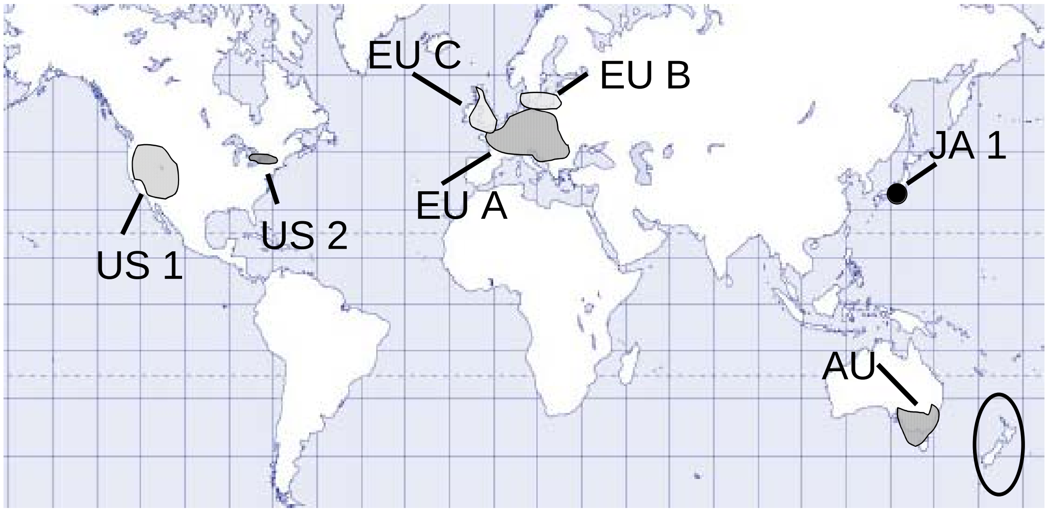

Figure 7. The approximate distribution of introduced clones. Native range is New Zealand. Introduced populations in Australia (AU) are clonally diverse. Introduced populations are comprised of 3 distinct clones (EU A, B, and C) in Europe, of two distinct clones in the US (US 1 and 2), and of one clone in Japan (JA 1). (Figure from Mark Dybdahl)

A single population is also known from Japan and genetic markers suggest that it represents an independently founded population. The genetic markers are consistent with the same origins as the typical western US clone (Dybdahl, personal communication).

In western North America, NZ mudsnails were first documented in 1987 from the Middle Snake River in Idaho (Bowler 1991). The exact time of arrival and source of the snails are unknown but it has been speculated that they arrived from the commercial movement of aquaculture products such as trout eggs or live fish (Bowler 1991; Bowler and Fresh 1992). No other populations were discovered until 1993 when NZ mudsnails were found in the Columbia River estuary near Astoria, Oregon, and 1994 during survey work in Montana and Wyoming in the Upper Madison River (Missouri River drainage, F. Pickett, PPL Montana). Figure 8 shows the range expansion during the second decade of the invasion. All western states, except New Mexico, now have known established populations. There are 59 infected drainages, classified as cataloging units in the Hydrologic Unit Code (HUC) system. Some of the HUCs have multiple, discrete populations. These maps were generated by the centralized database at http://www.esg.montana.edu/aim/mollUSca/NZ mudsnail/, which can also provide more detailed maps by area or time-frame. Additional collection records can also be entered on-line at this site.

III. Objectives

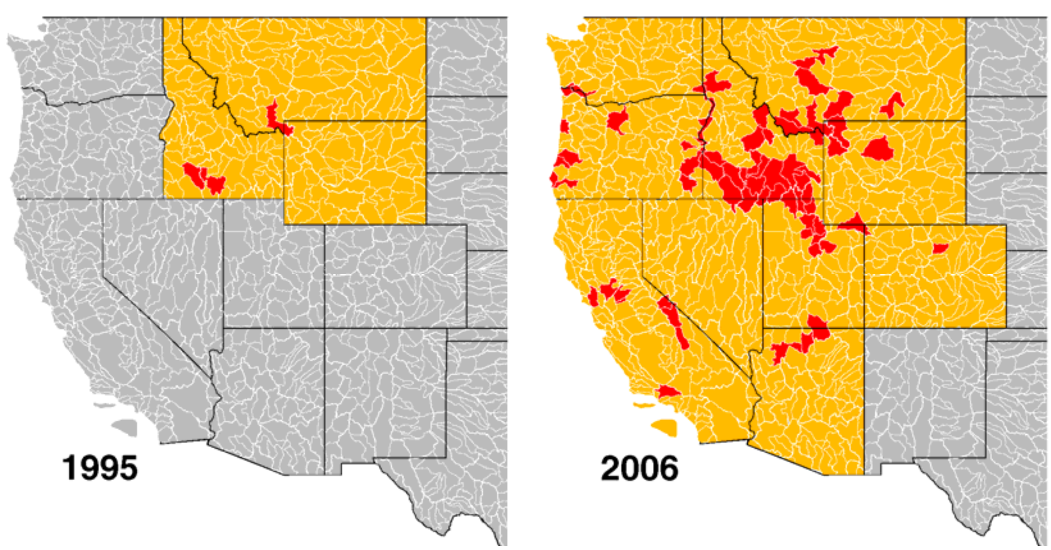

Figure 8. The spread of NZ mudsnails in the western USA during the second decade of its invasion. The small cells on the map represent the USGS cataloging units (8 digit HUCs). Positive HUCs and positive states are indicated in color. (Map by Dan Gustafson)

In 1993, the NZ mudsnail was discovered in the lower Columbia River estuary in locations subject to salinities that fluctuate between 0 and 30 parts per thousand where introduction pathways could have included recreational boats/trailers and contaminated hatchery transplants. Because the clone is identical to the Snake River population, it is unlikely that this population was founded independently by shipping traffic. The Lower Columbia River Aquatic Nonindigenous Species Survey published in October 2004 found that this species now occupies the entire estuary from Clatsop Spit to Calthlamet Bay (River Mile 30), and NZ mudsnails have been found at the mouth of the Kalama River. Other recent discoveries of NZ mudsnails in the Pacific Northwest include Garrison Lake on the southern Oregon Coast (2002); Devil's Lake in Lincoln City, Oregon (2003); Surf Side Estates Lake near Ocean Park Washington (2003); the New River on the southern Oregon Coast (2003); and Bully Creek in southeastern Oregon (2004).

NZ mudsnails were first collected in Utah in 2001 in the Green River downstream from Flaming Gorge Dam. Between September 2001 and May 2004, the snails were found at 28 locations within 16 stream basins. They can currently be found in many of Utah's high quality trout waters including the Green, Bear, Provo, Weber, Ogden, and Logan River Basins.

The NZ mudsnail was discovered in the Colorado River in Arizona in early 1996, having been identified for several years as *Fossaria sp.* In addition NZ mudsnails were discovered in Boulder Creek in Colorado near and in a private fish aquaculture facility in 2004. In 2005, a second Colorado population was identified in the South Platte River in Elevenmile Canyon.

In California, NZ mudsnails were first discovered in 2001 in the Owens River. A review of past samples shows that low densities actually occurred in 1999 but the snails had been misidentified (Herbst, personal communication). Since then, NZ mudsnails have been detected in Upper Owens River, Lower Owens, Bartlett Springs on the Owens dry lake, and Hot Creek within the Owens Basin. Populations were later discovered west of the Sierra Nevada, at Putah Creek, Lower Calaveras River and Mormon Slough, Lower Mokelumne River, Lower Napa River and Piru Creek. Another disjunct population was discovered in the Mono Basin, at Rush Creek.

Unlike many gastropods, NZ mudsnails produce fully formed "crawl-away" juveniles and lack larval forms specialized for dispersal. Because they are fully aquatic, they cannot disperse unaided among isolated watershed and drainages. Nevertheless, their capacity for invasive spread is exemplified by the invasion of Europe, which spanned 2,500 km in less than 140 years (Zaranko et al. 1997). The rate of spread may well be faster in North America. In about 20 years, NZ mudsnail populations have spread to 9 western states and three of the Great Lakes.

Numerous adaptations of the NZ mudsnail would seem likely to aid its spread within watersheds. Adults can pass alive through the digestive systems of several fish species (Bondesen and Kaiser 1949, Haynes et al. 1985) and float on masses of algae (Ribi and Arter 1986). Juveniles can float freely on the water surface without a substrate (Vareille-Morel 1983). The NZ mudsnail is positively rheotactic (movement in the opposite direction of the water flow) (Haynes et al. 1985). It can crawl at speeds exceeding 1 m/hour (Richards 2002) and can move as much as 60 m upstream in 3 months (Adam 1942). However, despite its potential for explosive population growth wherever it is found, rates of growth are highly variable. Downstream dispersal of populations in some western U.S. watershed might be limited by lakes and reservoirs where populations are either at low densities or are absent. (Dybdahl, personal communication).

The origins of the typical clone in the western U.S. might be either New Zealand or Australia, based on genetic markers. The typical western U.S. clone is identical to a widespread clone in Australia (Dybdahl, pers. comm.). The origins of the second western U.S. clone in the Middle Snake River are unknown (David Richards, Dan Gustafson, personal observation). On the other hand, the population in the eastern U.S. is a single clone that is identical to one of the clones in Europe (Mark Dybdahl, pers. comm..). Hence, the eastern and western U.S. populations were introduced by different mechanisms from different origins.

NZ mudsnails in the Great Lakes region were first found in Northeast and Southwest Lake Ontario and in the St. Lawrence River near Prescott, Ontario (Figure 9). The snail is usually found in substrates of silty sand (Zaranko et al 1997). Zaranko et al. (1997) failed to find NZ mudsnails in any other locations in Lake Ontario or in Lakes Erie and Huron in their extensive survey. Since Zaranko et al.'s (1997) study, the snail has been found in Lake Ontario near Rochester, NY in 2003 (Levri, unpublished data) and near Toronto (Zaranko, pers. comm..). The snail has also been found in Lake Superior near Thunder Bay (Grigorovich et al. 2003) and in Lake Erie near Erie, PA in 2005 (Levri and Kelly, in prep.). In the Great Lakes Region, NZ mudsnails have been found at depths ranging from 4 to 45 meters (Zaranko et al. 1997; Levri et al. in prep.). At Wilson, NY, NZ mudsnails have not been found in waters shallower than 15 meters and at depths deeper than 45 meters. Densities peak between 20 and 25 meters in depth. Efforts to find the snail in streams or rivers emptying into Lake Ontario have failed. This distribution, especially in shallow waters is perplexing as this clone is found in shallower waters in Europe. Some factor must be important in keeping the snail out of shallow water in the Great Lakes. This factor may be wave action, but wave action should not be important at 10 meters in depth, and the snails are not found there. Additionally, if wave action is important, the snails should be found in sheltered bays and inlets, but they have yet to be found in these areas.

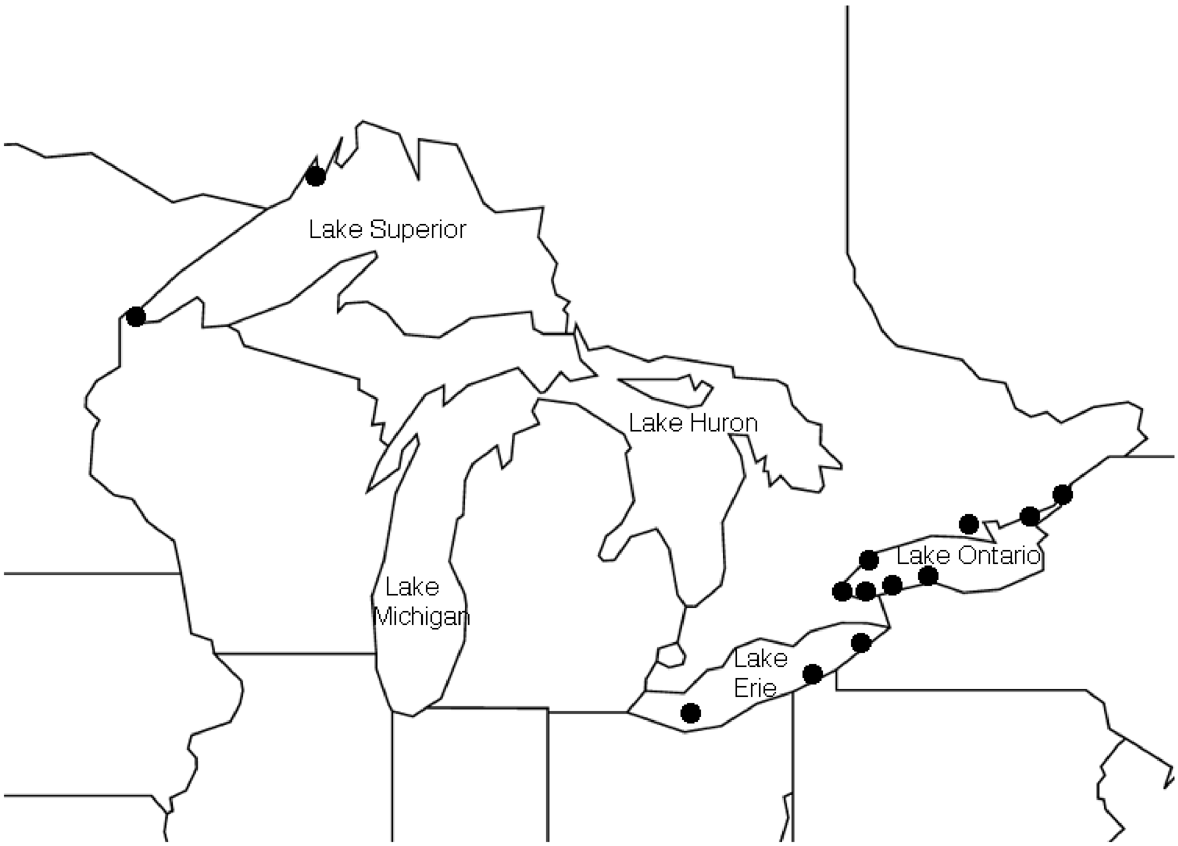

Figure 9. NZ mudsnail populations in the Great Lakes (map by Ed Levri).

2. Vectors and Pathways of Spread

The broad physiological and ecological tolerances of the NZ mudsnail may render it suited for dispersal by a wide range of vectors. Incomplete information regarding the timing and source of initial introductions within the United States obscures identification or ranking of individual vectors. As used here, a vector is the mechanism by which ANS are spread while pathways are the routes over which vectors pass. Vectors and pathways of spread and transport believed to contribute to the distribution of NZ mudsnails include:

III. Objectives

a. **Fish hatcheries and associated stocking operations**: The current infestations by NZ mudsnails at the Hagerman National Fish Hatchery and a number of state hatcheries in Idaho indicate the vulnerability of government and private aquaculture facilities. Contamination of water supplies and the ability of NZ mudsnails to pass live through fish digestive systems (Haynes et. al., 1986) may provide a vector for introductions to occur during fish stocking operations. Transfer of live organisms, their eggs or larvae, and associated water and packing materials between aquaculture facilities provides another vector for spread.

b. **Recreational watercraft and trailers**: When directly exposed to NZ mudsnails for a period of time, boats, canoes, kayaks and associated gear and trailers may become fouled, providing a contamination source when moved to uninfested waters. In addition, NZ mudsnails often attach themselves to aquatic macrophytes and clumps of algae. These plant materials and associated snails can then be moved by boaters or trailers between water bodies. NZ mudsnails can also be transported within the livewells of boats or entrained into water lines (particularly for jet skis and other jet-drive systems).

c. **Recreational water users**: Particularly when embedded in mud or attached to plant debris, NZ mudsnails may be transported on fishing gear, on waders and boots, swimsuits and swimming toys and even by hunting dogs and horses. Hikers, backpackers, horseback riders, and bicyclists may inadvertently transfer the snail when encountering multiple stream crossings during their outings. The snail's small size allows it to be carried in small crevices that might escape detection. NZ mudsnails inadvertently distributed via live bait sales or use can be transported to new sites if bait containers or their contents are discarded in or near the water. Given their ability to survive in the digestive tract of fish, movement of live or dead fish between watersheds by anglers can also be a vector.

d. **Natural resource management activities**: Personnel involved in monitoring projects, restoration activities, and other natural resource activities that cross watershed boundaries may transport NZ mudsnails to new waterbodies via their gear, vehicles, or clothing. Field staff may not have access to facilities or equipment that allows decontamination between work sites. Mudsnails can live in moist environments near the edges of streams, and therefore can be picked up and moved by people who are not wading in the water. Citizen and classroom monitoring groups are another potential vector for spread of ANS.

e. **Commercial shipping**: Most ballast water introductions are species with planktonic larval dispersal, which NZ mudsnails lack, making this vector unlikely, but possible. Discharge of ballast water has been associated with many introductions of ANS and could be a vector for NZ mudsnail introductions. Ballast water from foreign ports can serve as a continuing inoculation source of new NZ mudsnail clones, while ballast discharge from coastal shipping may spread snails already found in the United States (e.g., transport of Columbia River mudsnails to other West Coast estuarine ports). Zaranko et al. (1997) suggested that this mechanism may have been responsible for the presence of NZ mudsnails in Lake Ontario. Ships can also transport NZ mudsnails that have attached to or are embedded in mud on anchors and other surfaces.

f. **Sand/gravel mining, extraction, and dredging**: Any waterway operations that remove and transport mud, sand, and other bottom materials from areas with NZ mudsnails can serve as a vector for new introductions. Dredges that move frequently between rivers and estuaries are particularly vulnerable sources of regional spread. Maintenance of canals and ditches by landowners, ranchers, water and power agencies, and flood control personnel also has the ability to spread ANS.

g. **Aquatic plant trade and collections**: Similar to aquarium contamination, it is unknown if NZ mudsnails have ever been distributed as a contaminant by wholesale or retail aquatic plant suppliers. Contaminated home water gardens could then serve as a source for new introductions due to flooding, wildlife, or other vectors of secondary spread. Several authors have offered the hypothesis that initial introductions to Europe and Australia were a result of the transport of aquatic plants between Australia and botanical collections in Europe (Winterbourn 1972, Ponder 1988). They could also be unintentionally transferred through biological supply houses for use in classroom biology experiments.

h. **Transport by fish, wildlife and livestock**: It is already known that NZ mudsnails can survive passage through the digestive system of trout (Haynes et. al, 1986). Fish could therefore serve as a more localized source of spread, particularly for species that may migrate or stray into other tributaries or watersheds. It has been suggested that waterfowl and other birds could also spread NZ mudsnails between waterbodies via feet or feathers (Bycott 1936, Talling 1951, Lassen 1975). In addition, NZ mudsnails might be spread through consumption by waterfowl, but it is unlikely a snail could pass unharmed through the gizzard (Gangloff et al. 1998). Other wildlife (particularly aquatic and semi-aquatic species like frogs, raccoons, and otters) may serve as vectors via passive transport on a variety of geographic scales. They could also be spread on the feet or fur of domestic livestock which walk through streams, such as goats, sheep, cattle or horses or wildlife such as bison, deer and elk. Since mudsnails can live in moist areas along stream banks, they may be spread by animals that are walking along the riparian areas as well.

i. **Firefighting**: NZ mudsnails could be spread by firefighting machinery or equipment that is moved from one place to another across streams and rivers to fight backcountry or forest fires. Transporting large helicopter-deployed water buckets between water bodies is a particular concern. Spread could also occur through human and pack animal activity.

j. **Transport by water flow**: Water flow can spread NZ mudsnails downstream within a watershed (where they then may come in contact with new vectors that would transport them outside the basin). This vector typically would vary seasonally based on flood events or periodic management of water levels in ponds and reservoirs. In lakes and ponds, snails have been reported to raft on floating algae mats and other vegetation (Vareille-Morel 1983 and Ribi and Arter 1986 as cited in Ribi 1986, Dorgelo 1987). Additionally, NZ mudsnails can simply float at the water's surface or cling to the underside of the surface film (Gangloff et. al, 1998). Both floating and rafting behaviors are commonly observed in other snails, including anywhere that dead and uprooted vegetation accumulates in ponds. In addition to rafting and floating, gastropods have been reported to undergo "drifting" behavior in flowing water systems. Marsh (1980) found that *Physa gyrina* drifted at rates exceeding 500,000 individuals m^3 sec^{-1} under "normal" flow conditions. It is not known to what extent NZ mudsnails exhibit drift behavior.

k. **Transport by volitional movement**: As noted earlier, NZ mudsnails are capable of moving at speeds exceeding 1 m/hour (Richards 2002). Although unlikely to be a vector between river basins, volitional movement can obviously spread NZ mudsnails within a watershed (to sites where they then may come in contact with new vectors that could transport them outside the basin).

3. Information and Data Management

With funding from the US Fish and Wildlife Service, the New Zealand Mudsnail in the Western USA web site (http://www.esg.montana.edu/aim/mollUSca/NZ mudsnail/) is being hosted by the Department of Ecology, Montana State University in Bozeman, Montana. The purpose of the site is to be the most comprehensive and current database for information concerning the ecology of NZ mudsnails.

A basic foundation for the management of NZ mudsnail populations is to document and map its known locations; therefore, it is critical to timely map invasion patterns and abundance throughout the U.S. The sophisticated mapping capability of the New Zealand Mudsnail in the Western USA web site allows for easy input of new sightings and creation of accurate location maps. In addition, each location point has a description of the site and estimates of abundance. This web site and database needs to be expanded to include Great Lakes populations and any others that may show up.

The NZ mudsnail web site also provides conference minutes, recent findings, news, downloadable files, links, people involved with management and research, and a comprehensible bibliography.

4. Objective 1 Implementation

a. Assess risk of different pathways.

b. Identify additional pathways.

c. Develop guidance or criteria for risk and impact assessments.

d. Raise awareness about NZ mudsnails to audiences associated with identified pathways.

e. Develop a list server-discussion group for those interested in sharing information on NZ mudsnails.

f. Expand the New Zealand Mudsnail in the Western USA database, maps and web site to include eastern U.S. populations.

g. Facilitate coordination with USGS Nonindigenous Species database in Gainesville, Florida.

Priority pathways for targeting funds include fish hatcheries, recreational watercraft and trailers, anglers and hunters, and natural resource management activities.

5. Objective 1 Research Needs

The following questions need to be addressed to improve the capacity for measuring and managing risk of NZ mudsnail introductions:

a. Risk Assessment

1) Are there specific habitat types and/or environmental conditions that completely preclude establishment of NZ mudsnails? Are there environmental/habitat parameters that make an area more vulnerable to invasion.

2) How can relative risk of introduction and establishment of NZ mudsnails in uninfested waters be quantified?

b. Pathways

1) How important are the different human-mediated recreational vectors to the spread among watersheds: boat transport, angler movements, swimmers, etc?

2) How important are different vectors associated with economic activities: fish aquaculture, fish hatcheries, water use and transport?

3) Which suspected pathways have had the most prominent role in actual introductions of NZ mudsnails in the United States?
   a) between watersheds
   b) within watersheds

4) Are NZ mudsnails being distributed by biological supply houses? Could NZ mudsnails be unintentionally distributed with other species? Similarly, could NZ mudsnails be distributed through the Internet trade?

5) For those fish species used in aquaculture which will consume live snails, what is the maximum time period that NZ mudsnails can live within the digestive tract and still pass through as viable organisms?

6) What are the ranges of natural dispersal rates/distances that have been documented for NZ mudsnails upstream and downstream from initial infestations, and what physical factors affect those rates and distances?

