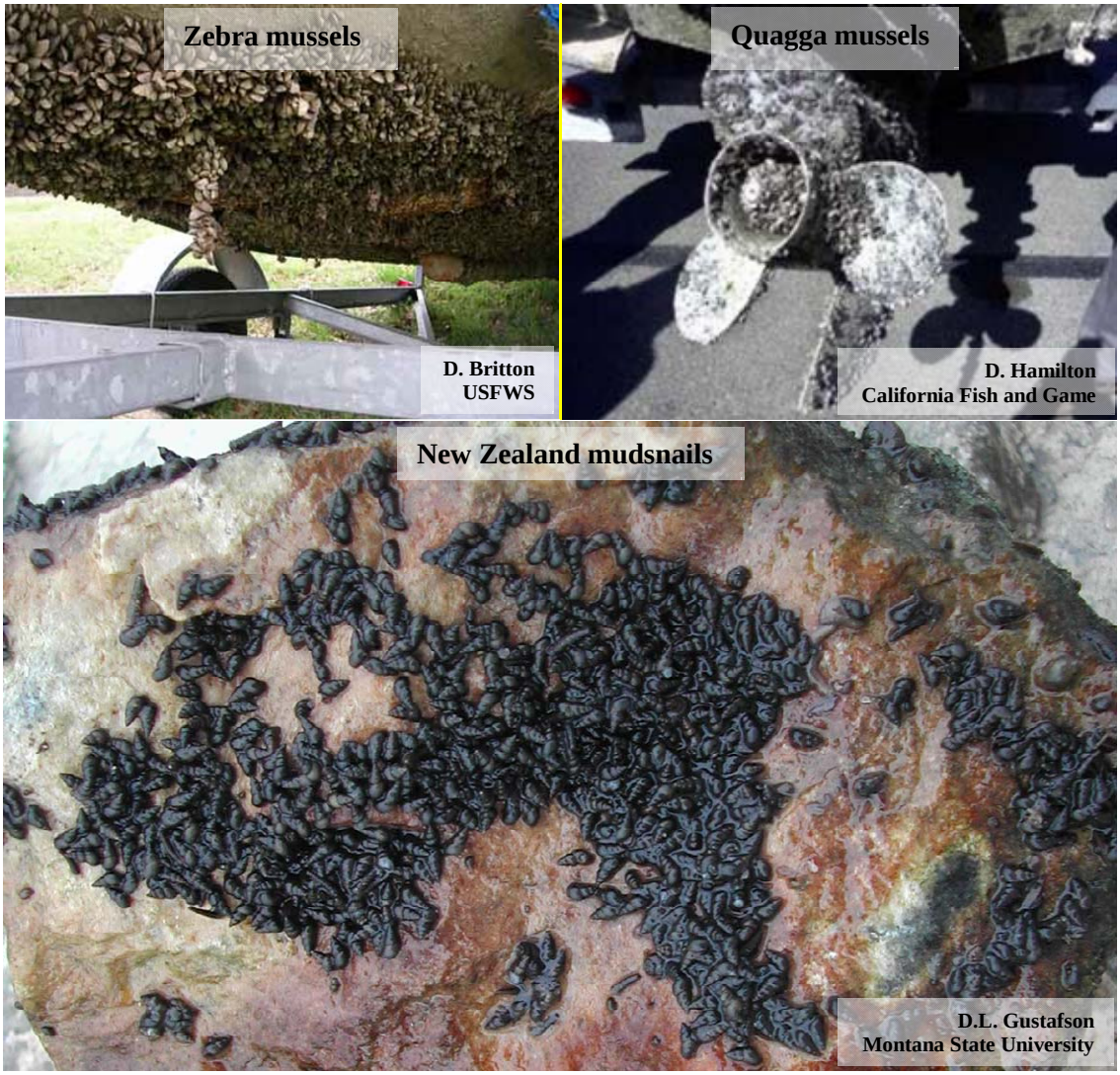
U.S. Fish & Wildlife Service

Freshwater Invasive Mollusk Prevention at Roadway Border Crossings into Alaska

Alaska Fisheries Technical Report Number 107



Fairbanks Fish and Wildlife Field Office
Fairbanks, Alaska
May 2010

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Freshwater Invasive Mollusk Prevention at Roadway Border Crossings into Alaska