7) Once NZ mudsnails occur in one tributary of a watershed, what is the likelihood that they will eventually occupy all reaches of the entire watershed that support their habitat needs?

B. Objective 2: Develop Methods of Detecting New Populations

1. NZ Mudsnail Sampling Methods and Procedures

NZ mudsnails occur in a wide variety of water bodies and on a wide variety of substrates including sand, leaf litter, organic detritus, silt, algae, aquatic macrophytes, gravel, cobbles, and boulders, as well as any other type of stable substrate (natural or artificial). With such a wide variety of habitats capable of being invaded, no single sampling method can be developed that is applicable in all situations. Numerous benthic invertebrate sampling methods have been developed and are widely used for different purposes and habitats including: Surber and Hess samplers, kick-nets, Ponar grabs, snorkeling, SCUBA, hand picking, suction dredges and colonization samplers or traps (Merritt and Cummins 1996). Once an invertebrate sample has been collected many techniques are Used to detect and count NZ mudsnails in the sample including: preservation in alcohol and examination under a microscope, visually inspecting contents of the sample live, and drying contents and floating snail shells.

Any of these methods can be used to detect NZ mudsnails depending upon different conditions, time and budget constraints, or individual preferences. As many samples as possible should be collected, no matter the method. No sampling method can ever guarantee 100% effective detection of NZ mudsnails and therefore not detecting NZ mudsnails at a site does not equate to its absence, or a negative location**.** NZ mudsnails are simply too small and can inhabit too many locations. Samples are not equivalent to a census, and one unobserved 1.0 mm NZ mudsnail can relatively quickly produce a whole population.

Formal sampling to detect NZ mudsnails is time consuming, expensive, requires some statistical sampling knowledge, and probably will not often be conducted. For specific information for estimating the detectability of NZ mudsnails using power analysis, see Appendix D. A more practical and efficient method with less statistical validity for detecting NZ mudsnails in wadeable waters is the use of a standard heavy-duty D-shaped kick net with mesh size $\leq$ 1 mm. The kick net is vigorously pushed through all available habitats, including vegetation, and also placed downstream of the biologist who vigorously kicks and agitates the substrate (cobbles, gravels, etc.) to collect what is kicked up with the net. Contents of the net are then placed in a large bucket of water; vegetation is washed in the bucket to remove snails and then safely discarded. Snails and other invertebrates are then poured into a < 1.0 mm mesh small, aquaria hand-net or suitable container. All that should remain in the bucket is heavier sand, gravel, or cobbles, which can be discarded. Contents of the small aquarium net are stored in 70-95% ethanol with collection labels written in pencil or alcohol-proof pen placed both in the container and attached on the outside of container. Samples are then visually searched for NZ mudsnails under a dissection scope. Preservation in 70% ethanol is also preferred for genetic analysis but soft body parts will become shriveled. If NZ mudsnails are abundant in the sample and easily visible during collection, some individuals should be removed and dried without alcohol.

III. Objectives

A good snail collection will often consists of three parts including preserved, relaxed soft parts, DNA samples and dried shells. The animals must be narcotized before fixing by keeping them alive in a clean container using the water of origin and adding a few crystals of menthol. After several hours, when the animals do not respond to touching, most of the water is carefully removed and replaced with 10% buffered formalin or Kahle's or Bouin's fluid. The latter 2 solutions provide better fixation, but they are acidic and they will damage or destroy the shells in time. They can be replaced with 5% buffered formalin after only several minutes to preserve the shells. An antacid tablet can be used to buffer formalin. The relaxed animals are stored in 70% ethanol.

DNA samples are easily obtained by placing a few snails directly into 90-100% ethanol. Chemically spiked ethanol should not be used for DNA samples. The fluid should be changed if it is much diluted. Different clones are identified by allozyme analysis (Dybdahl and Lively 1995). Samples for this analysis should be either alive or snap frozen, preferably in liquid nitrogen.

Excess shells are best preserved dry as they are easier to maintain and the color is preserved better. These should be placed into in 5-10% buffered formalin. Alcohol can also be used, but the shells will retain an unpleasant odor. In the lab the shells are cleaned with soap or ammonia water and rinsed with clean water before drying. NZ mudsnails can take a long time to completely dry out. The soft parts of large snails can be removed after killing the animal by suffocation or by freezing and then thawing. The operculum, if removed from the animal should be placed within the shell and held in place with a cotton plug.

Proper labeling is important. A standard collection label should include at least the following:

Collector's name
Water body
Date
County, State
Short description of site
GPS coordinates if available

An estimate of the area covered by the kick net during sampling should also be recorded. Another method would be to calculate the number of man-hours for which the sampling occurred. Either method would allow for estimation of a rough detection probability. Because these are simple qualitative methods, they will always yield rough estimates.

Casual sampling for NZ mudsnails by hand picking cobbles, vegetation, woody debris etc. along shorelines can also be used, if no other methods are available or if time is limited. This method will work reasonably well if the snails are abundant. If NZ mudsnails are detected using this method, proper preservation and documentation methods should be followed. If no NZ mudsnails are discovered by casual observation it should be documented (including details about the search method and intensity), but the data will be of limited use.

Both NZ mudsnail density and habitat location can vary dramatically seasonally. Typically NZ mudsnail densities are highest in late summer and early autumn, but can vary with location (Richards et. al. 2001, Richards 2004, Kerans et al. 2005). NZ mudsnail habitat location can also vary seasonally depending on food availability and other physical and chemical factors. A locality with NZ mudsnails in one season may not have them in another season. NZ mudsnails in winter often remain on the bottom of cobbles (Richards personal observation), or can possibly burrow into gravels to avoid cold temperatures. Therefore sampling efforts should not be rigidly defined but adjusted accordingly.

Another sampling method that has not been used widely to detect NZ mudsnails is the databases of county, state, tribal, and federal water quality agencies. These agencies have collected thousands of benthic invertebrate samples from thousands of miles of streams and rivers. If NZ mudsnails were present, there is a likely chance that they would have been collected during these widespread and ongoing sampling efforts. Most agencies typically Use D-net or Hess samplers and samples are often collected from riffle habitats. All NZ mudsnail positive sites in these databases likely can be considered valid (if they were not misidentified), but the absence of NZ mudsnails needs to be evaluated. NZ mudsnails may have been misidentified as other species because they are not included in keys used for North American benthic macroinvertebrates. In addition, a probability of detection estimate needs to be established comparing the relationship of NZ mudsnails found in cobble-riffle habitat samples to other non-sampled habitats.

Biologists who collect snails that fit the description of NZ mudsnails but are unsure of the specific identification should contact the ANS coordinator at their State fish and wildlife agency or U.S. Fish and Wildlife Service regional office.

2. Objective 2 Education and Outreach

Although methodology exists for sampling and identifying NZ mudsnails, there are untapped opportunities to involve additional audiences in implementing these methods. . Therefore, one goal of the outreach and education efforts must be to reach out to both professionals working in the field and concerned citizens who may assist in monitoring. While the desired result of increased monitoring and detection is the same for each group, the outreach approach needs to be tailored differently to reach these audiences.

A general campaign of public outreach will serve as an excellent first step in encouraging additional public monitoring. Existing community-based programs (e.g., stream watch teams) that include water quality or biological monitoring will need to be identified and contacted with sampling information. These groups have already demonstrated their commitment to the resource and should be easily recruited into the effort. As outreach increases, individual anglers and other recreationists will join the effort and it can be expected that there will be a number of individuals that will routinely inspect the waters they visit.

Fishery workers and other resource professionals that frequently visit aquatic areas need to be recruited into the effort of identifying introductions. Outreach strategies need to be implemented that will educate these professionals about the need to sample. However, a more effective outreach strategy may be to target higher level resource management professionals who have the authority to direct their staff to conduct surveys. These individuals need to be identified and targeted to insure that entire agencies adopt sampling protocols and not just individual employees.

In order to ensure that increased field monitoring is promptly translated to reportable results, it will be important to:

a. Develop list of local and national sources of taxonomic expertise for identifying potential NZ mudsnail populations and publicize widely.

b. Develop a key to Pacific Northwest aquatic snails with an emphasis on identifying nonnative snails such as NZ mudsnails, Chinese mystery snails, etc.

c. Outreach to watershed groups and government agencies collecting benthic invertebrate samples regarding identification and data gathering.

3. Objective 2 Implementation

a. Develop database to expand NZ website to collect information on NZ mudsnail sampling efforts (methods, frequency, detection limits, etc.) including those where NZ mudsnails have <u>not</u> been detected.

b. Review of existing local, state, federal databases and/or collections of macroinvertebrate samples (focused on watersheds where intentional NZ mudsnail sampling has not occurred).

c. Establish priority areas for monitoring, such as sites close to existing infestations or sites with special management needs or sites containing endangered or threatened species.

4. Objective 2 Research Needs.

a. Develop estimates of detection probabilities for a variety of substrates, ecoregions, and sampling methods and sampling designs.

b. Develop standardized techniques for detecting low abundance NZ mudsnail populations and for estimating densities in established populations.

c. Monitor existing populations on a precise schedule to understand population trends and their response to environmental factors.

d. Evaluate different detection methods in different habitat types to provide a way for establishing confidence in data that people submit.

C. Objective 3: Develop Strategies and Methods of Prevention, Control and Management

1. Risk of Future Introductions

The most effective way to avoid NZ mudsnail impacts is to slow or stop new introductions by the pathways described under Section II.A. Assuming resources and other factors set limits on the scope of a prevention program, it becomes desirable to evaluate the likelihood that a particular action will lead to an introduction. Despite advancements in modeling and analysis of past invasions, predicting if, where, and when nonnative species will become established in a new site is still unreliable. The probability of transport by potential pathways is difficult to calculate and highly variable spatially and temporally. Physiological thresholds that may be evident from current distribution and laboratory experiments do not provide certainty that those thresholds will hold true in locations where the species does not yet occur. This is particularly true for species as apparently phenotypically plastic as NZ mudsnails. Further complicating predictions of future NZ mudsnail introductions are a long list of information gaps regarding physical tolerances, habitat suitability, pathway probabilities, and the complex relationships between these factors (see Research section below). That said, it still may be feasible to assign relative risk rankings in order to prioritize pathway and water body management efforts. For example, introductions to new locations across broad geographic spans are highly likely to stem from human mechanisms rather than volitional movement or dispersal by fish, wildlife, and water flow.

However, unless the risk of an activity introducing NZ mudsnails to a particular location can be confidently determined to be zero, decisions regarding preventative measures not only must consider what is the actual level of risk (both probability and magnitude of impact), but what is the acceptable level of risk. If, for example, a fish hatchery detects one live NZ mudsnail in a sample of fish that will be stocked into an uninfested tributary, should that release be halted or do the benefits outweigh the anticipated level of risk? If there are snails found in another tributary of the same watershed, will other vectors (including volitional movement) minimize the impact of the hatchery's decision regarding distribution in the basin? How should the inherent uncertainty noted above regarding habitat use by invasive species be incorporated? For particular pathways, criteria need to be developed that guide these risk management decisions based on available data for the relevant vectors and watersheds of concern. A precautionary approach needs to be considered given the likely irreversibility of introductions that do occur. Appendix D provides an example of corresponding risk assessment and risk management criteria developed for stocking decisions at the Hagerman National Fish Hatchery in Idaho.

2. Management Options for pathways

Recognizing the challenges in setting prevention thresholds and prioritizing pathways of concern, there are many methods that may contribute greatly to reducing the spread of NZ mudsnails. Some prevention methods are applicable to a variety of pathways and invasive species. For example, where NZ mudsnail spread is associated with inadvertent contamination of equipment, clothing, or other materials, educational materials and programs aimed at the associated audiences can promote decontamination activities. Education on the harmful effects that NZ mudsnails have in conjunction with information on how to prevent the spread is essential in the control and management. Prevention of introduction is always the best tool to manage invasive species.

Hazard Analysis and Critical Control Point (HACCP) planning is another general tool for managing invasive species pathways. HACCP plans identify potential pathways of introduction of invasive species and identify how the pathways can be broken to prevent the introduction. Development and implementation of HACCP plans for activities likely to transport NZ mudsnails can significantly reduce spread.

Pathway-specific management options include:

a. **Fish hatcheries and other aquaculture operations**: For facilities where no known NZ mudsnail contamination occurs, close visual inspection of water systems, raceways, stocking equipment, as well as regular gut content analysis can detect the arrival of snails before they can be spread. For facilities with contaminated water supplies, well water or other alternative uncontaminated sources should be used for any situation where there is exposure to fish. Similarly, equipment (e.g., nets) used within contaminated water should not be used in areas of the facility that are on clean water. Gear used in the field should not be used in the hatchery, and all gear should be stored in walk-in freezers, if available, treated with decontamination methods or thoroughly dried. When there is evidence or even likely risk that fish are consuming live NZ mudsnails, releasing those fish only at sites already contaminated by mudsnails can avoid further spread. Current research on the effects of fish feeding, snail size, snail meal size, and fish size on snail transit and survival through the gastrointestinal tract of rainbow trout/steelhead will help develop a depuration strategy that infected hatcheries can implement before stocking fish. Preliminary investigations also suggest that copper, carbon dioxide under pressure, and hydrocyclonic separators may prove useful in both decontaminating fish hatchery water supplies and preventing spread into uncontaminated areas of a hatchery. Ozone has not been shown to be effective in killing NZ mudsnails in a hatchery environment (Moffitt, personal communication.)

b. **Recreational watercraft and trailers**: Given their small size, it may not be practical in many situations to completely eliminate NZ mudsnails that have contaminated recreational boats or trailers. However, providing information and resources (and/or regulatory requirements) to promote thorough cleaning of watercraft before it exits a contaminated site will certainly reduce risk. Promoting thorough drying of boats and trailers before launching at new locations will also minimize introductions. There are a number of guidelines developed under the 100th Meridian Initiative focused on reducing boater transport of zebra mussels that are applicable to NZ mudsnails. Similarly, boater movement surveys developed for the 100th Meridian Initiative that focus on NZ mudsnail infested waters can help target prevention activities toward potential "hot spots" for new introductions. For more information, see http://100thmeridian.org.

c. **Anglers, Hunters, and Natural Resource Management personnel**: In addition to outreach and HACCP measures noted above, providing resources to facilitate field decontamination of gear will aid in reducing risk (e.g., wash stations at high use water access sites). Associated with this approach is having a variety of decontamination methods that are known to be effective via scientific testing and are also practical for field use (see section 6 below). Anglers who catch fish in NZ mudsnail infested waters could be required to clean fish before moving between watersheds. As a more extreme measure, contaminated areas can be closed to public access (although this will only be effective if accompanied by adequate enforcement resources).

d. **Aquarium and aquatic plant trade and collections**: Stronger inspection and quarantine requirements for shipments of aquarium and water garden organisms, accompanied by effective requirements for disinfection or disposal of contaminated shipments, can reduce this pathway. The Lacey Act can facilitate federal enforcement of NZ mudsnail importations between states that prohibit possession of NZ mudsnails.

e. **Commercial shipping**: There are significant programs in place at the state, federal, and international level to reduce the discharge of contaminated ballast water. It is beyond the scope of this plan to analyze those programs. Where applied, it is likely that the current practice of open ocean ballast water exchange, as well as many onboard ballast water treatment methods currently under development, would be sufficient to eliminate the discharge of live NZ mudsnails. However, there are gaps in mandatory ballast treatment requirements that still leave some U.S. waters vulnerable to NZ mudsnail introductions via this pathway.

f. **Sand/gravel mining, extraction, and dredging**: There do not appear to be regulatory requirements governing inspection or cleaning of associated equipment for these activities. Voluntary or mandatory decontamination guidelines may help reduce risk. As a more extreme measure, contaminated areas can be closed to extraction or dredging activity. Individual state agencies may incorporate decontamination requirements when issuing permits for these activities, but often do not have personnel available to enforce the requirements.

g. **Transport by fish, wildlife and livestock**: Although impractical to limit in natural settings, netting and other predator avoidance methods typically used in fish hatcheries can reduce the ability for birds and other wildlife to spread NZ mudsnails from contaminated facilities. In some cases, trapping and moving animals from the area may be necessary. Livestock should be kept away from invaded streams and riparian areas.

h. **Transport by volitional movement**: It has been suggested that barriers such as copper stripping or electrical weirs may limit volitional movement of NZ mudsnails, particularly as a means of protecting high risk sites like fish hatchery water systems. Some investigations are underway but there is no applicable tool available yet.

i. **Transport by anchors:** Since the eastern clone is found in relatively deep water, the most likely method of dispersal is by movement of deep sediment by dredging or by movement of anchors. Inspection and cleaning of anchors may be necessary if they are used in invaded areas from 15-45 meters deep. Anchors used in western U.S. rivers by recreational boaters might also become fouled with aquatic vegetation and mud, and require inspection and cleaning.

3. Rapid Response

The following is a stepwise process for the rapid response to the report of a population of New Zealand mudsnails:

1. Confirm reports of new NZ mudsnail invasions.
2. Document the distribution of the NZ mudsnail population.
3. Convene Technical Advisory Body which has been designated to determine the feasibility of eradication and/or control methods.
4. Determine whether to attempt eradication or whether to implement control actions, and make recommendations to appropriate state agencies.
5. Develop a 'boilerplate' environmental review document approved during the PEA/PEIS. Allow a maximum of two weeks for completion of the document and availability to the public.
6. Public participation process.
7. Incorporate public comment.
8. State ANS Coordinator and Technical Advisory Panel to make a decision on whether to proceed with the proposed action.
9. If decision is to proceed, implement the proposed action.
10. Monitor the results of the action and determine success.

Eradication and control of newly discovered populations of NZ mudsnails will require quick action on the part of the appropriate agencies. States with ANS Management Plans should have a Rapid Response section which lays out specific actions based on state and federal government agency coordination. States with an invasive species or aquatic invasive species council may designate that body to determine what eradication or control steps need to be taken. States without ANS Management Plans or invasive species councils need to have a clear authority for making this decision. For example, in Colorado, which does not have an ANS Management Plan, the authority for determining actions in response to aquatic invasive species starts with the State Health Board which makes a recommendation to the Colorado Wildlife Commission. This process takes several weeks because it depends on when the two boards have regularly scheduled meetings.

For agencies to have the ability to implement actions in a rapid fashion, one recommendation is that each state conducts a Programmatic Environmental Assessment (EA) or Environmental Impact Statement (EIS) for the control of mudsnails and other aquatic nuisance species. After completion of a PEA/PEIS, a systematic process should be implemented to address confirmation and action of mudsnail populations and to implement rapid response measures.

4. Eradication

If prevention efforts fail to stop the spread of NZ mudsnails into a new water body, new populations should be eradicated where it is feasible and practical. It must be determined: 1) if total kill is likely, recognizing the survival of even one NZ mudsnail can negate an eradication attempt; 2) if environmental damage will be caused and if so estimated recovery costs, and 3) if there will be impacts to non-targeted and threatened and endangered species. Development of geographic-specific early detection and rapid response plans will facilitate quick action. These plans can include documents such as intended response actions.

Many times the newly discovered population of NZ mudsnails may be in a river or lake where chemical eradication will not be feasible and physical eradication difficult. This would be the case with large rivers or lakes where it is impossible to isolate the invader and treatment would be difficult to contain. In other situations the invader may occupy too large an area or other ecological or political restraints may rule. However, it must be recognized that there will be some opportunities where either of the methods would be applicable and effective.

Areas where eradication may be possible include small lakes and ponds, irrigation canals, and fish hatcheries. Many small lakes and ponds are isolated or may easily be isolated from the drainage making it easier to apply chemicals without downstream damage. In other cases draining and allowing the substrate to heat and dry in the summer or freeze in the winter would be equally effective. Irrigation canals are routinely shut down or sections are isolated and treated for eradication of unwanted plants, a method which could be used for snail control also. Fish hatcheries are another example of a situation where the snails could be completely eradicated although in some situations it may be difficult. Water flowing through most fish rearing facilities can be controlled and many have protocols used to remove bacteria or virus pathogens by chemical disinfection.

Chemical methods used to eradicate NZ mudsnails include: Bayer 73 (Francis-Floyd et al. 1997), copper sulfate, and 4-nitro-3-trifluoromethylphenol sodium salt (TFM). The only molluscicide known to have been tested against NZ mudsnails is Bayluscide (a.i. niclosamide). This test, conducted by Montana Fish, Wildlife, and Parks (FWP), was to determine the feasibility of eradicating NZ mudsnails from a small spring creek along the lower Madison River. One hundred percent mortality occurred after 48 exposure units of Bayluscide. An exposure unit is 1 ppm for 1 hour (Don Skarr, Montana FWP, personal communication).

Physical treatments include the use of temperature, humidity or desiccation to kill the target species. This includes draining the infested areas. NZ mudsnails can survive for long periods in a cool damp environment; however, draining the areas where they are congregated and exposing them to sunlight during the summer months may be sufficient for eradication. Using a flame thrower in a hatchery situation against the walls of raceways will kill any mudsnails attached. Mudsnails cannot withstand warm temperatures (Dwyer et al. 2003; Richards et al. 2004) or low humidity situations (Dwyer and Kerans, unpublished; Richards et al. 2004). Alternately, if an infested area could be drained in the winter and the substrate is frozen to a depth containing the mudsnails, then total eradication will occur.

5. Control and Containment

When complete eradication is deemed infeasible, the NZ mudsnail population should be isolated to prevent further spread by closing pathways and eliminating vectors. Posting of educational signs about mudsnails and ways to prevent their spread will increase awareness by the public about their role in the containment of NZ mudsnails. Some jurisdictions may choose to close the invaded area to fishing, hunting or other water sports.

Other techniques which may control the populations of NZ mudsnails without eradication are:

1. Periodic molluscicide application,
2. Periodic desiccation of waterbody, and
3. Periodic introduction of biological control agent.

A laboratory study was done in 2005 by Sean Garretson at Portland State University's Center for Lakes and Reservoirs using GreenClean® PRO to control NZ mudsnails. GreenClean® is a non-copper-based algaecide that eliminates a broad spectrum of algae on contact. It is designed for lakes, ponds, and other large bodies of water, as well as for unpainted surfaces, such as beaches, docks, and walkways. Its active ingredient, sodium carbonate peroxyhydrate, creates a powerful oxidation reaction that destroys algal cell membranes and chlorophyll, providing immediate control of algae. The producer, BioSafe Systems, claims that the algaecide is nonhazardous to fish and aquatic life (see www.biosafesystems.com).

Garretson's study had several objectives: 1) to investigate the effects of GreenClean® PRO on NZ mudsnail mortality, 2) determine the minimum algaecide concentration and exposure times that results in 100% mudsnail mortality, and 3) expose mudsnails to a range of concentrations including those that exceeded the maximum application rate recommended.

Application of GreenClean® PRO is an effective way to hinder if not eliminate NZ mudsnails in the lab. Mortality was 100% within 72 hours of exposure to a 0.5% concentration for 2 and 4 minutes, 1% concentration for 30 seconds, and minimum of 0.33% concentration for 8 minutes. Mortality was also 100% 48 hours after exposure to a 4% concentration for 2 minutes and 0.55% concentration for 8 minutes. Results demonstrate the detrimental effects that GreenClean® PRO has on NZ mudsnails under very specific lab conditions. Garretson concluded that uncertainty remains as to the effectiveness of application by field personnel.