Scott D. Ayers

Abstract

Freshwater aquatic invasive species have spread to suitable habitats around the world as a result of developing global transportation and trade. Successful invaders often have life history strategies that enable them to disperse using multiple vectors to establish populations in new areas. Once established, these invaders can degrade habitats and populations in local ecosystems. To date, the State of Alaska has no confirmed reports of freshwater invasive mollusks. However, non-native freshwater mollusks such as the zebra mussel *Dreissena polymorpha*, quagga mussel *Dreissena bugensis*, and New Zealand mudsnail *Potamopyrgus antipodarum* are potential invaders to Alaska waters in the near future. This report reviews current distribution, life history, ecology, dispersal vectors, and other qualities of these species to provide a background of biological information pertinent to a potential Alaskan mollusk invasion. Management plans developed for areas closer to established invasive mollusk populations are evaluated to assess approaches for developing an Alaskan-specific plan. Existing research suggests a high risk of non-native mollusks being introduced into Alaska waters by recreational watercraft. Local management plans for monitoring border points of entry are evaluated and recommendations provided for establishing an effective monitoring, prevention, and decontamination program for freshwater invasive mollusks at Alaska roadway points of entry.

Introduction

In 2008 the U.S. Fish and Wildlife Service (USFWS), Alaska Region, Aquatic Invasive Species (AIS) Program, requested the assistance of the Fairbanks Fish and Wildlife Field Office, Fisheries and Habitat Restoration Branch (FHR) to train U.S. Customs and Border Protection (Customs) agents at the U.S./Canada border port of entry on the Alaska Highway (hereafter referred to as the Alcan Portal) on how to inspect for and prevent the import of AIS, specifically the zebra mussel *Dreissena polymorpha*. The AIS Program provided FHR staff with printed outreach materials, a video with background information on AIS, and trailered boat inspection forms along with reporting requirements. The information and materials were presented to the Customs agents who were encouraged to inspect incoming trailered boats, share the information with recreational boaters, and report their findings to the USFWS. In 2009, the FHR was again funded by the AIS Program to further develop AIS prevention efforts at the Alcan Portal. The FHR recognized that while outreach was an important first step, an effective AIS monitoring and prevention program at the Alcan Portal would require continued collaboration with Customs to implement trailered watercraft inspections and would benefit from further analysis of the available options. This analysis of AIS introductions to Alaska on trailered watercraft is intended to serve as the basis for the AIS Program to develop an effective monitoring and prevention program at roadway border crossings. It should be noted that the terms "invasive"

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and "nuisance" are used interchangeably throughout this analysis with preference for the former except where the latter is a proper name, e.g., "Aquatic Nuisance Species Management Plan".

The goal of this analysis was to address concerns about the establishment of AIS via roadway transport by recreational watercraft at U.S./Canada ports of entry using the following objectives.

1) Identify potential freshwater mollusk AIS threats to Alaska.
2) Review AIS management plans and actions of states and provinces in close proximity to Alaska.
3) Summarize the literature for targeted AIS pertaining to:
    a) species identification;
    b) distributions;
    c) ecology and life history traits;
    d) environmental and experimental tolerances;
    e) dispersal vectors; and
    f) detection and decontamination methods for AIS on watercraft and trailers.
4) Identify optimal locations for inspection of recreational watercraft and trailers crossing into Alaska.
5) Review current practices at roadway ports of entry stations for Alaska.
6) Based on these results, provide recommendations for establishing an effective monitoring and prevention program for freshwater mollusk AIS on watercraft and trailers entering Alaska by road.

Freshwater Mollusk AIS Threats to Alaska

A review of State, Provincial, and regional management plans, available AIS research, and current distribution maps for invasive mollusks was performed to identify the most likely potential invaders to the freshwater ecosystems of Alaska by means of transport on recreational watercraft and trailers. The three species most commonly cited are the zebra mussel, quagga mussel *Dreissena bugensis* (also referred to as *Dreissena rostriformis bugensis*), and New Zealand mudsnail *Potamopyrgus antipodarum*. As such, they are the focus of this document.

AIS Management Plans in the Pacific Northwest and Alaska

Each State, Province, and relevant Canadian Federal Agency in the Pacific Northwest has, or is in the process of creating a management plan for AIS. A primary influence for developing these plans in the U.S. and for initiating dialogue among agencies has been Section 1204 of the National Invasive Species Act (NISA) of 1996. NISA authorized funds for the creation of State plans and reinforced the USFWS funded 100th Meridian Initiative (100th MI; 2009). The 100th MI is a cooperative effort among State, Provincial, and Federal governments to prevent the westward expansion of zebra mussels and other AIS in North America. The 100th MI acts as a clearinghouse to increase the awareness of AIS by promoting and coordinating information exchange. The 100th MI provides outreach and training aids, boat and trailer inspection forms, a database of infestations, accounts of volunteer monitoring programs, descriptions of applicable laws and regulations, and notices of coordination meetings. The 100th MI also supports River Basin Teams that focus on AIS in the watersheds of the Missouri, Colorado, Arkansas, Rio Grande, and Columbia rivers. Funding was also authorized by NISA for State AIS plan development and implementation.

Information is presented below about each of the reviewed management plans, including mollusk species listed as being of concern or with established AIS populations (Table 1). Monitoring

programs are also described. Coastal areas also include marine species within their AIS plans, but this information is outside the scope of this analysis and so is not reported here. A list of regional AIS contacts is available at http://www.fws.gov/answest/WRP%20Membership%20List%20March-2010.pdf.

Table 1. Populations of freshwater mollusk AIS of priority concern in the Pacific Northwest as listed in State, Provincial, and Regional management plans and updates.

Common name	Species	Established	Not established
Zebra mussel	*Dreissena polymorpha*		Alaska, British Columbia, Idaho, Montana, Oregon, Washington, Yukon Territory
Quagga mussel	*Dreissena bugensis*		British Columbia, Idaho, Montana, Oregon, Washington, Yukon Territory
New Zealand mudsnail	*Potamopyrgus antipodarum*	British Columbia, Idaho, Montana, Oregon, Washington	Alaska
Chinese mystery snail	*Cipangopaludina chinensis malleata*	Oregon, Washington	
Japanese mystery snail	*Cipangopaludina japonica*	Oregon, Washington	
Mimic lymnaea	*Pseudosuccinea columella*	Washington	
Big-ear radix	*Radix auricularia*	Washington	
Asiatic clam	*Corbicula fluminea*	Idaho, Oregon, Washington	

The State of Alaska

The Alaska Department of Fish and Game (ADFG) recognized the need for active management in addressing the AIS problem and, with the assistance of the Alaska Region Aquatic Species Program, created the Alaska Aquatic Nuisance Species (ANS) Management Plan (Fay 2002). Among other AIS threats, this plan identified the zebra mussel and New Zealand mudsnail as potential freshwater invasive mollusk threats to Alaska, and both are currently listed as high priority species (Table 1). The quagga mussel was not widely understood as a threat comparable to zebra mussels at the time the Alaska ANS Management Plan was developed and was not listed in the ADFG plan. However, it has since been listed as a potential freshwater invader with the Department of Fisheries and Oceans Canada (DFO), Pacific Region (DFO 2009), and has recently spread into multiple western United States (Stokstad 2007), prompting its inclusion in this analysis. The Alaska ANS Management Plan is available at http://www.adfg.state.ak.us/special/invasive/invasive.php.