Parasites of NZ mudsnails from New Zealand might also become useful to control population size. Studies of the efficacy and specificity of a trematode parasite from the native range of NZ mudsnails as a biological control agent have been positive so far (Dybdahl et al. 2005, Emblidge and Dybdahl *in prep*.). The parasite *Microphallus* sp. appears to be highly specific in the native range, infecting the most common genotypes (Dybdahl and Lively 1998, Lively and Dybdahl 2000). Experimental infections have shown that populations of the parasite from the source range of western U.S. snail clones are very effective at infecting the genotype found in the western U.S. Experimental infections and molecular genetic studies have also shown that these effective lineages of *Microphallus* sp. are highly specific.

However, biological control entails the introduction of another non-native species, and the costs of this have to be weighed against the costs of ecological damage caused by the NZ mudsnails. In addition, substantial research on specificity and effects on vertebrates is still required before this can be conducted on any scale to ensure that further harm to the environment does not result.

6. Preventing the Spread on Wading and Other Gear

Given the significance of fishing gear and equipment as a pathway for NZ mudsnail transport, emphasis has been placed on researching effective control methods. At this time, consensus has not been reached on one universal method that consistently eliminates all NZ mudsnails from gear without causing gear damage (see Objective 3 Research Needs below). Recommended practices include:

- Cleaning all mud and debris that might harbor NZ mudsnails from boot, waders and gear with a stiff brush.

- Putting fishing gear in a freezer for 6-8 hours will kill all attached NZ mudsnails (Medhurst 2003, Richards 2004).

- Putting fishing gear in water maintained at 120°F for a few minutes will eliminate NZ mudsnails (Medhurst 2003). The mudsnails can survive at 110°F so the water temperature needs to be accurate.

- Dry fishing gear at 84-86°F for at least 24 hours or at 104°F for at least two hours (Richards et al. 2004). Gear should be thoroughly brushed with a stiff bristled brush prior to drying.

- Where such extensive efforts are not possible, gear should be spread to dry superficially to minimize attachment of snails in water films, and shaken to dislodge snails at the site before moving to other water bodies. This method recognizes that complete kill is not actually essential to minimize and even eliminate accidental vectoring.

Freezing, hot water and drying at high temperatures may be difficult or impossible for many anglers or researchers who are moving from one water body to another in a short period of time. Two recent tests described below have revealed alternative methods of killing NZ mudsnails that are more adaptable to these conditions.

Researchers at California Department of Fish and Game exposed NZ mudsnails in laboratory tests to solutions of benzethonium chloride, chlorine bleach, Commercial Solutions Formula 409® Cleaner Degreaser Disinfectant, Pine-Sol®, ammonia, grapefruit seed extract, isopropyl alcohol, potassium permanganate, and copper sulfate. With the exception of grapefruit seed extract, potassium permanganate and isopropyl alcohol, these materials all killed mudsnails within five minutes (Hosea and Finlayson 2005). However bleach and Pine-Sol®, at concentrations efficacious in killing snails, did structural damage to wading gear. See Appendix E for more information.

The most effective solutions for killing NZ mudsnails which can be used in the field, according to this research are copper sulfate (252 mg/L Cu), benzethonium chloride (1,940 mg/L) and 50% Commercial Solutions Formula 409® Cleaner Degreaser Disinfectant. Appendix E has a thorough description of the procedure for cleaning wading or fishing gear using these solutions in the field. Wading gear cleaned using any one of the three methods was, in general, free of live NZ mudsnails that could be transported to another water body. Exposure to these materials causes NZ mudsnails to release from the substrate they're in contact with, which facilitates their removal. Anglers or waders using these methods would need to insure that the cleaning solutions do not enter surface water or other sensitive habitats.

Researchers at the Colorado Division of Wildlife (CDOW) found that Sparquat brand quaternary ammonium disinfectant (benzalkonium chloride) outperformed Commercial Solutions Formula 409® Cleaner Degreaser Disinfectant. Sparquat is the disinfectant routinely used by CDOW fishery biologists for inactivating Whirling Disease (*Myxobolus cerebralis)* spores from field gear. They found that two dilutions of Sparquat at 4 oz/gal and 6 oz/gal outperformed 50% Formula 409 at 5 and 10 minute exposures. The researchers are recommending that field personnel use 6 oz. Sparquat per gallon of water for at least 10 minutes exposure, preferably longer (Colorado Division of Wildlife Aquatic Section, August 2005).

Oregon State University has completed initial research on using dry ice as a disinfection method. Preliminary results indicate 100% mortality can be achieved in some situations with minimal damage to gear (Chan 2005).

7. Objective 3 Education and Outreach

a. Develop corps of volunteer anglers who can provide one-on-one technical assistance to other anglers regarding prevention methods and effective control techniques.

b. Develop a plan for public awareness of control measures, including biological, chemical and physical, and the potential benefit of their application.

8. Objective 3 Implementation

a. Write a model provision for States to adopt that requires HACCP plans for aquaculture seeking permits.

b. Develop a model/rule that will help State agencies and private organizations do HACCP plans.

c. Develop a Hatchery certification to indicate whether they are positive for NZ mudsnails and/or do not appear to have NZ mudsnails and are employing adequate prevention strategies.

d. Develop State rapid response plans. (Note: The Western Regional Panel has a model rapid response plan which can be used by States).

e. Develop a protocol for responding to new occurrences of NZ mudsnails.

f. Develop a model interagency/interstate agreement for monitoring and efficacy of control/containment efforts on existing occurrences of NZ mudsnails in waters that cross state lines.

g. Provide tools such as wash kits or wash stations (instead of providing information only) as a means for action.

h. Create a national web-based database on NZ mudsnail monitoring and control efforts for easy retrieval for researchers and managers.

i. Increase coordination with agencies and other biologists to get more timely input on new populations of NZ mudsnails.

9. Objective 3 Research Needs

The following list gives research topics that will increase our understanding of management and control strategies for NZ mudsnails.

a. Biological Control

1) What is the specificity of parasite biocontrol agents against native alternative hosts?

2) What population demographic models can be developed to show under what parameters a parasite biocontrol agent would control NZ mudsnail populations and to what degree?

3) What is the effect of trematode parasite biocontrol agents on other hosts in the life cycle?

4) Is the risk of biocontrol worth the benefits of NZ mudsnail control?

b. Chemical/Physical Control

1) Will chemical and or physical control techniques have acceptable ecological impacts?

2) Can we develop effective and ecologically-sound control methods in the mechanical, physical, chemical and biological control arenas?

3) Continue to test efficacy of current treatments of gear and determine whether a treatment must *kill* all mudsnails or simply get them to release from the gear.

4) Develop and test prevention methods for wader and gear enabled transport for a variety of ANS including whirling disease, didymo, etc. so that anglers and field crews don't have to use multiple disinfectants or choose to prevent the transmission of one ANS over another. Once a consistently effective method is identified, seek consensus to make it the recommended protocol used consistently by all agencies and organizations.

D. Objective 4: Develop Further Understanding of Ecological and Economic Impacts

1. Ecological Impacts

The extent of the ecological impact of NZ mudsnails to ecosystems in areas where it has invaded in western North America is not yet known, but studies to date indicate the likelihood of wide-ranging consequences. The full ecological impact of NZ mudsnails is likely to include effects on aquatic resources, such as competitive interactions with native aquatic invertebrates, and the associated changes in community structure and ecosystem function. Extremely high invasive snail densities (>500,000 m^2, Hall et al. 2003) contribute to the assumption of negative ecological impacts. Furthermore, the evidence that grazing herbivores like NZ mudsnails are extremely effective primary consumers in aquatic systems is well documented in the literature (e.g. Hawkins and Furnish 1987, Feminella and Hawkins 1995).

NZ mudsnails directly affect native biota by 1) consuming large quantities of the primary production, especially periphyton (Riley 2003, Hall et al. 2003); 2) competing with native gastropods, some threatened and endangered (Richards 2004, Riley 2003, Riley et al., *in review*); 3) competing with other grazing and detritivorous invertebrates that are the foundation of aquatic food webs (Cada 2004, Kerans et al. 2005, Cada and Kerans, *in review*); and 4) negatively impacting both invertebrates and vertebrates at higher trophic levels in aquatic food webs that depend on the aquatic invertebrate food base (Cada 2004, Hall et al. 2006, Vinson, personal communication).

NZ mudsnails may displace native biota in aquatic food webs; hence their invasion has caused an alteration in the energy flow pathways among trophic levels. In three streams in the Yellowstone region, mudsnail production constitutes the vast majority of total secondary production (Hall et al. 2006). In the Gibbon River and Polecat Creek, NZ mudsnails constitute 88-93% of total secondary production and their rate of production in Polecat Creek is one of the highest ever measured in a river. Community structure is dominated by mudsnails, and this degree of dominance by a single species is comparable to highly degraded communities.

Invading NZ mudsnails do not serve as an equivalent substitute energy source for predators. Mudsnails apparently pass through fish intestinal tracts undigested, and have low energetic value for these secondary consumers (Ryan 1982, McCarter 1986). A recent lab experiment in Utah showed that when trout were fed a diet of mudsnails, over 80% of the mudsnails were undigested. These trout lost weight, while trout fed native invertebrates gained weight. This appeared to result from the fish's inability to obtain enough energy to grow (Mark Vinson, personal communication). Hence, community structure might be directly and indirectly affected at higher trophic levels in the food web (e.g. predatory invertebrates, fish, and other vertebrates).

III. Objectives

The extent to which these changes in community structure and energy flow can affect fish populations is poorly understood. However, in a "worst case scenario," if NZ mudsnails replace higher valued food resources, fish reproduction, condition factor and population densities could be affected. Terrestrial animals such as birds may also be affected since some interact with aquatic food webs as well. Consequently, this invader could have effects that cascade through both aquatic and terrestrial food webs (e.g., Carpenter et al. 1985).

Because NZ mudsnail densities and biomass can be so high, they alter ecosystem processes such as nutrient cycling in rivers. Excretion of ammonium by mud snails supplies about 2/3 of the whole-stream demand by algae and bacteria for this limiting nutrient in Polecat Creek, WY, suggesting that mudsnails dominate the nitrogen cycle when biomass is high (Hall et al. 2003). It is also possible that they make rivers large sources of CO_2 by precipitating calcium bicarbonate to calcium carbonate to make their shells (Chavaud et al. 2003). By changing ecosystem functions such as C and N cycling, NZ mudsnails can indirectly alter the community structure and population dynamics of native organisms, as the snails have changed fundamental attributes of the ecosystem.

In conclusion, based on the current literature, direct effects of mudsnail invaders on stream communities potentially include 1) decreased densities of native herbivorous and generalist invertebrates, 2) decreased densities of attached filter-feeding organisms, and 3) decreased densities of invertebrate and vertebrate predators of native species displaced by NZ mudsnails. Species replacement is one of the most important contributors to the loss of biodiversity in freshwater communities.

Densities of the eastern population in Lake Ontario vary with time of year, peaking in the late summer and early fall and crashing during the winter (Zaranko et al. 1997). In Lake Ontario, densities also vary substantially from year to year ranging from 15 to over 5500 per square meter in several locations (Zaranko et al. 1997; Levri et al. in prep.). In both Lake Superior and Lake Erie, very few individuals have been found (two in each location).

Assessing the ecological effects of the eastern clone is difficult. The areas inhabited by NZ mudsnails have already been substantially impacted by zebra mussel (*Dreissena polymorpha*) and quagga mussels (*Dreissena bugensis*). Thus it is difficult to attribute damage to NZ mudsnails.

Studies of terrestrial communities suggest that changes in community structure associated with alien species and biodiversity loss can alter ecosystem function and disturbance regimes, but these effects have been less studied in aquatic systems. The stability of ecosystem functions in terrestrial systems such as nutrient cycling and productivity is reduced at lower levels of plant species richness (Tilman et al. 1996). In a marine system, grazer diversity was positively correlated with ecosystem properties (Duffy et al. 2003). Furthermore, exotic species in communities can increase the frequency of disturbance and lead to further changes in community structure (Mack and D'Antonio 1998), although these effects have not been studied in aquatic systems.

2. Economic Impacts

Economic impacts associated with the introduction of NZ mudsnails may derive from both direct and indirect effects and may vary regionally. Biofouling is a typical direct economic impact of exotic mollusks, as exemplified by the zebra mussel, *Dreissena polymorpha* (Mills et al. 1993). Zebra mussels may reach high densities, clog intake structures, and foul maritime equipment (Locke et al. 1993, Mills et al. 1993). It is estimated that the damage and control costs of the zebra mussel in intake pipes, water filtration systems, and electric generating plants is $100 million per year (Pimentel et al. 2000). The biofouling potential of NZ mudsnails is probably lower than that of the zebra mussel. However, NZ mudsnails have been documented to pass through water pipes and to emerge from domestic taps (Ponder 1988) and can block water pipes and meters (Cotton 1942 in Zaranko et al. 1997). With population densities as high as 800,000 individuals m^2 (Dorgelo 1987), there is a potential for biofouling, particularly in irrigation systems in arid regions.

Extremely high densities of invasive species can also have ecological consequences that result in indirect economic impacts. Indirect economic effects that occur because of changes in ecology are difficult to measure, but clearly occur. In the Greater Yellowstone Ecosystem, the effects of NZ mudsnails on natural communities and food webs may threaten the economically important recreational fishing industry in the region (Keiter 1991).

A second cost is related to the vulnerability of threatened or endangered native fauna to mudsnail invasion. For example, zebra mussels' tendency to settle on hard surfaces has lead to the fouling of native mussel valves, leading to high mortality rates (Schloesser et al. 1996). Many of these native mussels are either endangered or threatened, leading to costly study and salvage operations (Schloesser 1996). Mudsnails overlap with threatened and endangered species in the Snake River, ID, resulting in costs associated with protection of these species. Other associated costs include: research and development expenses incurred by agency and university personnel to prevent further spread; monitoring the distribution and spread of the snail to determine whether sensitive native species are being placed at risk; extra monitoring that must occur for threatened and endangered species within the range of the NZ mudsnail invasion; extra steps taken by agency personnel to ensure that facilities such as hatcheries do not act as vectors; extra requirements placed in permits for activities such as dredging, canal maintenance, etc., extra steps and materials used by agency personnel, researchers, citizen monitors, and consultants to decontaminate gear; and extra costs incurred for materials, transport and time of public outreach and information dissemination. Finally, contamination of private hatcheries and subsequent regulation and prohibition of their operations results in direct economic impact to these operators.

3. Objective 4 Implementation

a. Develop a protocol for pre/post-impact studies (ecological and economic) that can be applied consistently to new locations when incipient NZ mudsnail invasions are found.

b. Develop educational materials that address the reality that NZ mudsnail invasions have not been linked to conspicuous declines in native fish populations but also provide concrete evidence of negative impacts along with analogous stories of other invasions where such measurable impacts took years to hit (at a point where many management options were not longer a available).

c. Develop sources of funding for research, including contacts with foundations and coordination among agencies.

4. Objective 4 Research Needs

Ecological research aimed at predicting the invasiveness and ecological impact of this species in North American waters is needed. Research on economic impacts of these snails as biofoulers on manmade systems and as disruptors of natural systems is also needed.

a. Investigate the effects of snails on community structure and ecosystem function (including both vertebrates and invertebrates) and food webs. This should include both field surveys and experimental approaches aimed at understanding the interactions between mudsnails and native species.

b. Investigate the effects of NZ mudsnails on vertebrates at higher trophic levels, including trout and waterfowl. Conduct research that can effectively answer the question “how much do native fish populations decline in specific watersheds after NZ mudsnails become abundant?”

c. Determine whether the costs of control and management of NZ mudsnails are significant. This should also be measured in terms of no control with anticipated effects on recreational opportunities, loss of revenue to local economies, construction, enforcement, signage, as well as ecological impacts.

d. Investigate the basic ecology and ecological risk of the Great Lakes Clone.

E. Objective 5: Increase Understanding of the Need to Deal with NZ Mudsnails and Gain Support for Implementing National Plan Objectives

1. Education and Outreach Needs

A successful effort to contain and control NZ mudsnails will only be possible if an effective outreach and education campaign is developed and implemented. Many of the goals and objectives outlined in this plan are dependant upon the support and adoption of a large segment of the public. This cooperation and support must be earned through effective outreach.

Any successful communication effort begins with a plan that establishes who the target audiences are, what the desired outcome is from these audiences, where these audiences will be reached and how to reach them. Four primary audiences have been identified to be targeted with NZ mudsnail outreach efforts. These groups are: resource allocators, agency administrators, natural resource management implementers, and the public. Each of these groups has both shared and unique message needs. Each group needs to receive a message tailored to them to insure the greatest possibility of success. See Table 1 for list of audiences and messages.

Resource allocators are those key individuals that are capable of providing the financial and human resources needed to advance this effort (e.g., legislators). They are usually not scientists and do not want to receive detailed specifics about the organism. Rather, they are concerned about how NZ mudsnails fit into a larger picture. They want to know what the threat is, what the consequences are of various action options, what economic impact they might have, how they will affect the public and why they should receive a priority. These individuals will often be more receptive to messages that address human related impacts. To effectively reach this audience, materials need to directly address their concerns and be delivered in a fairly brief fashion. The most effective way to deliver messages about NZ mudsnails to these individuals will be through personal contact. A brief, well prepared, presentation is the most effective tool to use. The presentation will be crafted to be equally effective and compelling whether it is delivered as a PowerPoint presentation, a formal briefing or a short conversation.

Agency administrators are another important group to be targeted for outreach. These administrators are often resource allocators but also have the role of establishing priorities and policies for their agencies. These individuals need to be fully informed about NZ mudsnails and make policy decisions that result in a commitment to the control effort. Agency administrators will often need a higher level of detailed information than resource allocators. They need to be provided with concise and accurate information about management options which, when implemented will lead to greater success. The message to them will begin by establishing the need (this is essentially the same message provided to allocators) followed by suggestions for management options and strategies. Finally, they will be encouraged to secure the full cooperation of their implementation staffs. The message delivery to agency administrators will be most effective when conducted on an individual basis. However, presentations to groups of administrators can also be very effective. Effective tools for communicating with these individuals will be PowerPoint presentations, briefing papers, personal appeals (especially from people with established credibility) and peer communications.

Most natural resource management implementers are those individuals that are charged with the actual field level implementation of actions. They might be biologists, researchers, wardens or others that undertake the actions identified as part of the strategy. The outreach goal for this group is twofold. First is to insure that they understand and adopt any protocols that are established. Second is to enlist them as additional communicators to the public. No matter how good the planning and research are, the entire control effort will fail if the implementers do not follow through. They must make field observations to identify range and spread. They must implement cleaning and transport protocols. They must actively work to eliminate pathways of introduction and every other management recommendation developed. All of these require new actions on top of already overwhelming work loads. Outreach strategies should be carefully crafted to ensure their enthusiastic support. First, this audience must be educated as to the threat to the resource. They must clearly understand all aspects of identification, spread, control and prevention. Finally, they must be prepared to share their knowledge with others. The most effective way to reach implementers is to both reach them with the message directly and to have their administrator also ensure that they will adopt the appropriate actions.

Most implementers need more information than any of the target audiences. They need to understand the impacts and threats, the vectors of spread, the life history of the organism, the methods of control, any cleaning or disinfection protocols, how the public can help or hurt the effort, how to present to the public and much more. They will need fact sheets, clearly defined protocols, research results, information on support resources and outreach materials for public distribution. Implementers will best be reached through conferences and meetings, publication in professional journals, professional society meetings and publications, agency meetings and briefings and the like. It is not realistic to envision reaching many implementers through personal contact. PowerPoint presentations with support materials will likely be an effective tool for reaching these individuals. Web-based information and field identification guides/manuals are other important tools. Combining these efforts with communication directly from administrators will increase their impact.

Ultimately, the “public” needs to be completely integrated into the effort to control spread. However, the public is a broad group of people that must be broken into subgroups with targeted information. Although each segment of the public will receive the message through different venues, the basic objective is the same for all. Any reduction in spread will require cleaning, disinfecting or some other action on the part of certain segments of public. Modifying peoples’ behavior is a difficult task in that they are being asked to take action as opposed to just understanding the problem. This requires adoption of social marketing techniques in addition to education or outreach.

III. Objectives

Social marketing efforts are those that are specifically designed to change behavior by identifying the points of resistance and addressing these "costs" to the individual. Successful social marking convinces the target audience to take some sort of action that will "cost" them time or convenience; this happens because they perceive that the benefits gained are more valuable than the cost associated. This requires clear definition of the threat of NZ mudsnails, both current and potential. In addition, it must be demonstrated that the effort they invest will have a beneficial outcome. Key to this effort will be the ability to recommend practical actions. Establishing "pride of accomplishment" in those who participate can achieve a great breakthrough in this effort. Once this pride is established, an incentive is created for non-participants join the "better" group. Organizations such as the Federation of Fly Fishers, American Rivers, Trout Unlimited and others can be enlisted to help disseminate pertinent information to their members.

Another key to the social marketing effort will be to develop consumer materials that are specifically designed to elicit the desired outcome. There is a large body of work that defines the attributes of successful efforts and this will be used to craft effective tools and materials. Finally, the use of "celebrity" spokespersons will help to establish that it is "cool" to be a part of the solution.

An effective tool to be used in educating the public is to integrate invasive species education into school programs. Although teachers are provided with a host of materials and programs, there are significant opportunities to provide them with useful educational products. Any success in educating students will be very effective in a broader sense as they, in turn, educate their parents and other adults.

Many public and private organizations are already reaching out to the public with regular education messages about NZ mudsnails and aquatic invasive species in general. Any further education and outreach efforts on NZ mudsnails requires partnering with these existing efforts wherever possible. Success in this effort requires the broadest possible outreach mechanisms. Additionally, repeated messages often are much more effective than a single exposure so a saturated effort will produce far better results.

NZ mudsnails are a serious threat and must be addressed as such. However, outreach and education efforts must be handled with care to avoid confusing target audiences. There is a constantly growing list of aquatic invasive species that are invading North American waters. It is very difficult if not impossible for the average citizen to be aware of each individual species and in some situations people may feel overwhelmed by multiple messages each focused on single species. Therefore, it is important that the NZ mudsnail efforts be integrated into larger campaigns whenever possible. For example, "Stop Aquatic Hitchhikers"™ is a national branding campaign organized by the USFWS to address all aquatic invasives and in particular pathways associated with outdoor recreation. It is important that all NZ mudsnail efforts focus on those pathways with this existing campaign both to utilize the awareness that already exists and to support the branded concept.

Education and outreach efforts also must recognize that unlike invasive species with long and well-defined histories of major economic and ecological impacts (e.g., zebra mussels);

III. Objectives

NZ mudsnail impacts may "underwhelm" many audiences. For example, current findings for NZ mudsnail impacts mostly involve impacts to other invertebrates, nutrient cycling, etc. versus, for example, direct correlation to population crashes within valued fisheries. Furthermore, many current concerns about economic impacts from NZ mudsnails are more related to management actions to prevent spread (e.g., hatchery closures) rather than direct effects from the snails (i.e., those particular impacts would not exist if efforts to control the snails ceased). These factors may result in challenging "so what?" questions from target audiences, and in particular for those that seek answers in simple "sound bites." Education and outreach messages will need to find a balance between providing sufficient information to explain why concern still exists (e.g. explanation of lag times, food web connections, etc.) versus losing audiences with too much information; and a balance between over-exaggeration of risks versus failure to convince audiences that they should be concerned.