The Alaska ANS Management Plan describes multiple pathways for introduction of non-native AIS into Alaska. This list includes aquaculture, aquarium trade, live bait, scientific research, seafood retail and processing industries, recreational fisheries enhancement, and others. Boats, ships, and aircraft are also listed, with particular attention given to recreational boaters as potential transporters of AIS. The Management Plan also calls for coordinated efforts between State, Regional, National, and International programs; the creation of action response plans for species of concern; and a GIS database to show the locations of AIS sightings and established populations in Alaska.

The Alaska ANS Management Plan outlines and describes the need to establish a statewide, multi-agency body, an Alaskan Council on Invasive Species (ACIS), to address invasive species prevention, response, management, and eradication. As an interim means of addressing the need for an ACIS, a working group was established in 2006. The Alaska Invasive Species Working Group (AISWG) was developed under a memorandum of understanding between State, Academia, Federal, Tribal, and other entities in Alaska (AISWG 2006). The AISWG was partially funded by ADFG in 2007 with federal funds allocated to assist in implementation of the Alaska ANS Management Plan. The AISWG's actions have been reduced since 2008 due to lack of funding; however, teleconferences continue bi-monthly. An intra-departmental Invasive Species Team within ADFG has assisted in project planning, prioritizing funding opportunities, and addressing significant issues as they arise. Legislation proposing the establishment of an ACIS was again submitted in the recently completed session of the Alaska Legislature, but did not pass before the session closed. Until the time legislation passes creating an ACIS, teleconferences will continue to keep interested parties informed of actions in the state and opportunities for partnership (T. Davis, ADFG, personal communication).

The Province of British Columbia and the Yukon Territory

AIS management in western Canada is guided by the broad scope of the Canadian Action Plan to Address the Threat of Aquatic Invasive Species (Canadian Council of Fisheries and Aquaculture Ministers 2004). The plan identifies the major pathways through which AIS are introduced and spread in Canada, with a goal to minimize or limit the introduction of new AIS before they become established. This plan states that Federal and Provincial governments will work together with other stakeholders for better coordination of the management of vectors through which AIS enter Canadian waters or spread within the country. This approach is described as more effective than dealing individually with the large number of invasive species that are or could become established. However, implementation of all parts of this plan are still in the early stages in western Canada, as protocols are being put into place and jurisdictional concerns are being addressed (T. Therriault, DFO, personal communication). The Canadian Action Plan to Address the Threat of AIS is available at http://www.dfo-mpo.gc.ca/science/enviro/ais-eae/index-eng.htm.

The Invasive Alien Species Framework for British Columbia (British Columbia Ministry of the Environment 2004) provides background information and general guidelines for prevention of AIS introductions. It identifies cooperation, inventories, risk assessments, monitoring, outreach, and policy and legislative initiatives as priority actions for the Province. The Framework lists trailered boats as a pathway of introduction, but does not focus on control of a particular species or population. The Invasive Alien Species Framework for British Columbia is available at http://www.env.gov.bc.ca/wld/documents/alien_species_framework_BC_0205.pdf.

While the provincial government of British Columbia and the Pacific Region of DFO Canada have devised management options and action plans, the Yukon Territory has yet to start

addressing this problem. The absence of a plan to monitor, detect, or educate people about AIS in the Yukon Territory may reflect the fact that the AIS issue has not become sufficiently severe here to warrant devoting resources to it (N. Millar, Department of Environment, Yukon Government, personal communication). Although there have been some historic and modern introductions of exotic species into the Yukon Territory (goldfish, stickleback, and rainbow trout), there are currently no known populations of AIS in the Yukon Territory.

The Pacific Region of DFO currently lists zebra mussels and quagga mussels as potential freshwater invaders (Table 1; DFO 2009). A viable population of New Zealand mudsnails has recently been reported at Port Alberni on Vancouver Island, British Columbia. This population is believed to have been introduced from the Columbia River estuary via either recreational watercraft or contaminated fishing equipment (Davidson et al. 2008). Currently, there is no system in place to monitor border crossings in western Canada for transport of AIS via recreational watercraft (T. Therriault, DFO, personal communication). However, the Provincial government of British Columbia recently signed on as a member of the Columbia River Interagency Invasive Species Response Plan, in partnership with the State governments of Washington, Oregon, Idaho, and Montana, the Pacific Region of USFWS, and the Columbia River Inter-Tribal Fish Commission (British Columbia Ministry of the Environment 2009). This plan, established as part of the 100th MI, seeks to protect the Columbia River Basin from the spread of zebra and quagga mussels by coordinating a rapid, effective, and efficient interagency response to delineate, contain, and if feasible, eradicate dreissenid (zebra and quagga) mussel populations if they are introduced to the Columbia River Basin (Heimowitz and Phillips 2008).

The State of Washington

In 1998 the State of Washington published an ANS Management Plan, which was updated in 2001 (Washington Aquatic Nuisance Species Coordinating Committee 2001) to cover authorities, non-native species problems and concerns, accomplishments, and management actions for the State of Washington. The Plan lists the following freshwater mollusk AIS in Washington: New Zealand mudsnail; Chinese mystery snail *Cipangopaludina chinensis malleata*; Japanese mystery snail *Cipangopaludina japonicas*; mimic lymnaea *Pseudosuccinea columella*; big-ear radix *Radix auricularia*; and Asiatic clam *Corbicula fluminea* (Table 1). The Plan lists zebra mussels as a management class 1 ANS – a species that management activities should focus on to prevent introduction or eradicate pioneering populations within State waters. The updated Washington ANS Management Plan is available at http://wdfw.wa.gov/fish/ans/management.htm.

A report to the State Legislature (Pleus et al. 2007) by the AIS Prevention and Enforcement Program for Recreational and Commercial Watercraft, a combined effort by the Washington Department of Fish and Wildlife (WDFW) and the Washington State Patrol, lists zebra mussel, quagga mussel, and New Zealand mudsnails among AIS of primary concern (Table 1). At this time, however, of these three species, only the New Zealand mudsnail has established populations in the State. These populations are located in the lower Columbia River (Bersine et al. 2008; Davidson et al. 2008).

Washington State is taking active measures to mitigate the spread of AIS. Members of both the WDFW and Washington State Patrol have been trained on State AIS laws, identification, inspection, detection, and response. Port of entry stations have trained inspectors on site to inspect commercially hauled watercraft, which may be fined if found to be contaminated. Check stations have been put into place for random watercraft inspections, decontamination kits have

been developed and deployed, and signage has been posted at highway entry points to the State, as well as boat launches and marinas (Pleus et al. 2007).

The State of Idaho

Aquatic invasive species management in the State of Idaho is guided by the Idaho ANS Plan (Idaho Invasive Species Council Technical Committee 2007), which is a supplement to the earlier Idaho Strategic Action Plan for Invasive Species (Northwest Natural Resources Group 2005). Stated goals of the plan are to minimize the harmful ecological, economic, and social impacts of AIS through prevention of introduction, management of population growth, and prevention of dispersal within and from outside of Idaho. High priority freshwater AIS already known to occur in Idaho (as of 2007) include the New Zealand mudsnail and the Asiatic clam. High priority species are defined in the Plan as those species likely to have a high adverse impact but which are not yet found in Idaho and include both zebra and quagga mussels (Table 1). The Idaho ANS Plan is available at http://www.idahoag.us/Categories/Environment/InvasiveSpeciesCouncil/indexInvSpCouncil.php

The Idaho ANS Plan directs an effort to increase the effectiveness of controlling and preventing AIS, including early intervention programs, containment, control and restoration, education and training, research and technology transfer, assurance of adequate funding, creation of an adequate and effective legal structure, and coordination of efforts. The Idaho Department of Environmental Quality has posted decontamination procedures for monitoring equipment (Available at http://www.deq.state.id.us/water/data_reports/surface_water/monitoring/decontamination_procedures.pdf). Idaho has also taken the step of creating an invasive species fund to help support these actions by requiring all motorized and non-motorized watercraft longer than 10 feet that are launching in Idaho waters to purchase and display an Idaho invasive species fund sticker on an annual basis. The Idaho Department of Agriculture is also implementing plans to stop all boats entering the State for AIS inspections.