Table 1. **List of target audiences, outcomes, and possible vehicles for achieving those outcomes**

Audience	Outcome	Message and Means
Resource allocators (politicians) (may want to know about the priority relative to other invasive species)	• Allocate resources (personnel, funds, statements of intent, etc.)	**Message**: The New Zealand mudsnail is a real and serious threat to resources and the economy. (We don't know the threats, but we need to contain the threats, so we have to find out what they are.) **Means**: executive summary of the plan, PP presentations directly to resource allocators and key staffers, celebrity spokespeople
Agency administrators (some of whom might be resource allocators and set agendas for agencies)	• Make informed management decisions or direct the resources appropriately	**Message**: (Message should be similar to that above but with added case histories and suggestions such as creating a state ANS plan and rapid-response plan.) **Means**: executive summary, full plan, briefings to key staffers, international organizations, celebrity spokespeople, PP presentations with case histories (maybe about other invasive species)
Implementers (managers, biologists)	• Make wise daily operational decisions (prevention, detection) • Become additional communicators to the public	**Message**: The New Zealand mudsnail is a real and serious threat. You are an important part of the discoveries we make. You can make a difference (detection, monitoring, communicating to the public, raising awareness of ANS in general). **Means**: reports, presentations at professional meetings (such as American Fisheries Society), agency administrators, interagency meetings, division meetings, state ANS coordinators
Public with the following subgroups: • **Anglers** (or "keenly interested" stakeholders to include conservation groups) • **Other water resource Users** (recreationists, equipment operators, etc.) • **General** (such as those on the Lewis & Clark trail) • **Educators** • **Youth**	• Take personal responsibility for reducing spread of New Zealand mudsnail • Initiate change on a higher level	**Message**: Invasive species can be bad. You could be part of the problem. You can take action. (The action part may differ by subgroup: clean your gear and don't haul bait; if it doesn't look familiar, let someone know; etc. The action needs to be short and simple) **Means**: editorial coverage in magazines appropriate for each subgroup, celebrity spokespeople, manufacturing companies (stickers on boats, reels, and waders; John Deere and Caterpillar), insurance companies, trade organizations, radio spots (For youth) state REA coordinator, stations at watershed festivals and kids days, coloring or comic book, video game

Media, including Internet	• Broad dissemination of messages	**Message:** The New Zealand mudsnail is a real and serious threat. You are an important part of the discoveries we make. You can make a difference (detection, monitoring, communicating to the public, and raising awareness of ANS in general). **Means:** Press kits, suggested storylines, field trips with specific writers or broadcasters, website messages, blogs

2. Examples of Outreach Efforts

Several partnerships have evolved in the last five years to develop outreach materials targeting recreational users about the possibilities of moving NZ mudsnails to new uninfested waters. Listed below are examples:

a. Watch cards, brochures, posters, and signs

U.S. Fish and Wildlife Service developed watch cards that provide an alert about NZ mudsnails, explain how to identify them and collect samples, and instruct who to contact for new discoveries. Several versions of these cards have been distributed to a variety of audiences, including biologists and other professionals, recreational users, and participants in Lewis and Clark Bicentennial Commemoration events.

Idaho Department of Fish and Game and Idacorp, the power company, with support from the U.S. Bureau of Reclamation, the U.S. Fish and Wildlife Service, and Idaho State Parks and Recreation developed laminated signs with a cartoon NZ mudsnail, titled "Stop the Mudsnail!" The signs were distributed to various state and federal land agencies in the west.

Alaska Department of Fish and Game, Federation of Fly Fishers and the U.S. Fish and Wildlife Service created a "Most Unwanted" flyer titled "Alert! Dangerous Invader." The flyers were distributed to all the fishing guide services in Alaska to warn them of possible invasion and give them precautions to take with their clients.

b. Web sites

Montana State University maintains a website on NZ mudsnails with funding from the U.S. Fish and Wildlife Service. There are searchable maps of known and reported locations in the western U.S, information about biology and ecology, minutes from national meetings, pictures and a comprehensive bibliography. The website can be found at: http://www.esg.montana.edu/aim/mollusca/NZ mudsnail/

Several state wildlife agencies also have NZ mudsnail alerts or pages on their websites.

c. Workshops and conferences

There have been four New Zealand Mudsnails in the Western USA conferences, held in 2001, 2002, 2003 and 2005 at Montana State University in Bozeman. The minutes for these conferences which have information on current research, are available on the website above.

The Colorado Division of Wildlife and the U.S. Fish and Wildlife Service held a one-day workshop in April 2005 for over 100 biologists from federal, state and local agencies as well as private organizations and companies, on identification, biology and ecology of NZ mudsnails. The purpose was to provide information for field biologists to look for, identify and report NZ mudsnail sightings in the state.

d. Wash stations
Montana Department of Fish, Wildlife and Parks has purchased one permanent wash station and one mobile wash station for use at strategic locations in Montana where NZ mudsnails occur.

e. General ANS materials
There are many other publications and outreach efforts that feature NZ mudsnails along with other aquatic invasive species, giving guidance on how to avoid spread. Some examples include the "Threats to the West" brochure by the Western Regional Panel and "Aquatic Hitchhikers" by the Utah Division of Wildlife Resources.

3. Objective 5 Implementation

a. Fund staff in every State to do field outreach regarding NZ mudsnails and other invasives.

b. Coordinate with other programs such as the 100th Meridian Initiative and zebra mussel efforts.

c. Develop press kits and outreach materials.

d. Create sound bites that are understandable to the public.

e. Develop a canned template (in Adobe Illustrator or other usable application) so that information can be easily adapted.

f. Fund a website that is "public friendly." Provide dedicated support and have an outreach person to coordinate information and efforts.

4. Objective 5 Research Needs

a. How effective are existing NZ mudsnail education and outreach methods in changing behavior of target audiences?

IV. Implementation Plan

Section II of the NZ Mudsnail NMP contains chapters on each of the five objectives which include ideas for implementing education, management and research actions. In Section III, all of the suggested action items are brought together and prioritized below.

A. Priorities for Implementation

Tables 2, 3, and 4 give primary, secondary and tertiary priorities for suggested actions. Page numbers for location of the action item in the text are in parentheses.

Table 2. Primary Priorities for Implementation

Objective	Action Item
Objective 1. Pathways and Vectors	**Implementation** 1.1) Develop risk assessment of different pathways. 1.2) Develop guidance or criteria for risk and impact assessments 1.3) Support and expand New Zealand Mudsnail in the Western USA database, maps and web site to include eastern U.S. populations. 1.4) Facilitate coordination with USGS Nonindigenous Species database in Gainesville, FL **Research** 1.R1) Are there specific habitat types and/or environmental conditions that completely preclude establishment of NZ mudsnails? Are there environmental/habitat parameters that make an area more vulnerable to invasion? 1.R2) How can relative risk of introduction and establishment of NZ mudsnails in uninfested waters be quantified?
Objective 2. Detecting Populations	**Implementation** 2.1) Create a national web-based database for easy retrieval on NZ mudsnail sampling efforts (methods, frequency, detection limits) including those where NZ mudsnails have not been detected. 2.2) Increase coordination with agencies and other biologists to get more timely input on new populations 2.3) Develop list of local and national sources of taxonomic expertise for identifying potential NZ mudsnail populations and publicize widely. **Research** 2.R1) Evaluate different detection methods in different habitat types to provide a way for establishing confidence in data that people submit. 2.R2) Monitor existing NZ mudsnail populations on a precise schedule to understand populations trends and their response to environmental factors. 2.R3) Establish baseline data in States which currently have NZ mudsnail populations.
Objective 3. Prevention, Control and Management	**Implementation** 3.1) Develop a hatchery certification system to indicate whether facilities are positive for NZ mudsnails and/or do not appear to have NZ mudsnails and are employing adequate prevention strategies 3.2) Write a model provision for States that requires HACCP plans for aquaculture seeking permits

	Research 3.R1) Develop effective and ecologically-sound control methods in the mechanical, physical, chemical and biological control arenas 3.R2) Continue to test efficacy of current treatments of gear and determine whether a treatment must kill all mudsnails or simply get them to release from the gear. 3.R3) Develop and test prevention methods for water and gear enabled transport for a variety of ANS so that anglers and field crews don't have to use multiple disinfectants or choose to prevent the transmission of one ANS over another.
Objective 4. Ecological and Economic Impacts	**Implementation** 4.1) Develop sources of funding for research, including contacts with foundations and coordination among agencies. **Research** 4.R1) Investigate the effects of NZ mudsnails on community structure and food webs (both vertebrates and invertebrates) and ecosystem function. 4.R2) Investigate the effects of NZ mudsnails on vertebrates at higher trophic levels, including trout and waterfowl.
Objective 5. Outreach and Education	**Implementation** 5.1) Raise awareness to audiences associated with identified pathways 5.2) Develop corps of volunteer anglers who can provide one-on-one technical assistance to other anglers regarding prevention methods and effective control techniques **Research** 5.R1) How effective are existing NZ mudsnail education and outreach methods in changing behavior of target audiences?

Table 3. Secondary Priorities for Implementation

Objective	Action Item
Objective 1. Pathways and Vectors	**Implementation** 1.5) Identify additional pathways **Research** 1.R3) Using genetic markers, determine pathways of NZ mudsnail spread in the U.S. 1.R4) How important are different human-mediated recreational vectors to the spread among watersheds: boat transport, angler movements, swimmers, etc.? 1.R5) How important are different vectors associated with economics activities: Fish aquaculture, fish hatcheries, water Use and transport? 1.R6) Which suspected pathways have had the most prominent role in actual introductions of NZ mudsnails in the U.S? a) among watersheds, b) within watersheds 1.R7) For those fish species used in aquaculture and that will consume live snails, what is the maximum time period that NZ mudsnails can live within the digestive tract and still pass through as viable organisms? 1.R8) What are the ranges of natural dispersal rates/distances that have been documented for NZ mudsnails upstream and downstream from initial infestations, and what physical factors affect those rates and distances? 1.R9) Once NZ mudsnails occur in on tributary of a watershed, what is the likelihood that they will eventually occupy all reaches of the entire watershed that support their habitat needs.
Objective 2. Detecting Populations	**Implementation** 2.4) Review existing local, state, federal databases and/or collections of macroinvertebrate samples (focused on watersheds where intentional NZ mudsnail sampling has not occurred). 2.5) Conduct further outreach to watershed groups and government agencies collecting benthic invertebrate samples regarding identification and data gathering. **Research** 2.R3) Develop estimates of detection probabilities for a variety of substrates, ecoregions, and sampling methods and sampling designs. 2.R4) Develop standardized techniques for detecting low abundance NZ mudsnail populations and for estimating densities in established populations.
Objective 3. Prevention, Control and Management	**Implementation** 3.3) Develop a model/rule that will help State agencies and private organizations do HACCP plans. 3.4) Develop State rapid response plans. 3.5) Develop a protocol for responding to new occurrences of NZ mudsnails. 3.6) Provide tools such as wash kits or wash stations instead of providing information only. **Research** 3.R4) What is the specificity of parasite biocontrol agents against native alternative hosts? 3.R5) What population demographic models can be developed to show under what parameters a parasite biocontrol agent would control NZ mudsnail populations and to what degree? 3.R6) What is the effect of trematode parasite biocontrol agents on other hosts in the life cycle? 3.R7) Is the risk of chemical, physical, or biological control worth the benefits of NZ mudsnail control? 3.R8) Will chemical or physical control techniques have acceptable ecological

	impacts?
Objective 4. Ecological and Economic Impacts	**Implementation** 4.2) Develop a protocol for pre/post-impact studies (ecological and economic) that can be applied consistently to new locations when incipient NZ mudsnail invasions are found. **Research** 4.R3) Determine whether the costs of control and management of NZ mudsnails are significant? This should be compared with a no control option with anticipated effects on recreational opportunities, loss of revenue to local economies, construction, enforcement, signage as well as ecological impacts.
Objective 5. Outreach and Education	**Implementation** 5.3) Develop a list server discussion group for those interested in sharing information on NZ mudsnails. 5.4) Develop list of local and national sources of taxonomic expertise for identifying potential NZ mudsnail populations and publicize widely. 5.5) Develop a plan for public awareness of control measures, including biological, chemical and physical, and the potential benefit of their application. 5.6) Develop educational materials that address the reality that NZ mudsnails invasions have not been linked to conspicuous declines in native fish populations but also provide concrete evidence of negative impacts along with analogous stories of other invasions where such measurable impacts took years to hit (at a point where many management options were no longer available). 5.7) Develop press kits and outreach materials 5.8) Create sound bites that are understandable to the public. 5.9) Coordinate with other programs such as the 100th Meridian Initiative and zebra mussel efforts. **Research**

Table 4. Tertiary Priorities for Implementation

Objective	Action Item
Objective 1. Pathways and Vectors	**Implementation** **Research** 1.R9) Are NZ mudsnails being distributed by biological supply houses?
Objective 2. Detecting Populations	**Implementation** **Research**
Objective 3. Prevention, Control and Management	**Implementation** 3.7) Develop a model interagency/interstate agreement for monitoring and efficacy of control/containment efforts on existing occurrences of NZ mudsnails in waters that cross state lines. **Research**
Objective 4. Ecological and Economic Impacts	**Implementation** **Research**
Objective 5. Outreach and Education	**Implementation** 5.10) Develop a key to Pacific Northwest aquatic snails with an emphasis on identifying nonnative snails such as NZ mudsnails, Chinese mystery snails, etc. 5.11) Fund staff in every State to do field outreach regarding NZ mudsnails and other invasives. 5.12) Develop a canned template so that information can be easily adapted. 5.13) Fund a website that is "public friendly: Provide dedicated support and have an outreach person to coordinate information and efforts. **Research**

Table 5. Action Item Implementation Table:

Prioritized action items that are either in progress or slated for implementation during federal fiscal years 2005 and 2006 are summarized in tabular form, and correspond to numbered action items listed in the preceding three priority tables (in parentheses).

Actions Funded in Thousands of Dollars					
Related Objective	Action	Funded By	Implemented By	FY2005	FY2006
Objective 1: Identify Foci, Pathways and Vectors	NZ mudsnail web site management (1.3)	USFWS - R6	Montana State University	$6	
Objective 1: Identify Foci, Pathways and Vectors	Development of NZ mudsnail risk assessment in Madison River (1.1)	USFWS – R6	Montana State University	$18.5	
Objective 1: Identify Foci, Pathways and	Identifying sources and dispersal pathways of NZ mudsnail spread	USFWS – R6	Washington State University	$28	
Objective 2: Develop Methods of Detecting New Populations	Early detection surveys for NZ mudsnails in western Washington and Oregon (2.R3)	USFWS – R1	USFWS	$15	
Objective 2: Develop Methods of Detecting New Populations	Green River survey, Utah (2.R3)	USFWS – R6	Utah State University	$12	
Objective 3. Prevention, Control and Management	Research and development of control strategies for NZ mudsnails at fish hatcheries (3.R1)	USFWS – R1; USGS	University of Idaho/Idaho CFWRU	$25	$25
Objective 3. Prevention, Control and Management	Development of an angler-based outreach program for preventing the spread of a newly established NZ mudsnail population in the Deschutes River watershed, Oregon (5.1)	USFWS – R1	Portland State University		$10
Objective 3. Prevention, Control and Management	Preventing upstream invasions of NZ mudsnails through manmade structures (3.R1)	USFWS – R6	Colorado State University	$20	
Objective 5. Education and Outreach	NZ mudsnail training for biologists in Colorado (5.1)	USFWS – R6;	CO Division of Wildlife	$1.88	

Appendix A

Biology and Ecology

Life History and Tolerances

Life History and Reproductive Biology

The reproductive biology of NZ mudsnails suggests that it has the potential for rapid colonization. This species is dioecious (separate male and female sexes) and ovoviviparous (Winterbourn 1970a, b, Wallace 1978). Ova develop within the female's brood pouch and are born into the environment as fully functional animals. In New Zealand, female snails may be either sexual or asexual. Asexual female snails undergo a reproductive process known as parthenogenesis whereby eggs are produced that are competent to develop without fertilization. Parthenogenetically derived offspring are genetically identical to the female (i.e., clones). Clonal populations are polyploid and almost entirely female (Wallace 1992, Dybdahl and Lively 1995a). Clonal reproduction in NZ mudsnails increases the probability of success of introductions because populations can be established by only one female. Although NZ mudsnails reproduce both sexually and asexually in New Zealand, exotic populations are entirely clonal (Zaranko et al 1997, M. Dybdahl unpublished data). Only a few males have been documented from populations in Europe (Wallace 1978, 1979, 1992), and North America (Cada, unpublished data, M. Dybdahl, unpublished data), but males may comprise up to ten percent of populations in Australia (Wallace 1978).

Life history traits are a direct function of environmental conditions, as is the case for most poikilothermic organisms. Females reach maturity in about 3 to 6 months (J. Jokela, personal communication, Dybdahl and Kane *in prep*). Year-round reproduction and recruitment is possible where environmental conditions are moderate (Winterbourn 1970a, Schreiber et al. 1998). A study of one lake population in Australia showed that individual females brooded a maximum of 42 embryos, and the population brooded up to 81,000 embryos per m^{-2} (Schreiber et al. 1998). Snails reproducing in less productive, cooler, and more saline waters have variously been shown to produce fewer offspring, undergo longer gestation periods, and grow more slowly (Winterbourn 1970a, Harman 1974, Lassen 1979, Dorgelo 1991, Jacobson and Forbes 1997, Dybdahl 1997). In U.S. populations, Snake River individuals matured at larger sizes and carried bigger broods in river sites compared to spring sites, and brood sizes reached a maximum at 78 embryos (Dybdahl 1997).

Predicting invasiveness of NZ mudsnail populations is difficult because their performance varies widely among different clones and with environmental conditions. Individual clones in New Zealand differed significantly in size at maturity, brood size and susceptibility to parasites (Jokela et al. 1997a, Dybdahl and Lively 1998). These same traits may exhibit plastic variation under different environmental conditions, and these clone-specific traits remain distinct (Negovetic and Jokela 2001, Dybdahl and Krist 2004). A thorough understanding of the complex interplay between physiological tolerances and resulting life history traits of individual mud snail clones in invading populations is important for managing and predicting the spread of this species in North America.

Invasive populations of NZ mudsnails tend to be comprised of a single clonal genotype, but populations in the native range and Australia are comprised of a diverse array of clones (Dybdahl and Lively 1995, Dybdahl and Emblidge, *in prep*). In New Zealand, the diversity of clones allows NZ mudsnails to occupy a range of habitats. Genetic analyses indicate that European populations are comprised of three clones that occupy different parts of the range (Hauser et al. 1992, Jacobson et al. 1996, Dybdahl 1997). "Euro A" is found in freshwaters across broad areas of continental Europe, "Euro B" is found in estuaries in the Baltic Sea, and "Euro C" is found in Great Britain. In Lake Ontario, New York, a single clone identical to Euro A has been identified (Dybdahl and Emblidge *in prep*). This clone has also been found in Lake Erie and Lake Superior. In the western US, a single clonal genotype identical to a clone found in Australia has been identified (Dybdahl and Emblidge *in prep*). A new clone has been identified from a short section of the Snake River, Idaho (Dan Gustafson, personal communication). Each clone is likely to possess unique characteristics that affect invasiveness.

Environmental Tolerance

The environmental tolerances of NZ mudsnails as a species are very broad and increase the risk that this species might be capable of wide-spread colonization. This species is found in a wide range of aquatic habitat types, including diverse temperature, osmotic, flow, and disturbance regimes. However, ecological genetic studies of this species suggest that individual clonal lineages may have either narrow or broad ecological preferences or tolerances. Consequently, although clonal reproduction provides reproductive assurance for small numbers of colonizing individuals, clonal reproduction could limit the invasiveness of these snails depending on the environmental tolerances of clones in invading populations.

Most clones seem to have narrow environmental tolerances, but one European clone has invaded over a wide geographic range. In New Zealand, clonally reproducing females are derived from sexual populations in the same lakes (Dybdahl and Lively 1995a), and are endemic to specific lakes and habitats (Dybdahl and Lively 1995a, Fox et al. 1996, Jokela et al. 1999, reviewed in Jokela et al 2003). Clones seem to fix a narrow range of preference and tolerance for different habitat conditions. In New Zealand narrow preferences often result in distinctive habitat utilization among clones within a single system so that, for example clones found in the littoral zone of a lake may be distinct from the clones found in deep-water macrophyte beds in the same system (Fox et al. 1996, Jokela et al. 1999). Thus, asexual populations in New Zealand seem to be able to occupy a range of habitats because of a high diversity of clones, each of which is specialized on specific habitats. On the other hand, genetic analyses indicate that European populations are composed of only three clones (Hauser et al. 1992, Jacobson et al. 1996, Dybdahl 1997), but the colonization of freshwaters in continental Europe has been by a single broadly tolerant clonal lineage (Jacobson and Forbes 1997). Thus, the invasiveness and success of this species is likely to be a function of the clone present and local environmental conditions.

Although individual clonal lineages have been shown to have distinct habitat preferences, temperature, salinity, and flow tolerances for the species in general appear to be broad. It has been documented from nearly every freshwater habitat in New Zealand, including lakes, rivers, streams and springs. In lentic systems, the snails utilize a variety of microhabitats including; littoral shore lines (Quinn et al. 1996, Schreiber et al. 1998), submerged weed beds (Dorgelo 1987, Talbot and Ward 1987, Cogerino et al. 1995, Cunha and Moreira 1995, Quinn et al. 1996, van den Berg et al. 1997), deep bentho-pelagic regions (Zaranko et al. 1997), and floating vegetation masses (Vareille-Morel 1983, Ribi 1986, Ribi and Arter 1986). Snail habitat usage in lotic systems is similarly broad with no real trend towards specific preferences although several authors found that NZ mudsnail densities were highest in areas with an abundance of fine substrate (Tomkins and Scott 1986, Cunha and Moreira 1995), aquatic macrophytes (Lucas 1959, Dorgelo 1987, Cogerino et al. 1995, Cunha and Moreira 1995, Savage 1996), and low velocities (Jowett et al. 1991). However, densities were high in cobble habitat in Yellowstone National Park (Kerans et al. 2005). In New Zealand streams, NZ mudsnails are not common in streams prone to periods of sediment-moving flood flows (Winterbourn 1997, Holomuzki and Biggs 1999).

NZ mudsnails also seem to have wide temperature tolerances. Upper thermal tolerance (expressed as LD50) as determined in experimental analysis was found to be 32 C for snails acclimated at 15 C (Quinn et al. 1994). The lower lethal thermal tolerances of NZ mudsnails are less clear. In Norway, NZ mudsnails were restricted to estuaries in southern Scandinavia, leading to the conclusion that winter temperature may limit colonizing success (Okland 1979, Okland 1983). However, the species' ability to survive in the intermountain west of North America and in continental fresh waters of northern Europe, where mean temperatures at or below freezing persist for three to four months, suggest that it is capable of acclimating to temperatures below those encountered in its native range. In laboratory experiments, Hylleberg and Siegismund (1987) report that NZ mudsnails are less tolerant than European hydrobiid to temperatures less than 0 C in fresh water, but that nearly 100% survival was observed at 0 C for saline water. Analysis of life-history traits suggests that the suitable temperature range for successful invasion of the western U.S. clone is much narrower than indicated by these survival tolerance studies (Dybdahl and Kane *in review*). Lower temperatures caused slower rates of development and lower fecundity than higher temperatures, but had a weaker effect on size at maturity. Hence, overall fitness showed a peak at 18^{o} C and declined at cooler and warmer temperatures.

Hylleberg and Siegismund's (1987) field surveys found winter mortalities of NZ mudsnails approaching 100% followed by rapid recolonization in northern European estuaries. Similar, seasonal density fluctuations have been documented from other European populations (e.g. Dussart 1976, van den Berg et al. 1997), and in rivers in Yellowstone National Park where temperatures fluctuate seasonally but winter temperatures are moderated by the influence of geothermal inputs (Kerans et al. *in press*). However, it should be noted that several other researchers found that changes in density did not correspond to seasonal temperature extremes (Dorgelo 1987, Cunha and Moreira 1995).

Additionally, population fluctuations have been observed in regions of Australia where climates are more stable (Quinn et al. 1996, Schreiber et al. 1998).

Observations of drastic fluctuations in naturalized temperate-zone populations (with population low points correlated with winter months) would seem to implicate winter water temperature as a direct limiting factor (temperatures below a certain threshold are lethal). It may be that population fluctuations associated with seasonal changes in temperature are an indirect effect of temperature on some aspect of snail biology. The reproductive rate of NZ mudsnails is directly related to temperature (Winterbourn 1970a, Dybdahl and Kane *in review*). In lab experiments, the western U.S. population of NZ mudsnails survived and reproduced at a constant temperature of 12^{0}C, but optimal temperatures for reproduction and population growth were about 18^{0}C (Dybdahl and Kane *in review*). However, in field experiments performed during winter in Yellowstone National Park, NZ mudsnails reproduced when temperatures averaged approximately 7^{0}C (M. Dybdahl, unpublished data). Populations with low reproductive rate are more vulnerable to the effects of disturbances, so that perceived seasonal die-offs may be simply a temperature-dependant reproductive lag following an undetected disturbance. In addition, mathematical models developed for NZ mudsnails suggest that such drastic fluctuations may result from factors intrinsic to the population dynamics of the snail and not necessarily be related to extrinsic environmental drivers (Kerans 2003).

NZ mudsnails are euryhaline organisms. Populations are known from both brackish and fresh water habitats in New Zealand and Europe (Winterbourn 1970a, b, Lassen 1979, Okland 1983, Hylleberg and Siegismund 1987), and the recently discovered population in the Columbia River estuary near Astoria OR. Winterbourn (1970a) reported a maximum acute salinity tolerance of 21 parts per thousand (ppt) (seawater being 32 ppt) in laboratory trials. However, he collected NZ mudsnails from the field at salinities approaching 27 ppt (Winterbourn 1970a). Jacobson and Forbes (1997) found that two clones collected from Europe had broad salinity tolerances and were able to feed, grow, and reproduce at salinities ranging from 0 to 15 ppt but that the salinity optima for these functions occurred at 5 ppt. The clone found in the Columbia River estuary experiences salinities that vary daily from 0 to 32 (Dybdahl and Kane *in review*).

NZ mudsnail individuals can tolerate the high frequency of disturbance (scouring events) characteristic of many South Island, New Zealand, river systems (Winterbourn 1981), but population sizes are strongly affected by flow regime. The animals' tough shells, small size, and hydrodynamic shape make them likely to survive scouring flows. In an experimental flume, Holomuzuki and Biggs (2000) found that only 8% of NZ mudsnails were dislodged because they behaviorally shifted to deeper, more stable sediments as flows increased. Mortality rates associated with the effects of dislodgement and downstream displacement were very low. Scouring flows merely serve to redistribute snails rather than kill them outright (Holomuzuki and Briggs 1998). Nevertheless, local densities of NZ mudsnails were inversely correlated with disturbance frequency in New Zealand streams (Holomuzuki and Briggs 1998).

NZ mudsnails seem tolerant of most anthropogenic impacts. Several authors have noted that it does well in moderately eutrophic systems (Dorgelo 1987, Scott et al. 1994). In stable habitats with high nutrient loads and abundant macrophytes, mud snails dominated (relative abundance of 90%) invertebrate communities in New Zealand streams (Duggan et al. 2002). In Australia, the success of NZ mudsnail introductions seems to be associated with agricultural runoff and nutrient inputs (Scheiber et al. 2003). However, in some instances, elevated nutrient levels were shown to adversely affect population densities and individual survival (Tomkins and Scott 1986, Hickey and Vickers 1994).

Similar to most gastropods, NZ mudsnails are sensitive to dissolved metals and a range of lethal and sub-lethal effects have been documented (Harman 1974, Moller et al. 1994, Dorgelo et al. 1995, Golding et al. 1997). Golding et al. (1997) demonstrated that snails undergo avoidance and immobility behavior in response to elevated levels of dissolved arsenic. However, the levels of arsenic used in the Golding experiments were one to two orders of magnitude greater than those found in thermal waters with naturally occurring high levels of arsenic (Savka 1993). Dorgelo et al. (1995) found that elevated levels of cadmium and copper resulted in a decrease in growth rate of approximately 50 % for NZ mudsnails. These findings suggest that NZ mudsnails have metal tolerances similar to those observed for other gastropods (Harman 1974).

It is apparent from the literature that the NZ mudsnail is a species that has unusually broad habitat tolerances. Furthermore, the typical clone found in western U.S. rivers has spread across a range of habitats and environmental conditions from Oregon to Montana to Arizona and California. Habitats include a variety of rivers and streams, although two lakes (Hebgen in Montana and Crawley in California) in heavily colonized river systems have not been colonized (M. Dybdahl, unpublished data, D. Becker personal communication). Hence, it is difficult to envision abiotic environmental conditions that would pose an obstacle to the further spread of this species in the middle latitudes of North America.

Population and Community Ecology

Abundance

NZ mudsnails have been found to be the numerically dominant organism or gastropod in lakes and streams in New Zealand (Hopkins 1976, Towns 1981a, b, Talbot and Ward 1987, Scott et al. 1994), Europe (Cogerino et al. 1995, Cunha and Moreira 1995, Savage 1996), and Australia (Schreiber et al. 1998). However, the species is not numerically dominant in all New Zealand systems, especially in small streams and rivers. For example, Winterbourn (1978) found that the snail was absent from small forested streams on the South Island. Rounick and Winterbourn (1982) found it present in only eight of 43 low-order streams surveyed throughout New Zealand, and Scrimgeour and Winterbourn (1989) found that it comprised less than 0.1% of organisms collected from the Ashley River, New Zealand.

As discussed earlier, densities of NZ mudsnails can fluctuate widely. In Australia, densities ranged between seasonal highs of 50,000 m^{-2} during summer and lows of 1800 m^{-2} during the winter (Ponder 1988, Schreiber et al. 1998). Similarly, densities often undergo broad fluctuations in Europe (Siegesmund and Hylleberg 1987, Dorgelo 1987, van den Berg 1997, Savage 1996) where water bodies freeze in winter and are re-colonized the following spring. However, Quinn et al. (1996) and Schreiber et al. (1998) found that NZ mudsnail densities fluctuated between 1800 and 50,000 individuals m^{-2} in Lake Purrumbete (Australia) where seasonal temperature fluctuations are considerably less extreme. Similar patterns have been observed in New Zealand (Talbot and Ward 1987, Scott et al. 1994). Patterns of density fluctuations observed over such a range of climates may indicate that factors other than environmental parameters contribute to mudsnail population demography. As mentioned previously, fluctuations could result from factors intrinsic to snail biology (Kerans 2003).

Reports of NZ mudsnails reaching densities in excess of 100,000 individuals m^{-2} exist in the literature, the most spectacular of which is a report of 800,000 individuals m^{-2} (Lucas, 1959 in Dorgelo, 1987). Investigations of the snail's distribution in the Greater Yellowstone Ecosystem have shown that it is capable of reaching densities approaching 300,000 individuals m^{-2} at some locations (Kerans et al *in press*), and over 500,000 individuals m^{-2} in one geothermally-influenced stream (Hall et al 2003). Population densities fluctuate seasonally in Yellowstone rivers, reaching highest levels in July or September, and very low levels in March (Kerans et al *in press*).

Feeding Habits

The feeding habits of NZ mudsnails have been subject to a number of experimental investigations. Generally, they are thought to be grazers (herbivores of attached periphyton) and/or detritivores (consumers of decaying plant and animal material). Hanlon (1981) found that NZ mudsnails feeding on decaying deciduous leaf material grew faster and fed more rapidly on soft-cuticle leaves such as willow and aspen than on tougher beech and oak leaves. However, it was not known if the snails in this experiment were feeding on the decaying plant material itself or on associated bacteria. Similarly, Haynes and Taylor (1984), while conducting a food-preference experiment, found that NZ mudsnails were attracted to stones soaked in crushed amphipods, indicating that they feed on decaying animal material. Snails were also attracted to stones colonized by algae. NZ mudsnail spent more time on patches with periphyton than those without periphyton in a field experiment using slate tiles, (Kerans et al. in prep.). Both these results indicate the importance of herbivory in this species.

Herbivory in NZ mudsnail have been documented in field experiments (Towns 1981a, Rounick and Winterbourn 1983, Winterbourn and Fegley 1989). Rounick and Winterbourn (1983) found that NZ mudsnails grazing rates were considerably less than those observed for mayflies, stoneflies, and caddisflies in a New Zealand stream, but that its assimilation efficiency (amount of food material converted to animal biomass) was higher than that observed for these taxa. Additionally, Winterbourn and Fegley (1989) reported that NZ mudsnail affected periphyton biomass on their experimental tiles.

The feeding habits of NZ mudsnails are, like its life history traits and environmental tolerances, potentially quite variable in nature. Indeed, the above discussion makes it clear that everything from diatoms to detritus is fair game. Given that NZ mudsnail are capable of exploiting a wide array of resources, this species will potentially compete with a wide array of organisms that fill different trophic niches in North American aquatic systems.

Interspecific interactions—competition and facilitation

The effect of NZ mudsnails on the invertebrate fauna of New Zealand, Europe and Australia is largely unknown. However, in North America, a few studies demonstrate complex and variable interactions between NZ mudsnails and other gastropod and macroinvertebrate species, including both negative (competition) and/or positive (facilitation) interactions. The mechanisms of competition may include both interference (direct agonistic encounters, e.g. for space) and exploitation (e.g. for resources).

NZ mudsnails may compete with other gastropods, and potentially reduce gastropod biodiversity. Bowler (1991) and Bowler and Frest (1992) speculated that NZ mudsnails could have an impact on the diversity of Snake River gastropods. In the Snake River (Idaho), NZ mudsnail have invaded areas occupied by five threatened or endangered species of native aquatic snails (Federal Register 1992, Richards et al. 2001). Competition between mudsnails and native gastropods could be for resources or for moisture refugia (undersides of rocks) during water fluctuations in this highly regulated system (Bowler 1991). Consistent with this speculation, the distributions of the threatened Bliss Rapids Snail (*Taylorconcha serpenticola*) and NZ mudsnails did not overlap in field studies (Richards et al. 2001). The densities of NZ mudsnails and a narrowly endemic snail in a Yellowstone stream (*Pyrgulopsis robusta*) were positively correlated among sites, but preliminary evidence suggested that they were negatively correlated in another stream (Riley et al. *in review*).

NZ mudsnails may also affect other grazing macroinvertebrates. NZ mudsnails negatively affected the survivorship but not the growth of mayfly species in experiments conducted in a tributary of the Madison River in Montana (Cada 2004). However, a survey of NZ mudsnails and native benthic macroinvertebrate densities across four Yellowstone rivers revealed few negative correlations as expected if interactions were negative (Kerans et al. 2005 *in press*).

Interference competition is common in studies of gastropods and other benthic animals. Brown et al. (1994) observed that at high densities, agonistic interactions between snails (in the form of shell-shaking activity) increased significantly in an experimental population of *Physella*. Similarly, Cuker (1983) found that at high gastropod density, the densities of attached invertebrates such as Chironomidae were lower. It was thought that high snail densities resulted in the dislodgement of these organisms and their fixed benthic feeding retreats. Interference competition, for space as an example, may result from extremely high densities known from invasive NZ mudsnail populations. Densities of 100,000 to 800,000 individuals m^{-2} are known from Europe (Lucas 1959 in Dorgelo 1987), and measured densities over 500,000 individuals m^{-2} in the Greater Yellowstone Ecosystem (Hall et al. 2003). At such high densities, NZ mudsnails may simply physically exclude other grazing organisms by occupying attachment space.

Experimental studies demonstrate that NZ mudsnails interfere with other benthic macroinvertebrates. The numbers of mayflies foraging for periphyton on the tops of tiles declined in a short-term (2 h) field experiment when NZ mudsnails were present (Kerans et al. in prep.). In addition, in a longer (2 mo) experiment in the Madison River in Yellowstone National Park, densities of macroinvertebrates from many different functional feeding groups were lower on tiles with high abundances of NZ mudsnails (Kerans et al. 2005). Both these results suggest that interference was the mode of competition.

Exploitative competition for periphyton also may occur between NZ mudsnails and other benthic invertebrate grazers. Studies have shown that snails are capable of changing both algal density and community composition in stream systems (review in Hawkins and Furnish 1987; see also Winterbourn and Fegley 1989, Attwood 1996, Kjeldsen 1996). Kjeldsen's work in lowland streams of Denmark demonstrated that gastropod grazing was an important factor in regulating periphyton biomass. In New Zealand, Winterbourn and Fegley (1989) remarked that NZ mudsnails were capable of influencing their studies of periphyton, necessitating control measures. Death (1991) showed that NZ mudsnails depressed periphyton biomass in experiments in several New Zealand streams. In the Yellowstone area, studies of competition between NZ mudsnails and a narrowly endemic snail (*Pyrgulopsis robusta*) showed that both species reduce algal food resource levels, and that NZ mudsnails have a negative effect on the growth of *Pyrgulopsis robusta* (Riley et al. *in review*). Laboratory and field experiments between the threatened Bliss Rapids Snail (*Taylorconcha serpenticola*) and NZ mudsnails suggest they compete (Richards and Kerans, in prep). Finally, Cada and Kerans (in review) showed that periphyton biomass was lower in reaches of a Madison River tributary where NZ mudsnail abundance was higher. Reduction of periphyton biomass may negatively affect other invertebrates and have wide-ranging affects on ecosystem processes in streams dominated by bottom-up interactions (Carpenter et al. 1985).

Not all interactions among NZ mudsnails and other species are negative. Schreiber et al. (2002) showed that NZ mudsnails facilitated the colonization of macroinvertebrates in an experiment in an Australian stream. In a Yellowstone stream, periphyton biomass increased with NZ mudsnail density, suggesting self-facilitation (Riley et al. *in review*). Further study in this system showed that a likely mechanism is fertilization, which suggests that the negative effects of resource exploitation by the invasive may be negated (Riley et al. *in preparation*).

The role of species interactions in the success and impact of NZ mudsnails is far from clear. Mathematical models show that both positive and negative interspecific interactions between NZ mudsnails and other species may add even greater complexity to already complex interactions (Kerans, 2003). Low densities of NZ mudsnails may attract some macroinvertebrates (Schreiber et al 2002), but high abundance might inhibit colonization of other species, as shown in the Madison River (Kerans et al. 2005). Low and intermediate densities may stimulate algal growth and ameliorate the impact of invasion, but high densities can have negative effects on resources shared with native species. More studies are needed to determine the effect that invasion will have on native community structure. Specific studies of competitive interactions in North American populations are also needed**.**

Interspecific interactions—Predators and Parasite

Predators and parasites of NZ mudsnails occur in both native and introduced populations, but their effect in regulating population size is not well known. In New Zealand and Australia short-finned and long-finned eels (*Anguilla australis* and *A. dieffenbachii*), brown trout (*Salmo trutta*), and bullies (*Gobiocloneus spp.*) have been reported to consume NZ mudsnails, but it is unclear if these accounts represent actual targeted feeding behavior or if individuals found in stomach samples were accidentally ingested with other prey (Burnet 1969, Cadwallader 1975, McDowall 1991, Levri 1998). There is no strong evidence that predators control populations in New Zealand (Nyström and McIntosh 2003)

It has been suggested that North American Ostariophysine fish (Catostomidae and Cyprinidae), which posses pharyngeal teeth, may be capable of consuming and crushing the shell of this species. However, in many streams where NZ mudsnails have invaded in North America, fish lack these specialized adaptations to feed on snails. In a tributary of the Madison River, Montana where NZ mudsnail densities were moderate (20,000 individuals/m^2), only one NZ mudsnail was found in the stomachs of 29 brown trout and 17 sculpin (*Cottus bairdi*) (Cada 2004) when most stomachs contained several food items. On the other hand in the upper Madison River right outside the boundaries of Yellowstone National Park, stomachs of mountain whitefish (*Prosopium williamsoni*) contained many NZ mudsnails (W. Dwyer, United States Fish and Wildlife Service, personal observation). These results suggest that some fish species may avoid NZ mudsnails, whereas others eat them readily

Even if some trout and other species eat NZ mudsnails they may gain little energy because studies have shown that NZ mudsnails are capable of passing through the digestive canal of trout alive and intact (Bondesen and Kaiser 1949, Haynes et al. 1985). Additionally, it has been shown that NZ mudsnails offer little or no energy compared to other common food items to those fish successful in crushing its shell (Ryan 1982). Thus, there may be consequences to fish that eat NZ mudsnails over other food sources. In an experiment done in a tributary of the Madison River where areas exist where NZ mudsnails have low and high abundances, the sculpin lost more weight when caged in areas where NZ mudsnails were abundant than where NZ mudsnails were rare (Cada 2004). On the other hand, no difference in weights was recorded for brown trout. More experimentation and field studies are needed to determine how NZ mudsnails influence fish communities.

Mudsnails are infected by up to 14 species of trematode parasites in New Zealand (Winterbourn 1974, Jokela and Lively 1995a and b, Dybdahl and Lively 1998), and because these parasites castrate or sterilize their hosts, they could have important population regulatory effects. These trematode parasites have a two-host life cycle; they alternate between the snail and the digestive tract of a vertebrate host. In the snail, the parasites undergo asexual proliferation in the gonad, thereby eliminating reproduction in infected individuals. None of these parasites have been found in introduced populations in Europe or North America. One of these parasites (*Microphallus* sp.) is known to occur in the Australian introduced range (Schreiber et al. 1998, Emblidge and Dybdahl *in preparation*). In Europe, the colonization in very low frequencies of NZ mudsnails by a European castrating trematode species has been reported (Gerad et al. 2003). Preliminary studies of parasite populations in streams of the Greater Yellowstone Ecosystem showed that a digenetic trematode of fish might Use NZ mudsnails as an intermediate host (Beck et al. 2004).

One particularly well-studied trematode of mudsnails, *Microphallus sp*., seems to have strong population regulatory effects on its snail host populations. *Microphallus sp*. uses a variety of water birds as a vertebrate host to complete its life cycle. For example, dabbling waterfowl such as the native grey duck and the introduced mallard become infected after consuming snails found on the surfaces of aquatic macrophytes (Winterbourn 1974). The parasites reproduce sexually in the vertebrate host, and eggs pass into aquatic habitats where they may be ingested by snails. Whether a parasite egg leads to infection of a particular snail is genetically determined. For example, parasites are locally adapted to infect snails from the same lake or habitat (Lively 1989, Lively and Jokela 1996, Lively and Dybdahl 2000). Furthermore, parasite populations differ in their infectivity to different snail clones (Dybdahl and Lively 1995b, Jokela et al. 1997b, Dybdahl and Lively 1998, Dybdahl and Krist 2004). These specific interactions, along with the castration of members of different clones, lead to large fluctuations in population density in specific clones over time (Dybdahl and Lively 1998). However, we know of no support for the proposition that parasites control population size in this species in its native range.

Appendix B

State and Federal Regulations and State ANS Plans

Note: As with all State and Federal regulations, they are current at a specific time. These are currently in effect at the time of approval of this management plan.

Alaska: While NZ mudsnails are not specifically classified as prohibited under Alaska law, AS 16.05.241 gives the Board of Fisheries the authority to prohibit and regulate the live capture, possession, transport and release of native and exotic "fish" (which is defined to include aquatic invertebrates) or their eggs. With that authority, 5 AAC 41.070 - which prohibits the import of "fish" for the purpose of stocking or rearing in the waters of the state - was developed. Another statute, AS 16.05.920(a), states that unless permitted by regulation adopted under AS 16.05, a person may not take, possess, transport, or purchase "fish" or any "fish" part (again with fish defined to include aquatic invertebrates). Alaska does have an approved state ANS management plan which identifies NZ mudsnails as one of the highest potential threats. Key elements of that plan include development of a NZ mudsnail education and outreach plan, and NZ mudsnail monitoring and detection. The Alaska Department of Fish and Game has partnered with the USFWS to increase sport fish industry awareness in particular and the public in general with posters, ID cards, preserved samples and presentations at outreach events.

Arizona: A pending proposed rule change to R12-4-401 of the Arizona Administrative Code would add NZ mudsnails as a restricted wildlife species, making them illegal to possess, transport, or import without special license. Currently, Arizona law requires granting of an exemption or special license to possess "aquatic wildlife" (which includes mollusks) unless the specimens are intended for use in the aquarium trade or for restaurants or markets licensed to sell food. Arizona does not have an approved state ANS management plan at this time.

California: Title 14, Section 671 (c)(9) of the California Code of Regulations classifies NZ mudsnails as "restricted." Therefore, it is unlawful to import, transport, or possess live NZ mudsnails in the state except under permit issued by the California Department of Fish and Game. California does not have an approved state ANS management plan at this time.

Colorado: The Colorado Wildlife Commission listed the NZ mudsnail as a prohibited species in 2003 in the Colorado Wildlife Regulations, Chapter 0, Article 012 B.1. The regulation prohibits the release, importation, transportation, stocking, sale, acquisition or possession for release without authorization in writing by the Colorado Division of Wildlife. Colorado DOW has a statewide NZ mudsnail management plan in place. Because NZ mudsnails were identified in Boulder Creek and in a private aquaculture facility on the Creek, the Colorado DOW closed the area to fishing for 90 days and worked to create a Best Management Practices document to keep the snails from being transported through fish stocking. Colorado does not have a state ANS management plan.

Hawai'i: NZ mudsnails are not specifically classified as "prohibited", "restricted," or "conditionally-approved" under Chapter 4-71 of the Hawaii Administrative Rules. As a result, live snails can not be imported or possessed in the state without a permit until classified by the Board of Agriculture. The Hawai'i state ANS management plan defines four management classes for species already in the state. NZ mudsnails are included under a separate section listing species not yet established in Hawai'i (note that the plan includes NZ mudsnails as a potential marine aquatic invasive species but does not include them in the list of potential inland water aquatic invasive species). The Hawai'i plan does not include any action items specific to NZ mudsnails, but many of its general action items regarding prevention, detection, and control are applicable.

Idaho: NZ mudsnails are not specifically regulated by the state of Idaho. However, under Idaho Administrative Code 13.01.10.100, "no person shall import, export, transport into or cause to be transported within, release or sell within the state of Idaho any living wildlife including wildlife eggs" without first obtaining a permit from the Idaho Department of Fish and Game. Further, the Director of IDFG is prohibited from issuing permits for species that pose a threat to wildlife in Idaho either via threat of disease, genetic contamination, or displacement of/competition with existing species. The exceptions to these provisions do not apply to NZ mudsnails. Idaho does not have an approved state ANS management plan at this time. However, Idaho has formed a state invasive species council and is drafting a state invasive species management plan. Idaho is also addressing NZ mudsnails by Hazard Analysis and Critical Control Point (HACCP) plans for state fish hatcheries and field crews as well as improving public awareness with signage and other outreach materials.