The State of Montana

With over 70 non-indigenous aquatic species reported in the State as of 2002, the State of Montana developed an ANS Management Plan to coordinate efforts (Montana Aquatic Nuisance Species Technical Committee 2002). Similar to other plans, the goals of this plan are to minimize the harmful ecological, economic, and social impacts of AIS through prevention and management of introduction, population growth and dispersal, and classification of all non-indigenous aquatic species in Montana into different management classes for appropriate actions. Priority Class 1 AIS, those not currently in Montana but having a high potential to invade there with limited or no known management, include zebra mussels. Priority Class 2 listed species, those that are established in Montana and have the potential to spread with little or no known management strategies, are limited to New Zealand mudsnails. Two other priority classes are established in their plan: Class 3 species are not known to be currently established in Montana and have a high potential for invasion, but have appropriate management techniques available; and Class 4 are known to be present in Montana but have appropriate management techniques available. No Class 3 or 4 mollusks were in Montana at the time the plan was written. Other actions called for within the Plan include education and research, establishment of an invasive species council, annual surveys of high-risk waters, emergency response, and a citizen monitoring network. The Montana ANS Management Plan is available at http://fwp.mt.gov/fishing/guide/ANS/default.html.

More recently, quagga mussels have been added to the list of species that fit into the Class 1 category in Montana (E. Ryce, Montana Department of Fish, Wildlife, and Parks, personal communication). Montana has also created a separate category of prohibited species as another means to stop invasives. Prohibited species are described as live, exotic wildlife species, subspecies, or hybrid of that species, including viable embryos or gametes, that may not be possessed, sold, purchased, exchanged, or transported in Montana. This list includes zebra and quagga mussels and New Zealand mudsnails in the mollusk category. The State Department of Fish, Wildlife, and Parks has been operating check stations to look for AIS since 2004.

The State of Oregon

The State of Oregon developed the Oregon ANS Management Plan in 2001 after the realization that their 134 non-indigenous aquatic species were not being comprehensively managed (Hanson and Sytsma 2001). As with the plans of other States, the goals of this plan are to minimize the harmful ecological, economic, and social impacts of AIS through prevention and management of introduction, population growth, and dispersal, and classification of non-indigenous species in Oregon. Management Class 1 species are defined in the Plan as those not known to be present in Oregon at the time of its writing, but with high potential to invade, or which had been reported in Oregon but with limited populations, and included species such as Asian clam and New Zealand mudsnail (both present in Oregon), as well as zebra mussel (not yet reported in Oregon). Management Class 2 listed species, those present and established in Oregon with impacts that may be mitigated or controlled with appropriate management do not, at the time, include any mollusks. Two other management classes are established in the plan: Class 3 are established throughout Oregon with impacts that have no available or appropriate management techniques; and Class 4 are currently considered to have a low potential to invade and establish in Oregon due to physiological or dispersal limits. Other actions called for within the Plan include establishment of a management structure to coordinate AIS activities, education and research, establishment of an invasive species council, annual surveys of high-risk waters, technical assistance to watershed councils, and emergency response plans. Current invasive mollusk species of concern for Oregon (R. Boatner, Oregon Department of Fish and Wildlife, personal communication) are listed in Table 1. The Oregon ANS Management Plan is available at http://www.clr.pdx.edu/publications/files/OR_ANS_Plan.pdf.