Kansas: New Zealand mudsnails are specifically prohibited from being possessed, released, or imported under Kansas Administrative Rules 115-18-10. The Kansas ANS Management Plan, completed in 2005, lists NZ mudsnails as a priority species of special concern.

Montana: New Zealand mudsnails are listed as prohibited in the Administrative Rules of Montana (ARM 12.6.2201-2230). NZ mudsnails may not be possessed, sold, purchased, exchanged, or transported in Montana, except as provided in Montana Code Annotated 87-5-709. Permits for the possession of NZ mudsnails can be issued to colleges, universities or government agencies if they are being used for scientific research. In the Montana ANS Management Plan, completed in 2002, NZ mudsnails are listed in Priority Class 2: species that are present and established in Montana and have the potential to spread in Montana. There are limited or no known management strategies for these species. These species can be managed through actions that involve mitigation of impact, control of population size, and prevention of dispersal to other water bodies.

Nevada: The list of prohibited species in Nevada Administrative Code (NAC) 503.110 does not include NZ mudsnails. Nevertheless, state statute NRS 503.597 prohibits any person to receive, bring or have brought or shipped into the state, or remove from one stream or body of water in the state to any other, or from one portion of the state to any other, or to any other state, any aquatic life or their spawn, eggs, or young, except with written consent and approval by the Nevada Department of Wildlife. NAC 503.140 lists a number of taxonomic groups that are exempt from this general statutory restriction, although even exempt species cannot be released to the wild without written NDOW authorization. Although this list of exempted species does not exempt NZ mudsnails specifically, it does exempt "saltwater fish, crustaceans, or mollusks." It is unclear whether that category would be applied to NZ mudsnails given their estuarine range. Nevada does not have an approved state ANS management plan at this time.

New York: The state of New York has no specific laws or regulations governing the control or prohibition of NZ mudsnails within the state. However, Environmental Conservation Law (ECL) does have a general provision that would cover NZ mudsnail as "wildlife." ECL 11-0507 (3) states: "No person shall willfully liberate within the state any wildlife except under permit from the department. The department may issue such permit in its discretion, fix the terms thereof and revoke it at pleasure. These provisions do not apply to migratory game birds, importation of which is governed by regulation of the department."

Oregon: NZ mudsnails are not specifically classified as "prohibited", "controlled", or "non-controlled" under Oregon Administrative Rule 635-056. As a result, live snails are prohibited from being possessed; imported; purchased; sold; exchanged; or offered for sale, purchase or exchange without a state permit until they are classified. The Oregon ANS Management Plan does not include any action items specific to NZ mudsnails, but many of its general action items regarding prevention, detection, and control are applicable. The first version of the Plan completed in 2001 classified NZ mudsnails under Management Class 1, which are species not known to be present in Oregon but with a high potential to invade, or reported in Oregon with limited populations. The Plan assigns prevention of introduction and eradication of pioneering populations as appropriate management activities for this class. However, in 2003 the Oregon Invasive Species Council removed NZ mudsnail from its list of "100 Most Dangerous Invaders Threatening Oregon" because the snails' expansion within the state no longer met the list's criteria of absence and/or range restricted to a small area. As a result, revisions currently under development for the Oregon ANS Management Plan would shift NZ mudsnails to Management Class 3, which are species that are established throughout Oregon with impacts but no available or appropriate management techniques. "These species warrant further evaluation and research to ascertain potential control and to prevent establishment in new waterbodies."

Pennsylvania: In Pennsylvania, though no regulations pertain specifically to NZ mudsnail, one general regulation would cover this species. While the language used is for fish, the term "fish" actually applies to any animal placed into Pennsylvania waters. Chapter 73.1, Title 58 of the Pennsylvania Code, Part II – Fish and Boat Commission, states, "Species of fish may not be transported into this Commonwealth from another state, province or country and liberated in a watershed of this Commonwealth without previous written permission from the Commission, nor may a species of fish be transferred from waters in this Commonwealth into another drainage of this Commonwealth where this particular species is not always present without prior written consent from the Commission. Inspection for species composition or presence of disease, or both, will be required at the discretion of the Commission on all lots of fish transported into this Commonwealth." This regulation can be accessed online at: http://www.pacode.com/secure/data/058/chapter73/s73.1.html

Utah: NZ mudsnails are a prohibited species that may not be collected, imported, transported or possessed without procuring a variance to Wildlife Resources Rule R657-3, Collection, Importation, Transportation and Possession of Zoological Animals. Utah does not have a state ANS management plan, however many staff have been trained in HACCP planning. Utah Division of Wildlife Resources staff chair the Utah ANS Task Force, a partnership of agencies and other interested stakeholders to increase the education and outreach on ANS across the state.

Washington: Washington Administrative Code 220-12-090 classifies NZ mudsnails as "prohibited." Live specimens of prohibited species can not be possessed, purchased, sold, imported, transported, propagated, or released without a permit. This restriction does not apply to the transportation or release of organisms in ballast water (note that Washington has other statutory and administrative requirements addressing ballast water management). Prohibited aquatic animal species that are captured in state waters and not immediately returned to the water from which they were captured must be killed before removing the prohibited aquatic animal species from within the riparian perimeter of the body of water. State requirements are also established regarding removal of aquatic vegetation and transport of water. The Washington ANS Management Plan classifies NZ mudsnails under Management Class 2, which are species that are present and established in the state. Assigned management activities for this class include mitigating impact, controlling population size, and preventing dispersal to other water bodies. The plan does not include any action items specific to NZ mudsnails, but many of its general action items regarding prevention, detection, and control are applicable.

Wyoming: NZ mudsnails are specifically prohibited from being imported, possessed, confined and/or transported into the state of Wyoming as specified by the Wyoming Game and Fish Commission Chapter 10 – Regulations for Importation, Possession, Confinement, Transportation, Sale and Disposition of Live Wildlife, Section 5, subsection b (i) (C). Wyoming does not have a state ANS management plan. The Wyoming Game and Fish Department is training staff in HACCP planning and requires that fish imported from out of state come from a facility that has an approved HACCP plan in place.

Appendix C

Detecting NZ Mudsnails Using Power Analysis

Given that many methods are currently being used in benthic surveys, the most important criterion for use is to define some level of probability of detection. An example of a probability of detection level used for hydrobiid snails was that used by Richards et al. (2005) for *Taylorconcha* sp. in the Snake River, Hells Canyon. This species primarily occupies cobble habitat. They tested a simple 20-cobble count method and estimated that it had a detection probability of > 0.95 for densities $\geq$ 1 *Taylorconcha* sp./m^2 on cobble habitat in the Snake River below Hells Canyon Dam using ten 20-cobble counts. Cobble counts could also work for NZ mudsnails, but estimates of detection probabilities would have to be established based on the number of NZ mudsnails found on cobbles relative to other substrates. Thus detection level densities of NZ mudsnails using cobble counts would have to be quite high and would be most useful after NZ mudsnails had become well established in a system. Ideally it is desired to detect NZ mudsnails when they first become established at low densities and when they are technically a 'rare' species in the community composition. There is a large selection of literature on methods for detecting rare species, including freshwater mollusks (Merritt and Cummins 1996, Green and Young. 1993, Strayer and Smith 2003, and others).

Determining if a water body contains NZ mudsnails when they occur in low densities can be difficult. It would be extremely difficult to state that no NZ mudsnails are present at a site, because that would require sampling every square centimeter of substrate. Therefore, the ability to find the snails depends on sampling design and effort. Informal searches that state for example, "researchers failed to detect NZ mudsnails in a 2 hour search" are of limited value. In a formal sampling design, instead of saying that NZ mudsnails are truly absent from a site, it can be stated that NZ mudsnails were not detected given a certain amount of effort using a certain design, or that a design with 'x'% chance of detecting a NZ mudsnail population with a density of 'y'/m^2 failed to find any (Strayer and Smith 2003). Power analysis easily can provide a means to state the later, given the assumption that NZ mudsnails are distributed in the system that approximates a Poisson distribution (Green and Young 1993). This is usually the case when the probability of collecting an individual in any given sample is low (rare) and/or populations are aggregated (i.e. when we want to detect NZ mudsnails at low densities). All that is needed for power analysis is:

1) An agreed upon probability of detection (power; 1-β),
2) An agreed upon detection level or density (for example 1 individual/$10m^2$ of substrate), and
3) The appropriate number of quadrats sampled.

In marine invertebrate studies the generally accepted standard power is 1- β = 0.80 (Green and Young 1993), while in freshwater invertebrate studies a power of 0.85 is often used (Merritt and Cummins 1996). Commonly used detection level probabilities (density, # NZ mudsnails/quadrat) for rare species is more arbitrarily defined, but a value of 0.1 individual /sample unit size has been suggested as a maximum value (Green and Young 1993).

The following graph (figure 3) gives a range of sample sizes needed for four levels of probability of detection (1-β = 0.75, 0.80. 0.85. and 0.90) at a given mean density per quadrat. For example, to state that there was an 85% chance of detecting NZ mudsnails at a density of 0.05 individuals/quadrat (e.g. 1 individual/20 m^2 using a 1.0 m^2 quadrat) a sample size of 38 quadrats would be required. Also, if this protocol was followed and 38 quadrats were sampled and no NZ mudsnails were collected, it would be statistically correct to state that, "following this sampling design, there was an 85% confidence that NZ mudsnail density was < 1 snail/20 m^2."

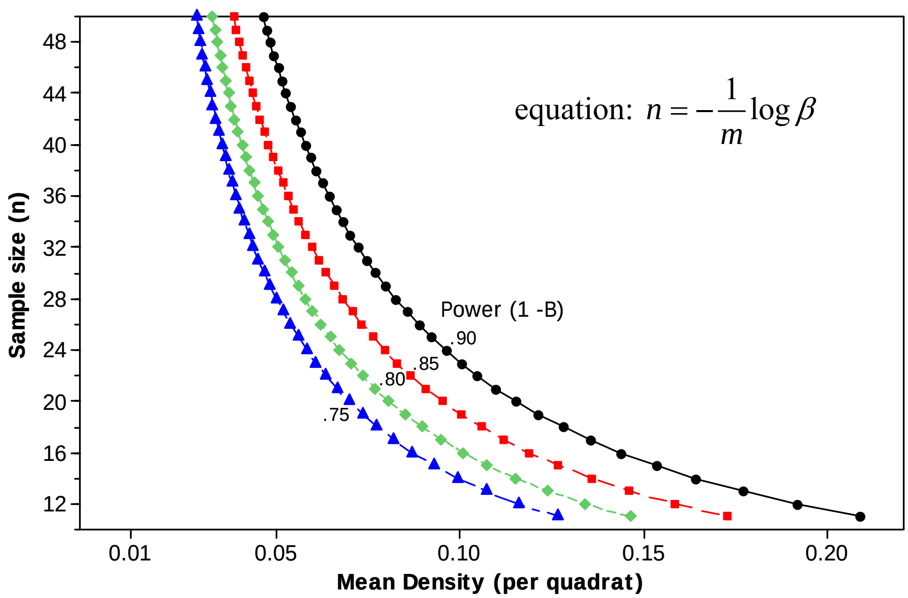

Figure 10. Necessary sample size *n* as a function of mean density (per quadrat) for various degrees of power 1 – β, when sampling the Poisson distribution (modified from Green and Young 1993).

Appendix D

NZ Mudsnail Risk Assessment and Management Criteria For the Hagerman National Fish Hatchery

(*Excerpted from: Burge, H. and P.J. Heimowitz. 2005. Risk Assessment and Risk Management Recommendations for New Zealand mudsnail introduction from Hagerman NFH steelhead releases. US Fish and Wildlife Service.*)

Introduction

Current policy of the Department of the Interior (Executive Order #13112, Invasive Species) and the US Fish and Wildlife Service requires that programs ". . . *not authorize, fund, or carry out actions that it believes are likely to cause or promote the introduction or spread of invasive species in the United States or elsewhere unless, pursuant to guidelines that it has prescribed, the agency has determined and made public its determination that the benefits of such actions clearly outweigh the potential harm caused by invasive species; and that all feasible and prudent measures to minimize risk of harm will be taken in conjunction with the actions*."

The New Zealand mudsnail (NZ mudsnail) was first discovered in the Snake River, Idaho in 1987 (Richards 2002c). In 2002, they were discovered in springs at the Hagerman National Fish Hatchery in Idaho, prompting concerns about subsequent spread through hatchery operations. This report evaluates the risk of such spread and associated risk management considerations relative to Executive Order #13112.

In Idaho, NZ mudsnail are widespread in the Hagerman Valley, Snake River, and Snake River reservoirs, but are absent from Brownlee Reservoir (Shinn 2002). Although numerous sites have been surveyed in Northern Idaho, the only recorded finding occurred in 2001 when a single NZ mudsnail was collected in Kalispell Creek. Up to date locations of NZ mudsnail positive sites in Idaho and other western states is available at http://www2.montana.edu/NZ mudsnail/

In the Clearwater Basin the Service sampled 14 sites in the South Fork Clearwater River (Burge 2003a) in addition to more than 50 sites sampled throughout the Clearwater basin by Dr. Gustafson of Montana State University. None of these surveys have found NZ mudsnails in the Clearwater basin. Note that there is no standardized, nationally-accepted sampling protocol for NZ mudsnail surveys; therefore there are no methods for establishing statistical confidence regarding absence determinations. The Nez Perce Tribe did find NZ mudsnails in Sweetwater Creek, a tributary to Lapwai Creek in the Lower Clearwater drainage in July, 2003.

The Service also sampled 34 sites in the Salmon River basin (Burge 2003b) to add to Dr. Gustafson's 55 survey sites. NZ mudsnails were found at 6 locations in the Salmon River basin. The Service found a few NZ mudsnails approximately 50 miles below the Pahsimeroi River in the main Salmon River at Tower Rock Recreational Site. A moderate to abundant population is known to occupy the mouth of the Pahsimeroi River and Pahsimeroi Hatchery, and the Service found a moderate number of snails approximately 2 miles above the Hatchery in the Pahsimeroi River. Last September moderate numbers of NZ mudsnails were found in the main Salmon River below the Pahsimeroi, however they could not be relocated on a recent trip in April, 2004. Most significantly, an abundant population was discovered approximately 40 miles above the Pahsimeroi in Squaw Pond. Squaw Creek Steelhead Pond is a man-made, earthen pond adjacent to Squaw Creek, approximately 1 km upstream from its confluence with the Salmon River (Osborne and Rhine 2000). It is used by Idaho Department of Fish and Game (IDFG) as an acclimation and release site for steelhead smolts from Magic Valley Hatchery. The pond is also used as a fish-out pond for rainbows stocked from Nampa Hatchery. Both Nampa and Magic Valley hatcheries are infected with NZ mudsnails, to varying degrees. The pond is drained early each fall after steelhead are released, but when full, the pond supports a healthy growth of algae. When surveyed in September, 2003 the pond was already drained although ground water maintained a small pool and outflow channel. NZ mudsnails were observed on the substrate and within the algal mats remaining in the pool. In April, 2004 the pond was recently refilled, the flow in the outflow channel was increased, and pools had been created in the channel to provide a release site for steelhead smolts. Although NZ mudsnails were abundant in the outflow channel prior to refilling the pond (Fred Partridge, pers. comm.) we only observed them in a small side channel below the recently created pools. The increased flow had obviously flushed snails in the main outflow channel downstream.

The potential for NZ mudsnail introduction to the upper Salmon River (Stanley area) from currently occupied areas in the Salmon River (Pahsimeroi area) is greater than in the South Fork Clearwater River. The upper Salmon is typically used by wading anglers (Tom Curet pers. comm.) that are more likely to carry NZ mudsnails in the laces of their wading boots, whereas South Fork Clearwater anglers are mostly bank fishermen that seldom get in the water. Also an angler unknowingly transporting NZ mudsnails from the lower Salmon River would have a shorter travel time to the upper Salmon River than to the Clearwater River. The longer travel to the upper Clearwater River from a NZ mudsnail positive site would provide a longer duration for desiccation, which is one of the preferred methods for control of NZ mudsnails (Richards *et al*. 2004). Additionally because of the recreation aspect of the Stanley basin the upper Salmon River is used more heavily by rafters and floaters than the upper Clearwater basin. Recreationalists also do day float trips downstream from Stanley, but it is unlikely they get far enough downstream and into areas known to have NZ mudsnails, then unknowingly transport them back upstream.

NZ mudsnails have no natural predators in North America, whereas in New Zealand several native fish species frequently eat them (Richards 2002a). They have been found in catchable size rainbow trout at Hagerman State Hatchery, (IDFG data) and in whitefish stomachs (Cada 2003). Dwyer (2001) force fed NZ mudsnails to rainbow trout and observed an 85% survival rate after 2.5 hours in the trout; he also predicted some survival out to about 5 hours. Food passage time for trout is variable ranging from 6 or 8 hours up to 24 hours, and is affected by temperature, fish size, and other factors. So given these factors, a possible scenario could be for a fish to ingest a live snail prior to loading into a distribution truck and either passing a live snail in the tank during transport or in the stream after release. Either way the snail could be introduced into that water body and potentially start a population via cloning.

Currently Hagerman NFH is releasing steelhead into the Salmon River at several locations above and below the farthest known upstream infestation at Squaw Creek Steelhead Pond. Although NZ mudsnails can move upstream volitionally as noted earlier, any point in the main stem Salmon River downstream of Squaw Creek is particularly susceptible to invasion from that population. When the pond is drained in early fall, algae mats carrying NZ mudsnails are likely flushed downstream. It is interesting to note, however, that no NZ mudsnails were observed in Squaw Creek above the mouth or in the Salmon River directly below Squaw Creek. Lower Squaw Creek appeared to be suitable habitat and supported an abundant population of native *Physa* snails. Current Hagerman NFH stocking sites in the upper Salmon basin upstream of Squaw Creek include the Yankee Fork tributary and Sawtooth Hatchery. They also release steelhead into East Fork Salmon River and the Little Salmon River drainage, a tributary to the lower Salmon River. All of these sites have been used by Hagerman and other IDFG hatcheries as fish release sites for the past 10-15 years.

Potential Establishment

NZ mudsnails were initially found in the Hagerman Valley in 1987 by Dr. Peter Bowler (Richards 2002c). Hagerman NFH has been releasing steelhead into the Salmon River basin since 1978. We do not know exactly when NZ mudsnails colonized the springs at Hagerman, however based on the size of the population we can surmise that it was before they were first discovered in the fall of 2002. Nampa and Magic Valley Hatcheries, which are also infected to varying degrees with NZ mudsnails, also release fish into the Salmon River basin.

Recent releases from Hagerman NFH into the South Fork Clearwater River occurred in Newsome Creek and American River from 2001 to 2003 (Magic Valley Hatchery in 2000). There was a Hagerman NFH release into the Clearwater River in 1989, but the presence of NZ mudsnails at Hagerman NFH at that time is unknown. Hagerman NFH is the only station infected with NZ mudsnails that was programmed to directly release fish into the South Fork Clearwater River. While rainbow trout from Nampa Fish Hatchery (NZ mudsnail positive) are transferred to Clearwater Hatchery then redistributed into the South Fork Clearwater, IDFG is utilizing fish only from the clean part of Nampa Hatchery for this program.

There are several environmental factors that may prevent the colonization or limit the success of NZ mudsnails in the Upper Salmon and Clearwater rivers. Under higher water velocities (>.5 m/s) (Richards 2003; Lysne 2003) the long spiral shell of the NZ mudsnail causes it to wash away easily. While average water temperature of 7^{o}C did not prevent survivorship, growth, or reproduction, optimum growth occurs at 19^{o}C, so colder winter temperatures will slow population growth. Also, Dr. Gustafson (pers. comm.) theorized that ice formation and scouring may limit successful colonization. Recent observations suggest that the clone that has invaded the Western U.S. is a “river” clone and is unlikely to invade lakes or reservoirs in ecologically disruptive densities (Dybdahl 2002). Concerning the Snake River reservoir populations, Dybdahl (2002) suggested that they are not self-sustaining, but are maintained by immigration from riverine habitats, whereas the absence of NZ mudsnails from Brownlee Reservoir is possibly due to the large fluctuation zone and depths greater than 60 feet (Shinn 2002).

The South Fork Clearwater River has many of the features that would classify it as unsuitable habitat for widespread establishment of NZ mudsnails. However, there is always the possibility for a small population surviving in a pocket of suitable habitat. Given that possibility, a small colony could become the point of invasion, potentially seeding establishment of larger populations of NZ mudsnails in more suitable habitat downstream or a stepping stone to other waters.

While the upper Salmon River may also be unsuitable habitat, if a small colony was established upstream of Squaw Creek Steelhead Pond there is no increased risk of invasion into more suitable habitat downstream, due to the present occurrence of NZ mudsnails. Additionally there are other factors that add support to the theory of potentially unsuitable habitat in the upper Salmon River. The length of time that stocking into an area from infected facilities has been occurring must be considered. In the Salmon River, stocking from hatcheries has been occurring probably as long (greater than 20 yrs) as there have been NZ mudsnails in the facilities, whereas in the South Fork Clearwater River, stocking from Magic Valley Hatchery occurred in 2000 and from Hagerman NFH in 2001 to 2003. Also, the level (number of fish) of stocking in the Salmon River was much greater than in the Clearwater River. Approximately 900,000 steelhead are released annually into the upper Salmon River from Hagerman NFH, compared to 200,000 into the South Fork Clearwater River. While more than 20 years of large releases does not ensure that NZ mudsnails will not become established in the future, it does support the theory of low potential for establishment. Additionally, the lack of a contiguous population downstream of the two locations that currently have well established NZ mudsnail colonization in the Salmon River drainage help support the theory of unsuitable habitat. The Little Salmon River can also be grouped with the upper Salmon River regarding unsuitable habitat and the potential for downstream introduction of NZ mudsnails already present.

Water chemistry played a minor role (5%) in growth and reproductive rates, but may determine distribution (Dybdahl 2003). Hall *et al*. (2002) reported that NZ mudsnails production is highest in vegetated habitats, but cobble can also support high densities.

Schreiber *et al*. (2003) found that NZ mudsnails frequently occurred in sites draining catchments with multiple types of human activities (grazing, agriculture, towns). This is typical pattern for successful invaders (D'Antonio *et al*. 1999 in Schreiber *et al*. 2003). The pattern may not be related to disturbance, but to other factors. In its native habitat the NZ mudsnail occurs in higher densities in agricultural catchments than in forested catchments (Quinn and Hickey 1990 in Schreiber *et al*. 2003). These streams also have higher amounts of algae, which provide increased food resources, possibly leading to higher abundance of NZ mudsnails.

As a final note, adaptation and habitat change need to be considered when contemplating potential distribution of NZ mudsnails. Already endowed with phenotypic plasticity, genetic change in existing NZ mudsnail populations could lead to greater tolerance of habitats in Idaho that currently may not support establishment. Such genetic changes could be disseminated relatively rapidly given the snail's asexual method of reproduction. Similarly, future climate or habitat change as well as other broad-scale environmental changes could potentially transform isolated NZ mudsnail refugia into continuous and wide-ranging populations.

Risk Mitigation

Hagerman NFH has developed a Hazard Analysis and Critical Control Point (HACCP) Plans for both steelhead and rainbow trout production. These Plans provide a structured method to identify risks and focus procedures on minimizing the unintended spread of species through natural resource pathways. These Plans include visual inspections in all springs, rearing units, and at all phases of the rearing cycle. To date, the presence of NZ mudsnails has been confirmed in all the open springs and spring ponds at Hagerman NFH; however, they are not found in the egg incubation water or the water source Used for filling distribution trucks. They have not been observed in the inside rearing tanks or on raceway walls, however since a small number has been found in the head boxes and tailraces they have undoubtedly passed through the raceway (Kurt Schilling, pers. comm.). The raceways are also desiccated annually which contributes to the control of NZ mudsnails at the facility.

Fish are also checked for presence of snails in their stomach at several times during the rearing phase. To date, no live snails have been found in over 1,200 steelhead sampled annually and only recently (March 2004) two empty NZ mudsnail shells were found in steelhead from the upper deck at Hagerman NFH (Kurt Schilling, pers. comm.) Whether the shells were empty when ingested or live snails were digested is unknown; however, the incidence of snail consumption by steelhead is very low.

The HACCP Plans call for specific measure to be taken to reduce the risk of transporting snails off station. These measures include; using a clean water source to fill the distribution truck, taking fish off feed 48 hours prior to transport, and sweeping raceway floors and walls 24 to 48 hours prior to transport. Hatchery staff utilize large mesh screens on the dewatering tower of the fish pump to allow any NZ mudsnails to fall back into the raceways rather that be loaded into the transport truck. Staff also conduct visual checks of transport trucks and fish pump water and any NZ mudsnails, if seen, would be physically removed (Kurt Schilling, pers. comm.).

Even by instituting all the steps outlined in the Hagerman NFH HACCP Plans, there is no way to guarantee that NZ mudsnails will not be transported off station during fish stocking. The only way to guarantee no possible introduction from Hagerman NFH would be to curtail stocking. While this would work in the South Fork Clearwater River since Hagerman NFH is the only infected hatchery stocking there, in the upper Salmon River this management action would be pointless unless matched by IDFG for their infected hatcheries.

The HACCP Plan calls also for surveys of current release sites for the presence/absence of NZ mudsnails. The Clearwater and Salmon rivers were surveyed and plans are in place to establish annual monitoring sites in the Clearwater and upper Salmon rivers to see if NZ mudsnails colonize these areas in future years.

Risk Assessment
A long list of unknowns makes it difficult to quantify the risk of NZ mudsnail spread by Hagerman NFH operations. For example, what are the odds that NZ mudsnails will survive if introduced into new sites like the Clearwater and if they survive, will they cause ecological problems? Eventually, many of these issues will be addressed in the ANS Task Force National NZ Mudsnail Management and Control Plan and assessed in the Hatchery-based NZ Mudsnail Introduction Risk Assessment Model, both of which are currently under development. In the interim, the following criteria have been developed to assess the risk of NZ mudsnail spread by hatchery release operations. A hatchery release will likely cause or promote the spread of NZ mudsnails if**:**

- Evidence of live or dead NZ mudsnails in any quantity has been found associated with water Used in rearing or transport of subject fish, inside facilities that indicate availability for consumption by subject fish, or inside subject fish within the last 12 months, and;

- NZ mudsnails have not yet been found in the watershed of the tributary where the hatchery release is to occur.

Risk Management Recommendations
The above risk assessment involves a conclusion about likely risk based on a scientific analysis of available information. The rest of this report addresses the decision of how to manage this risk. This decision considers the science-based conclusions of the risk assessment, but also needs to factor in scientific uncertainty, mitigating circumstances (e.g., additional sources of risk), and other consequences of the decision (ecological, political, socio-economic, etc.).

The following factors were compiled and prioritized to guide decision-making for Hagerman NFH operations that are likely to introduce or spread NZ mudsnails into the South Fork Clearwater River, Upper Salmon River, and Little Salmon River. These factors should be used to determine whether continued hatchery release operations are justifiable despite a risk assessment conclusion that the operation will likely cause or promote the spread of NZ mudsnails. Note that these factors need to be reevaluated to determine if they are appropriate for guiding decision-making for other Pacific Region Fisheries operations, and modified accordingly.

1) **Ongoing stocking by other parties** (i.e. any advantage from not stocking from a Service hatchery is negated by practices in the watershed by other parties)

2) **Potential introduction from other vectors** (i.e. type and level of human recreation, natural waterfowl or fish movement, etc.)

3) **Contamination abundance/history of infected water, facility, and/or fish**

4) **Effectiveness of HACCP plan or control measure implemented at the infected facility**

5) **Habitat suitability** (i.e. water velocity, mean water temperature, ice formation and scouring, vegetation, substrate, nutrient loading, food availability, natural or man-caused habitat disruption, reservoir water level fluctuation, etc.), recognizing uncertainty due to potential changes in habitat quality or NZ mudsnail tolerance

6) **History of previous stocking for infected hatcheries** (i.e. number of fish and years, this may help support or refute a determination of habitat suitability)

7) **Contiguous NZ mudsnail populations downstream of established colonies** (this may help support or refute a determination of habitat suitability)

8) **Distance of nearest NZ mudsnail population**

9) **Public benefit of continuing the operation relative to the anticipated costs of resulting NZ mudsnail spread**

10) **Potential for development of a new invasion point or stepping stone population** (i.e. possibility of seeding unoccupied habitat downstream or an intermediate step for NZ mudsnails to reach a new water body)

11) **Natural resource or societal benefit of continuing the operation relative to the anticipated risks of resulting NZ mudsnail spread**

12) **Potential for development of a 'significant' population** (i.e. marginal habitat, pockets or fragmented suitable habitat availability, well established native snail or macroinvertebrate populations, etc.) (significant could be defined as one that may impact listed species or reach densities high enough to displace native invertebrates through spatial factors)

13) **Potential for continued stocking from infected Service hatcheries to promote continued stocking from infected facilities by other parties**

14) **Potential for continued operation to compromise other Service invasive species programs even if biological risk is inconsequential**

Literature Cited can be found in Appendix F: Bibliography

Appendix E

Controlling the Spread of New Zealand Mudsnails on Wading Gear

California Department of Fish and Game, Administrative Report 2005-02

The following procedures for cleaning NZ mudsnail infested wading gear can be followed upon exiting infested waters. Wading gear should be cleaned prior to leaving the site. If this is not possible then wading gear should be completely sealed inside a large plastic bag and cleaned before it is used in any other waters. Three different cleaning protocols have been tested and found to be effective using specific cleaning solutions.

1. Immersion Procedure

a. Remove wading gear upon exiting NZ mudsnail infested waters. Avoid allowing infested wading gear to come in contact with interior surfaces of vehicles or camping gear such as tests or trailers. NZ mudsnails can be transferred to any surface they come in contact with and they could later be transferred back to cleaned wading gear. Turn waders right side out and remove insoles from wading boots.

b. Place waders, wading boots, boot insoles and the streambed contact end of a wading stick, if used, in a container of sufficient size to allow the gear to be completely covered by a cleaning solution.

c. Pour sufficient cleaning solution into the container with the infested wading gear to completely cover the gear. It may be necessary to weight down the gear to ensure that it remains immersed in the cleaning solution.

d. Allow the wading gear to remain in the cleaning solution for at least 5 minutes.

e. Remove the wading gear from the cleaning solution one piece at a time and inspect it to make sure that all debris that could harbor NZ mudsnails has been removed from the gear as well as any NZ mudsnails that could be lodged in cracks or crevices. If necessary, Use a stiff plastic bristled brush such as a kitchen brush to remove any remaining debris and mud.

f. Rinse wading gear in clean water. Do not use water from the mudsnail infected source. This may reintroduce NZ mudsnails to the wading gear.

g. Return cleaned wading gear to its appropriate storage container.

2. Dry Sack Procedure

a. Remove wading gear upon exiting NZ mudsnail infested waters. Avoid allowing infested wading gear to com in contact with interior surfaces of vehicles or camping gear such as tests or trailers. NZ mudsnails can be transferred to any surface they come in contact with and they could later be transferred back to cleaned wading gear. Turn waders right side out and remove insoles from wading boots.

b. Place wader, wading boot and boot insoles into a dry sack (recommended size: 65 liter). Walking sticks will need to be cleaned separately outside of the dry sack to avoid rupturing the sack.

c. Add 8 to 10 liters of cleaning solution to dry sack and seal.

d. Pick up the dry sack and shake it back and forth using a rolling motion to ensure that the contents are thoroughly coated with the cleaning solution. Continue shaking for approximately 30 seconds.

e. Let dry sack sit undisturbed for at least 5 minutes. Then repeat the shaking and mixing for another 30 seconds.

f. Open the dry sack and remove the contents one piece at a time and inspect it to make sure that all the debris that could harbor NZ mudsnails has been removed from the gear as well as any NZ mudsnails that could be lodged in cracks or crevices. If necessary, use a stiff plastic bristled brush such as a kitchen brush to remove any remaining debris and mud.

g. Rinse wading gear in clean water. Do not use water from the mudsnail infected source**.** This may reintroduce NZ mudsnails to the wading gear.

h. Return cleaned wading gear to appropriate storage container.

3. Spray Bottle Procedure (Note: This procedure has only been tested using a copper sulfate cleaning solution)

a. Remove wading gear upon exiting NZ mudsnail infested waters. Avoid allowing infested wading gear to come in contact with interior surfaces of vehicles or camping gear such as tests or trailers. NZ mudsnails can be transferred to any surface they come in contact with and they could later be transferred back to cleaned wading gear. Turn waders right side out and remove insoles from wading boots.

b. Place waders, wading boots, boot insoles and the streambed contact end of a wading stick, if used, in a container of sufficient size to allow the gear to be easily accessed.

c. Using a standard one liter squeeze-trigger type spray bottle containing the cleaning solution, spray the wading gear to the point of saturation and runoff with the cleaning solution. Be sure to treat the inside of the wading boots as well as the outside. Use the stream setting to be sure and dislodge any debris from the wading boots. Be sure to treat both top and under side of gravel guards if they are permanently attached to the waders.

d. Allow the wading gear to set for at least 5 minutes with the cleaning solution on it. Remove the wading gear one piece at a time and inspect it to make sure that all debris that could harbor NZ mudsnails has been removed from the gear as well as any NZ mudsnails that could be lodged in cracks or crevices. If necessary, use a stiff plastic bristled brush such as a kitchen brush to remove any remaining debris or mud.

e. Rinse wading gear in clean water. Do not use water from the mudsnail infected source. This may reintroduce NZ mudsnails to the wading gear.

f. Return cleaned wading gear to appropriate storage container.

4. Cleaning Solutions

a. **Copper sulfate:** Dissolve 3.785 grams of copper sulfate pentahydrate crystals (99.1% purity) for each gallon of solution you want to make. This will achieve a concentration of 252 mg/L of copper in the cleaning solution.

b. **Benzethonium chloride:** Dissolve 7.57 grams of benzethonium chloride (97% purity) for each gallon of cleaning solution you want to make. This will achieve a concentration of 1.947 mg/L in the cleaning solution.

c. **Commercial Solutions Formula 409® Cleaner Degreaser Disinfectant:** Dilute the commercially available solution 1:1 with clean water to achieve the needed concentration for the cleaning solution (i.e. one gallon of Formula 409® Disinfectant to one gallon of water).

Appendix F

Bibliography

Attwood, S. W. 1996. The impact of grazing by *Neotricula aperta* (Gastropoda:Pomatiopsidae) on post-spate recovery of the algal aufwuchs in the lower Mekong River: changes in standing crop and species diversity. Natural History Bulletin of the Siam Society 44:61-74.

Armitage, K.B. 1958. Ecology of the riffle insects of the Firehole River, Wyoming. Ecology 39:571-580.

Beck, L., B. MacConnell, B. L. Kerans, and C. Hudson. 2004. Assessment of the New Zealand mud snail *Potamopyrgus antipodarum* as a potential fish disease vector. Report to the Fish and Wildlife Service. 12pp.

Bondesen, P. and E. W. Kaiser. 1949. *Hydrobia* (*Potamopyrgus*) *jenkinsi* (Smith) in Denmark illustrated by its ecology. Oikos 1:252-281**.**

Bowler, P. A. 1991. The rapid spread of the freshwater hydrobiid snail NZ mudsnail (Gray) in the Middle Snake River, Southern Idaho. Proceedings of the Desert Fishes Council 21:173-182.

Bowler, P. A. and T. J. Frest. 1992. The non-native snail fauna of the Middle Snake River, Southern Idaho. Proceedings of the Desert Fishes Council, 23:28-44.

Brown, K. M., K. R. Carman, and V. Inchausty. 1994. Density-dependent influences on feeding and metabolism in a freshwater snail. Oecologia 99:158-165

Burge, H.L. 2003a. Memorandum: Preliminary field survey on the presence/absence of the New Zealand mudsnail in the South Fork Clearwater River, Idaho, August, 2003.

Burge, H.L. 2003b. Memorandum: Field survey on the presence/absence of New Zealand mudsnails in the Salmon River basin, Idaho, October, 2003.

Burnet, A. M. R. 1969. A study of the inter-relationship between eels and trout, the invertebrate fauna and the feeding habits of the fish. Fisheries Technical Report of New Zealand No. 36.

Cada, C. 2003. Effects of *Potamopyrgus antipodarum* on trout and fish diets and growth. Presented paper. New Zealand Mudsnail in the Western USA: Conference, August, 2003.

Cada, C. 2004. Interactions between the invasive New Zealand mud snail, *Potamopyrgus antipodarum*, baetid mayflies, and fish predators. M. S. Thesis, 126 pp. Montana State University, Bozeman, MT

Cada, C. A. and B. L. Kerans. Community response to *Potamopyrgus antipodarum* invasion. In review.

Cadwallader, P. L. 1975. Feeding relationships of galaxiids, bullies, eels and trout in a New Zealand river. Australian Journal of Marine and Freshwater Research 26:299-316.

Carlton, J.T. and J.B. Geller. 1993. Ecological roulette: the global transport of non-indigenous marine organisms. Science 261:78-82.

Carpenter, S.R., J.F. Kitchell and J.R. Hodgson. 1985. Cascading trophic interactions and lake productivity. BioScience 35:634-639.

Cejka, T. 1994. First record of the New Zealand Mollusc NZ mudsnail (Gray 1843), (Gastropoda, Hydrobiidae) from the Slavak section of the Dunaj River. Biologia Bratislava 49:5657-5658.

Chavaud, L., J. K. Thompson, J. E. Cloern, and G. Thouzeau. 2003. Clams as CO_2 generators: the *Potamocorbula amurensis* example in San Francisco Bay. Limnology and Oceanography 48:2086-2092.

Cogerino, L., B. Cellot and M. Bournaud. 1995. Microhabitat diversity and associated macroinvertebrates in aquatic banks of a large European river. Hydrobiologia 304:103-115.

Cook, D.B. and M.C. Johnson. 1974. Benthic invertebrates of the St. Lawrence-Great Lakes. Journal of the Fisheries Research Board of Canada 31:763-782**.**

Cotton B.C. 1942. Some Australian freshwater Gastropoda. Transactions of the Royal Society of Australia 66:75-82.

Crozet, B. 1985. Influence of the sewage treatment plant effluents on the structure of the benthic communities of Lake of Geneva. Verh. Internat. Verein. Limnol. 22:2327-2331.

Crozet, B., J. C. Pedroli, and C. Vaucher. 1980. Premieres observations de *Potamopyrgus jenkinsi* (Smith) (Mollusca, Hydrobiidae) en Suisse romande. Revue suisse Zoologie 87:807-811.

Cuker, B. E., 1983. Competition and coexistence among the grazing snail *Lymnaea*, Chironomidae, and microcrustacea in an arctic epilithic lacustrine community. Ecology 64: 10-15.

Cunha, M. R. and M. H. Moreira. 1995. Macrobenthos of *Potamogeton* and *Myriophyllum* beds in the upper reaches of Canal de Mira (Ria de Aveiro, New Portugal): community structure and environmental factors. Netherlands Journal of Aquatic Ecology 29:377-390.

Dahl, A. and L. B. Winther. 1993. Life-history and growth of the prosobranch snail *Potamopyrgus jenkinsi* in Lake Esrom, Denmark. Verh. Internat. Verein. Limnol. 25:582-586.

D'Antonio, C.M., T.L. Dudley, and M.C. Mack. 1999. Disturbance and biological invasions: direct effects and feedback. In: Ecosystems of Disturbed Ground (Ed. L. Walker), pp. 413-452. Elsevier, Amsterdam.

Davis, Ken. 2004. Emergency Delineation of New Zealand Mudsnail Population in Putah Creek, Yolo County, California. Final Report, January 20, 2004.

Death, R. 1991. Environmental stability: its effects on stream benthic communities. Dissertation, University of Canterbury. 317 pp.

Dorgelo, J. 1987. Density fluctuations in populations (1982-1986) and biological observations of *Potamopyrgus jenkinsi* in two trophically differing lakes. Hydrobiological Bulletin 21:95-110.

Dorgelo, J. 1991. Growth, food and respiration in the prosobranch snail *Potamopyrgus jenkinsi* (E. A. Smith) Hydrobiidae, Mollusca). Verh. Internat. Verein. Limnol. 24:2947-2953.

Dorgelo, J., H. Meester, and C. van Velzen. 1995. Effects of diet and heavy metals on growth rate fertility in the deposit-feeding snail *Potamopyrgus jenkinsi* (Smith) (Gastropoda: Hydrobiidae). Hydrobiologia 316:199-210.

Duffy, J.E., P. Richardson, and E.A. Canuel. 2003. Grazer diversity affects ecosystem functioning in seagrass beds. Ecology Letters 6:637-645

Duggan, I.C., et al. 2002. Ecoregional differences in macrophyte and macroinvertebrate communities between Westland and Waikato: are all New Zealand lowland streams the same? New Zealand Journal of Marine and Freshwater Research 36:831-845

Dussart, G. B. J. 1976. The ecology of freshwater mollusks in north west England in relation to water chemistry. Journal of Molluscan Studies 42:181-198.

Dwyer, W.P. 2001. Brief history of listing New Zealand mudsnail as aquatic nuisance species and the "big question: do fish eat New Zealand mudsnail?" Presented paper. New Zealand Mudsnail in the Western USA: Conference, July, 2001.

Dwyer, W. P., B. L. Kerans and M. M. Gangloff. 2003. Effect of acute exposure to chlorine, copper sulfate, and heat on the survival of New Zealand mud snails. Intermountain Journal of Sciences 9: 53-58.

Dybdahl, M. F. 1997. Genotypic variation of an exotic freshwater snail in the Snake and Madison Rivers (USA) populations. Abstract. Society for Conservation Biology Annual Meeting. Victoria, British Columbia.

Dybdahl, M.F. 2002. The invasiveness of an exotic snail in the Greater Yellowstone Ecosystem: life-history tolerances under ambient conditions. Final Report: The invasiveness of an exotic snail in the Greater Yellowstone ecosystem and energy flow under ambient conditions. B.L. Kerans, M. Dybahl, and R. Hall. 2002.

Dybdahl, M.F. 2003. Where NZ mudsnails are NOT found in GYE. Presented paper. New Zealand Mudsnail in the Western USA: Conference, August, 2003.

Dybdahl, M. F. and C. M. Lively. 1995a. Diverse, endemic and polyphyletic clones in mixed populations of a freshwater snail (*NZ mudsnail*). Journal of Evolutionary Biology 8:385-398.

Dybdahl, M. F. and C. M. Lively. 1995b. Host-parasite interactions: infection of common clones in natural populations of a freshwater snail (*NZ mudsnail*). Proceedings of the Royal Society of London 260:99-103.

Dybdahl, M. F. and C. M. Lively. 1996. The geography of coevolution: comparative population structures for a snail and its trematode parasite. Evolution 50:2264-2275.

Dybdahl, M.F. and C.M. Lively. 1998. Host-parasite coevolution: evidence for rare advantage and time-lagged selection in a natural population. Evolution 52:1057-1066.

Dybdahl, M.F. and A.C. Krist. 2004. Genotypic versus condition effects on parasite-driven rare advantage. Journal of Evolutionary Biology *in press.*

Dybdahl, M.F., A. Emblidge, and D. Drown. 2005. Studies of a trematode parasite for the biological control of an invasive freshwater snail. Report to the Idaho Power Company.

Emblidge, A. and M.F. Dybdahl. *In review.* The role of enemies in invasions: resistance to native range parasites in an invasive freshwater snail.

Federal Register. 1992. Endangered and threatened wildlife and plants: determination of endangered or threatened status for five aquatic snails in south central Idaho. Vol. 57, No. 240.

Feminella, J. W. and C. P. Hawkins. 1995. Interactions between stream herbivores and periphyton: a quantitative analysis of past experiments. Journal of the North American Benthological Society 14:465-509.

Fox, J. A., M. F. Dybdahl, J. Jokela, and C. M. Lively. 1996. Genetic structure of coexisting sexual and clonal subpopulations in a freshwater snail (*NZ mudsnail*). Evolution 50:1541-1548.

Gerard. C., Blanc, A. and K. Costil. 2003. *Potamoprygus antipodarum* (Mollusca: Hydrobiidae) in continental aquatic gastropod communities: impact of salinity and trematode parasitism. Hydrobiologia 493: 167-172.

Giannotti, A.L. and K.J. McGlathery. 2001. Consumption of *Ulva lactuca* (Chlorophyta) by omnivorous mudsnail *Ilyanassa obsolete* (Say). Journal of Phycology 37:209-215.

Golding, L. A., M. H. Timperley, and C. W. Evans. 1997. Non-lethal responses of the freshwater snail *NZ mudsnail* to dissolved oxygen. Environmental Monitoring and Assessment 47:239-254.

Green, R. H. and R. C. Young. 1993. Sampling to detect rare species. Ecological applications. 3(2): 351-356.

Grigorovich, I. A., Korniushin, A. V., Gray, D. K., Duggan, I. C., Colautti, R. I., and MacIsaac, H. J. 2003. Lake Superior: an invasion coldspot? Hydrobiologia 499: 191-210

Hall, R. O., J. L. Tank, and M. F. Dybdahl. 2003. Exotic snails dominate carbon and nitrogen cycling in a highly productive stream. Frontiers in Ecology and the Environment. 1:407-411.

Hall, R.O., M.C. Vanderloop and M.F. Dybdahl. 2002. Production of New Zealand mudsnails and native invertebrates in Firehole River, Gibbon River, and Polecat Creek. Final Report: The invasiveness of an exotic snail in the Greater Yellowstone ecosystem and energy flow under ambient conditions. B.L. Kerans, M. Dybdahl, and R. Hall. 2002.

Hanlon, R. D. G. 1981. The influence of different species of leaf litter on the growth and food preference of the Prosobranch Mollusk *Potamopyrgus jenkinsi* (E. A. Smith). Archives of Hydrobiologie 91:463-474.

Harman 1974. Snails (Mollusca: Gastropoda). in C. W. Hart and S. L. H. Fuller (eds.) Pollution Ecology of Freshwater Invertebrates. Academic Press, New York. pp. 275-312.

HaUser, L., G. R. Carvalho, R. N. Hughes, and R. E. Carter. 1992. Clonal structure of the introduced freshwater snail *NZ mudsnail* (Prosobranchia: Hydrobiidae), as revealed by DNA fingerprinting. Proceedings of the Royal Society of London 249:19-25.

Hawkins, C. P. and J. K. Furnish. 1987. Are snails important competitors in stream ecosystems? Oikos 49:209-220.

Haynes, A. and B. J. R. Taylor. 1984. Food finding and food preference in *Potamopyrgus jenkinsi* (E. A. Smith) (Gastropoda: Prosobranchia). Archives of Hydrobiologie 100:479-491.

Haynes, Alison, B. J. R. Taylor, and M. E. Varley. 1985. The influence of the mobility of *Potamopyrgus jenkinsi* (Smith, E. A.) (Prosobranchia: Hydrobiidae) on its spread. Archives of Hydrobiologie 103:497-508.

Hebert, P.D.M., B.W. Muncaster, and G.L. Mackie. 1989. Ecological and genetic studies on Dreissena polymorpha (Pallas): a new mollusc in the Great Lakes. Canadian Journal of Fisheries and Aquatic Sciences 46:1587-1591.

Hebert, P.D.N., C.C. Wilson, M.H. Murdoch, and R. Lazar. 1991. Demography and ecological impacts of the invading mollusc Dreissena polymorpha. Canadian Journal of Zoology 69:405-409.

Hickey, C. W. and M. L. Vickers. 1994. Toxicity of ammonia to nine native New Zealand freshwater macroinvertebrate species. Archives of Environmental Contamination and Toxicology 26:292-298.

Holomuzki and Biggs 1998. Distributional responses to flow disturbance by a stream-dwelling snail. Oikos 87:36-47

Holomuzki, D. J. and B. J. F. Biggs. 1998. Distributional responses to flow disturbance by a stream-dwelling snail. Bulletin of the North American Benthological Society (Abstract) 15:100.

Holomuzki, J. R. and B. J. F. Biggs. 2000. Taxon-specific responses to high-flow disturbance in streams: implications for population persistence. Journal of the North American Benthological Society. 19: 670-679.

Hopkins, C. L. 1976. Estimate of biological production in some stream invertebrates. New Zealand Journal of Marine and Freshwater Research 10:629-640.

Hosea, R.C. and B. Finlayson. 2005. Controlling the spread of New Zealand mud snails on wading gear. California Dept. of Fish and Game Administrative Report 2005-02. 38 pp.

Hubendick, B. 1950. The effectiveness of passive dispersal in *Hydrobia jenkinsi*. Zoologiska bidrag fran Uppsala 28: 493-504.

Huryn, A. D. and M. W. Denny. 1997. A biomechanical hypothesis explaining upstream movement by the freshwater snail *Elimia*. Functional Ecology 11:472-483.

Hylleberg, J. and H. R. Siegismund. 1987. Niche overlap in mud snails (Hydrobiidae): freezing tolerance. Marine Biology 94:403-407.

Jacobsen, R., V.E. Forbes, and O. Skovgaard. 1996. Genetic population structure of the prosobranch snail NZ mudsnail (Gray) in Denmark using PCR-RAPD fingerprints. Proceedings of the Royal Society of London B. 264:1065.

Jacobson, R. and V.E. Forbes. 1997. Clonal variation in life-history traits and feeding rates in the gastropod, *NZ mudsnail*: Performance across a salinity gradient. Functional Ecology (In Press).

Johnson, P. D. and K. M. Brown. 1997. The role of current and light in explaining the habitat distribution of the lotic snail *Elimia semicarinata* (Say). Journal of the North American Benthological Society 16:545-561.

Jokela, J. and C. M. Lively. 1995a. Parasites, sex, and early reproduction in a mixed population of freshwater snails. Evolution 49:1268-1271.

Jokela, J. and C. M. Lively. 1995b. Spatial variation in infection by digenetic trematodes in a population of freshwater snails (*NZ mudsnail*). Oecologia 103:509-517.

Jokela, J., C. M. Lively, J. A. Fox, and M. F. Dybdahl. 1997a. Flat reaction norms and "frozen " phenotypic variation in clonal snails (*NZ mudsnail*). Evolution 51:1120-1129.

Jokela, J., C. M. Lively, M. F. Dybdahl, and J. A. Fox. 1997b. Evidence for a cost of sex in the freshwater snail *NZ mudsnail*. Ecology 78:452-460.

Jokela, J., C.M. Lively, M.F. Dybdahl and J. A. Fox. 2003. Genetic variation in sexual and clonal lineages of a freshwater snail. *Biol. J. Linn. Soc* 79:165-181

Jokela, J., M. F. Dybdahl and C. M. Lively. 1999. Habitat specific variation in life-history traits, clonal population structure, and parasitism in a freshwater snail (*NZ mudsnail*). Journal of Evolutionary Biology (in press).

Jowett, I. G., J. Richardson, B. J. F. Biggs, C. W. Hickey, and J. M. Quinn. 1991. Microhabitat preferences of benthic invertebrates and the development of generalized *Deleatidium* spp. habitat suitability curves, applied to four New Zealand Rivers. New Zealand Journal of Marine and Freshwater Research 25:187-199.

Kareiva, P. I.M. Parker, and M. Pascual. 1996. Can we use experiments and models in predicting the invasiveness of genetically engineered organisms? Ecology 77:1670-1675.

Keiter R.B. 1991. An introduction to the ecosystem management debate. Pages 3-18 in R.B.Keiter (ed.) The Greater Yellowstone Ecosystem. Yale University Press.

Kerans, B. L. (2003). Models of interactions of two species: lessons for invasion of *Potamopyrgus antipodarum*. Paper presented at the 3rd Annual New Zealand mud snail in the Western USA conference.

Kerans, B.L. and C. Cada. 2002. Foraging behavior and interference competition. Final Report: The invasiveness of an exotic snail in the Greater Yellowstone ecosystem and energy flow under ambient conditions. B.L. Kerans, M. Dybdahl, and R. Hall. 2002.

Kerans, B. L., M. F. Dybdahl, M. M. Gangloff, and J. E. Jannot. 2005. *Potamoprygus antipodarum*: distribution, abundance, and effects on native macroinvertebrates in the Greater Yellowstone Ecosystem. Journal of the North American Benthological Society 24(1): 123-138.

Kerans, B. L., C. Cada, and J. Zickovich. Interspecific competition for foraging locations between *Potamopyrgus antipodarum* and other macroinvertebrates. In preparation.

Kjeldsen, K. 1996. Regulation of algal biomass in a small lowland stream: field experiments on the role of invertebrate grazing, phosphorus and irradiance. Freshwater Biology 36:535-546.

Langenstein, S. and P. A. Bowler. 1990. On-going macroinvertebrate analysis using the biotic condition index and the appearance of NZ mudsnail (Gray) in Box Canyon Creek, Southern Idaho. Proceedings of the Desert Fishes Council 21:183-194.

Lassen, H. H. 1978. The migration potential of freshwater snails exemplified by the dispersal of *Potamopyrgus jenkinsi*. Natura Jutlandica 20:237-241.

Lassen, H. H. 1979. Reproductive effort in Danish mudsnails (Hydrobiidae). Oecologia 40:365-369.

Levri, E. P. 1998. The influences of non-host predators on parasite-induced behavioral changes in a freshwater snail. Oikos 81:531-537.

Lively C.M. and J. Jokela. 1996. Clinal variation for local adaptation in a host-parasite interaction. Proceedings of the Royal Society of London B 263:8891-897

Lively, C. M. 1992. Parthenogenesis in a freshwater snail: reproductive assurance versus parasitic release. Evolution 46:907-913.

Lively, C.M. 1989. Adaptation by a parasitic trematode to local populations of its host. Evolution 46:1663-1671

Lively, C.M. and M.F. Dybdahl. 2000. Parasite adaptation to locally common host genotypes. *Nature* 405:679-681

Locke, A., D. M. Reid, H. C. van Leeuwen, W. G. Sprules, and J. T. Carlton. 1993. Ballast water exchange as a means of controlling dispersal of freshwater organisms by ships. Canadian Journal of Fisheries and Aquatic Sciences 50:2086-2093.

Loo, S. 2003. Potential factors affecting the spread of *NZ mudsnail* in southeastern Australia. Presented paper. New Zealand Mudsnail in the Western USA: Conference, August, 2003.

Lysne, S. 2003. Experimental studies of competition, predation, and habitat Use with *NZ mudsnail* from the middle Snake River, Idaho. Presented paper. New Zealand Mudsnail in the Western USA: Conference, August, 2003.

Lucas, A. 1959. Les Hydrobia (Bythnellidae) de l'Ouest de la France. Journal of Conchology 99:3-14.

Mack, M.C. and C.M. D'Antonio. 1998. Impacts of biological invasions on disturbance regimes. Trends in Ecology and Evolution 13:195-198.

Marsh, P. C. 1980. An occurrence of high behavioral drift for a stream gastropod. The American Midland Naturalist 104: 410-411.

Martinez-Lopez, F., J. Jimenez, J. Subias, and J. F. Amela. 1986. Sobre la distribucion de *Potamopyrgus jenkinsi* (Smith, 1889) (Gastropoda: Prosobranchia) en las cuencas de los Rios Mijares, Turia Y Juncar. IberUS 6:245-255.

McCarter, N.H. 1986. Food and energy in the diet of brown and rainbow trout from Lake Benmore, New Zealand. New Zealand Journal of Marine and Freshwater Research 20:551-559

McDowall, R. M. 1990. New Zealand freshwater fishes: a natural history and guide – Heinemann Reed, Wellington.

Medhurst, R. B. and D. B. Herbst 2003. An alternative method for decontamination: bleach toxicity in New Zealand mudsnails from upper Owens River. In: Chavez Writing and Editing, August 26 and 27, 2003. *NZ mudsnail* in the Western USA: Conference 2003. Minutes of the Third Annual Conference. Montana State University, Bozeman, Montana.

Medhurst, R.B. 2003. Presentation of results at the New Zealand Mudsnail Stakeholder Meeting, November 17, 2003, Mammoth Lake, California

Merritt, R. W. and K. W. Cummins. 1996. An introduction to the aquatic insects of North America. 3rd Edition. Kendal/Hunt Publishing Co. Dubuque, Iowa. 862pp

Michaut, P. 1968. Donnees biologiques sur un Gasteropode Prosobranche recemment indroduit en Cote-d'Or, *Potamopyrgus jenkinsi*. Hydrobiologia 32:513-527.

Mills, E. L., J. H. Leach, J. T. Carlton, and C. L. Secor. 1993. Exotic species in the Great Lakes: A history of biotic crises and anthropogenic introductions. Journal of Great Lakes Research 19:1-54.

Moller, V., V. E. Forbes and M. H. Depledge. 1994. Influence of acclimation and exposure temperatures on the acute toxicity of cadmium to the freshwater snail *NZ mudsnail* (Hydrobiidae). Environmental Toxicology and Chemistry 13:1519-1524.

Moyle, P.B. and T. Light. 1996. Fish invasions in California: do abiotic factors determine success? Ecology 77:1666-1670.

Negovetic, S. and J. Jokela. 2001. Life-history variation, phenotypic plasticity, and subpopulaiton structure in a freshwater snail. Ecology 82:2805-2815.

Okland, J. 1979. Distribution of environmental factors and fresh-water snails (Gastropoda) in Norway: Use of European invertebrate survey principles. Malacologia 18:211-222.

Okland, J. 1983. Factors regulating the distribution of fresh-water snails (Gastropoda) in Norway. Malacologia 24:277-288.

Osborne, R.S. and T. D. Rhine. 2000. Steelhead volitional release experiment, Squaw Creel Pond, Idaho, 1999 Project Progress Report. IDFG Rpt. 00-52. January, 2000.

Ponder, W. F. 1988. *NZ mudsnail*, a Molluscan colonizer of Europe and Australia. Journal of Molluscan Studies 54:271-286.

Quinn, G. P., P. S. Lake, and E. S. G. Schreiber. 1996. Littoral benthos of a Victorian lake and its outlet stream: spatial and temporal variation. Australian Journal of Ecology 21:292-301.

Quinn, J.M. and C.W. Hickey. 1990. Characterization and classification of benthic invertebrate communities in 88 New Zealand rivers in relation to environmental factors. New Zealand Journal of Marine and Freshwater Research, 24, 387-409.

Quinn, J. M., G. L. Steele, C. W. Hickey, and M. L. Vickers. 1994. Upper thermal tolerances of twelve New Zealand stream invertebrate species. New Zealand Journal of Marine and Freshwater Research 28:391-397.

Ribi, G. 1986. Within-lake dispersal of the prosobranch snails, *Vivipaus sater* and *Potamopyrgus jenkinsi*. Oecologia 69:60-63.

Ribi, G. and H. Arter. 1986. Ausbreitung der Schneckenart *Potamopyrgus jenkinsi* im Zurichsee von 1980 bis 1984. Vjierteljahrsschr. Naturforsch. Ges. Zuer. 131:52-57.

Richards, D. C., L. D. Cazier, and G. T. Lester. 2001. Spatial distribution of three snail species, including the invader *NZ mudsnail*, in a freshwater spring. Western North American Naturalist 61: 375-380.

Richards, D.C. 2002a. The New Zealand mudsnail in the western USA. Web page: http://www2.montana.edu/NZ mudsnail/ . Department of Ecology, Montana State University, Bozeman, Montana 59717.

Richards, D.C. 2002b. Greeting and overview presentation. New Zealand Mudsnail in the Western USA: Conference, August, 2002.

Richards, D.C. 2002c. The New Zealand mudsnail invades. Aquatic Nuisance Species Digest. Vol. 4, No. 4, 42-44.

Richards, D.C. 2003. Competition between *NZ mudsnail* and threatened Bliss Rapids snail. Presented paper. New Zealand Mudsnail in the Western USA: Conference, August, 2003

Richards, D. C. 2004. Competition between the threatened Bliss Rapids Snail, *Taylorconcha serpenticola* (Hershler et al.) and the invasive, aquatic snail, *NZ mudsnail* (Gray). Ph. D. dissertation. 175pp. Montana State University, Bozeman, MT

Richards, D. C., C. M. Falter, G. T. Lester, and R. Myers. 2005. Listed Mollusks. Responses to FERC Additional Information Request AR-2. Hells Canyon Project. FERC No. P-1971-079. 180 pp.

Richards, D. C., O'Connell, and D. C. Shinn. 2004. Simple control method for the New Zealand mudsnail, *NZ mudsnail*. Journal North American Fisheries Management. 24:114-117.

Richards, D.C. and B. L. Kerans. Competition and coexistence between an invasive species and its threatened native congener: influence of the New Zealand mudsnail *Potamopyrgus antipodarum* on the Bliss Rapids snail *Taylorconcha serpenticola* in Idaho's Snake River drainage

Riley, L.A., M.F. Dybdahl, and R.O. Hall. 2002. Invasive species impact: resource competition between stream snails within the Greater Yellowstone Ecosystem. In Final Report: The invasiveness of an exotic snail in the Greater Yellowstone ecosystem and energy flow under ambient conditions. B.L. Kerans, M. Dybdahl, and R. Hall. 2002.

Rounick, J. S. and M. J. Winterbourn. 1982. Benthic faunas of forested streams and suggestions for their management. New Zealand Journal of Ecology 5:140-150.

Rounick, J. S. and M. J. Winterbourn. 1983. The formation, structure and utilization of stone surface organic layers in two New Zealand streams. Freshwater Biology 13:57-72.

Riley, L.A. 2003. Exotic species impact: exploitative competition between stream snails? M.S. Thesis, Washington State University, Pullman, Washington. 48 pages.

Ryan, P. A. 1982. Energy contents of some New Zealand freshwater animals. New Zealand Journal of Marine and Freshwater Research 16:283-287.

Savage, A. A. 1996. Density dependant and density independent relationships during a twenty-seven year study of the population dynamics of the benthic macroinvertebrate community of a chemically unstable lake. Hydrobiologia 335:115-131.

Savaka, M. W. 1993. Processes affecting the transport of Arsenic in the Madison and Missouri Rivers, Montana. Master's Thesis, University of Montana, Missoula. 90 p.

Scarsbrook, M. R. and C. R. Townsend. 1993. Stream community structure in relation to spatial and temporal variation: a habitat template study of two contrasting New Zealand streams. Freshwater Biology 29:395-410.

Schloesser, D. W. 1996. Mitigation of unionid mortality caused by zebra mussel infestation: cleaning of unionids. North American Journal of Fisheries Management 16:942-946.

Schloesser, D. W., T. F. Nalepa, and G. L. Mackie. 1996. Zebra mussel infestation of unionid bivalves (Unionidae) in North America. American Zoologist 36:300-310.

Schreiber, E. S. G., A. Glaister, G. P. Quinn, and P. S. Lake. 1998. Live history and population dynamics of the exotic snail *NZ mudsnail* (Prosobranchia: Hydrobiidae) in Lake Purrumbete, Victoria, Australia. Australian Journal of Marine and Freshwater Research.

Schreiber, E. S. G., G. P. Quinn, and P. S. Lake. 2003. Distribution of an alien aquatic snail in relation to flow variability, human activities and water quality. Freshwater Biology. 48: 951-961.

Schreiber, E. S. G., P. S. Lake, and G. P. Quinn. 2002. Facilitation of native stream fauna by an invading species: Experimental investigations of the interaction of the snail, *NZ mudsnail* (Hydrobiidae) with native benthic fauna. Biological Invasions 4: 317-325.

Scott, D., J. W. White, D. S. Rhodes, and A. Koomen. 1994. Invertebrate fauna of three streams in relation to land Use in Southland, New Zealand. New Zealand Journal of Marine and Freshwater Research 28:277-290.

Scrimgeour, G. J. and M. J. Winterbourn. 1989. Effects of floods on epilithon and benthic macroinvertebrate populations in an unstable New Zealand river. Hydrobiologia 171:33-44.

Shinn, D.C. 2002. Update of the New Zealand mudsnail distribution, abundance, and ecology in the Snake River, Idaho. Presented paper. New Zealand Mudsnail in the Western USA: Conference, AugUSt, 2002.

Siegismund, H. R. and J. Hylleberg. 1987. Dispersal-mediated coexistence of mud snails (Hydrobiidae) in an estuary. Marine Biology 94:395-402.

Simberloff D. and P. Stiling. 1996. How risky is biological control? Ecology 77:1965-1974.

Stadler, T., M. Frye, M. Neiman, and C.M. Lively. 2005. Mitochondrial haplotypes and the New Zealand origin of clonal European *Potamopyrgus*, an invasive aquatic snail. Molecular Ecology 14:2465-2473

Staton, L. 2003. Assessment of New Zealand mudsnail (*P. antipodarum*) as a potential fish parasite vector. Presented paper. New Zealand Mudsnail in the Western USA: Conference, August, 2003.

Strayer, D. L. and D. R. Smith. 2003. A guide to sampling freshwater mussel populations. American Fishery Society Monograph 8. American Fisheries Society. Bethesda, Maryland. 103pp.

Strzelec, M. and M. Krodkiewska. 1994. The rapid expansion of *Potamopyrgus jenkinsi* (E. A. Smith, 1889) in Upper Silesia (Southern Poland) (Gastropoda: Prosobranchia: Hydrobiidae). Malakologische Abhandlungen Staatliches MUseum fur Tierkunde Dresden 17:83-86.

Strzelec, M. and W. Serafinski. 1996. Population ecology of *Potamopyrgus antipodarum* (Gray, 1843) in a recently colonized area: Upper Silesia (Southern Poland) (Gastropoda: Prosobranchia: Hydrobiidae). Malakologische Abhandlungen Staatliches MUseum fur Tierkunde Dresden 18:75-82.

Talbot, J. M. and J. C. Ward. 1987. Macroinvertebrates associated with aquatic macrophytes in Lake Alexandrina, New Zealand. New Zealand Journal of Marine and Freshwater Research 21:199-213.

Talling, J. F. 1951. The element of chance in pond populations. The Naturalist 1951:157-170.

Tilman, D., D. Wedin and J. Knops. 1996. Productivity and sustainability influenced by biodiversity in grassland ecosystems. Nature 379:718-720

Tomkins, A. R. and R. R. Scott. 1986. Effects of treated sewage effluent on the macroinvertebrates of a fine sediment substrate stream. Mauri Ora 13:1-12.

Towns, D. R. 1979. Composition and zonation of benthic invertebrate communities in a New Zealand kauri forest stream. Freshwater Biology 9:251-262.

Towns, D. R. 1981a. Effects of artificial shading on periphyton and invertebrates in a New Zealand stream. New Zealand Journal of Marine and Freshwater Research 15:185-192.

Towns, D. R. 1981b. Life histories of benthic invertebrates in a Kauri forest stream in Northern New Zealand. Australian Journal of Marine and Freshwater Research 32:191-211.

van den Berg, M. S., H. Coops, R. Noordhuis, J. van Schie, and J. Simons. 1997. Macroinvertebrate communities in relation to submerged vegetation in two *Chara* dominated lakes. Hydrobiologia 342/343:143-150.

Vareille-Morel, C. 1983. Les mouvements journaliers du mollusque *Potamopyrgus jenkinsi*, Smith, Etude sur le terrain et en laboratoire. Haliotis 13:31-34.

Wallace, C. 1979. Notes on the occurrence of males in populations of *Potamopyrgus jenkinsi*. Journal of MollUScan Studies 45:61-67.

Wallace, C. 1978. Notes on the distribution of sex and shell characteristics in some Australian populations of *Potamopyrgus* (Gastropoda: Hydrobiidae). Journal of the Malacological Society of Australia 4:71-76.

Wallace, C. 1992. Parthenogenesis, sex, and chromosomes in *Potamopyrgus*. Journal of MollUScan Studies 58:93-107.

Wilcove, D.S., D. Rothstein, J. Dubow, A. Phillips, and E. Losos. 1998. Quantifying threats to imperiled species in the United States. BioScience 48:607-615

Winterbourn, M. J. 1973. A guide to the freshwater Mollusca of New Zealand. Tuatara 20:141-159.

Winterbourn, M. J. 1970a. Population studies on the New Zealand freshwater Gastropod, *NZ mudsnail* (Gray). Proceedings of the Malacological Society of London 39:139-149.

Winterbourn, M. J. 1970b. The New Zealand species of *Potamopyrgus* (Gastropoda: Hydrobiidae). Malacologia 10:283-321.

Winterbourn, M. J. 1972. Morphological variation of *Potamopyrgus jenkinsi* (Smith) from England and a comparison with the New Zealand species *NZ mudsnail* (Gray). Proceedings of the Malacological Society of London 40:133-145

Winterbourn, M. J. 1974. Larval trematoda parasitising the New Zealand species of *Potamopyrgus* (Gastropoda: Hydrobiidae). Mauri Ora 2:17-30.

Winterbourn, M. J. 1978. The macroinvertebrate fauna of a New Zealand forest stream. New Zealand Journal of Zoology 5:157-169.

Winterbourn, M. J. and A. Fegley. 1989. Effects of nutrient enrichment and grazing on periphyton assemblages in some spring-fed, South Island streams. New Zealand Natural Sciences 16:57-65.

Winterbourn, M. J. and P. A. Ryan. 1994. Mountain streams in Westland, New Zealand: Benthic ecology and management issues. Freshwater Biology 32:359-373.

Winterbourn, M. J., J. S. Rounick, and B. Cowie. 1981. Are New Zealand stream ecosystems really different? New Zealand Journal of Marine and Freshwater Research 15:321-328.

Winterbourn, M.J. 1997. New Zealand mountain stream communities: Stable yet disturbed? In Evolutionary Ecology of Freshwater Animals, B Streit, T, Städler and C.M. Lively (eds), BirkhäUser Verlag Basel/Switzerland, p 31-54.

Zaranko, D. T., D. G. Farara, and F. G. Thompson. 1997. Another exotic Mollusk in the Laurentian Great Lakes: the New Zealand native *NZ mudsnail* (Gray 1843) Gastropoda, Hydrobiidae). Canadian Journal of Fisheries and Aquatic Sciences 5 4:809-814.