The Oregon Invasive Species Council (OISC), created under the Oregon legislature (ORS 561.685) produced an Oregon Invasive Species Action Plan in 2005 to focus on all invasive species (not just aquatic) to Oregon (Oregon Invasive Species Council 2005). The stated goal of this Plan is to facilitate efforts to keep invasive species out of the State, find invasions before they establish permanent footholds, and eradicate incipient populations of undesirable species using coordination and education. The OISC consists of 12 members including State, Federal, Academia, Industry, and other groups with interest in invasive species. In addition to other activities, the OISC has an annual review of their activities, gives out awards to recognize people and organizations that make contributions to protecting Oregon from invasive species, and has created a list of the 100 most dangerous invaders threatening Oregon that is updated annually. The Oregon Invasive Species Action Plan is available at http://www.oregon.gov/OISC/docs/pdf/oisc_plan6_05.pdf.

State and Province Management Plan Summary

A few common themes were found in this review of States and Provincial AIS Management Plans. There is an increased awareness of the AIS problem throughout the region and an increase in actions to stop the spread of AIS. All areas, with exception to the Yukon Territory,

now have management plans in place to direct actions towards containment, removal, and exclusion of AIS. Also, all States, with exception of Alaska, have formal Invasive Species Councils to guide efforts between State, Federal, and Non-Governmental Organizations.

Field Identification Information

Correct identification of AIS is necessary for documenting their presence and enacting measures to stop their spread. It is also important to be able to differentiate between AIS and naturally occurring local species (e.g., Alaskan native mollusks; Appendix 1). The information presented below will assist with the field identification of adult zebra mussels, quagga mussels, and New Zealand mudsnails. However, clear guides with color images of the various life stages or growth forms that may be encountered should also be developed or obtained for inspection purposes.

Zebra Mussel

Zebra mussels are bivalve mollusks of the Order Veneroida, whose shells consist of two plates called valves that connect with a flexible hinge. They can attain sizes of 5 cm, although most are much smaller in North America (Miller et al. 1992). Unlike freshwater mussels native to North America that have a single byssal thread present only in juveniles, zebra mussels can have over 100 byssal threads that remain through adulthood. These are the threads that help the mussels cling to surfaces, including other mussels. Their shells are elongate and generally shaped like common seashore mussels with a zebra-like stripe pattern and a flattened margin on the hinge at the back (Figure 1; Mackie and Schloesser 1996). As their species name, *D. polymorpha*, suggests, they can exhibit extreme variation in shell color and pattern (Marsden et al. 1996).

Figure 1. Image of zebra and quagga mussels with basic descriptive differences. Photo courtesy of U.S. Geological Survey.

Quagga Mussel

Quagga mussels are bivalve mollusks of the Order Veneroida and are similar in shape to the closely related zebra mussel, but generally are more rounded in appearance and without the flattened surface at the hinge. Like zebra mussels, they also produce byssal threads in high numbers as juveniles and adults. Quagga and zebra mussels can be differentiated based on other shell morphological characters as well. Quagga mussels lack a carina, or acute angle, between the ventral and dorsal surfaces in comparison to zebra mussels (May and Marsden 1992). Also, when viewed from the front or ventral side, zebra mussels are symmetrical (the same on both sides), while quagga mussels are distinctly asymmetrical (Domm et al. 1993). Quagga mussels have varied coloration with white, black, or cream bands, and tend to display dark concentric rings that become paler in color near the hinge (Figure 1; Mackie and Schloesser 1996; Marsden et al. 1996). There is also an all white morph found in Lakes Erie and Ontario (Marsden et al. 1996). Domm et al. (1993), Marsden et al. (1996), and the U.S. Army Corps of Engineers Zebra Mussel Research Program (2002) provide detailed illustrations of the differences in shell morphology and coloration within and between zebra and quagga mussels. The U.S. Army Corps of Engineers (2002) illustrations are available at: http://el.erdc.usace.army.mil/zebra/zmis/zmishelp4/distinguishing_between_dreissenid_species.htm.

New Zealand Mudsnail

The New Zealand mudsnail is a member of the gastropod Order Prosobranchia, the lungless snails. Prosobranch snails are distinguished from other gastropods by the presence of an operculum, a sort of 'trap door', which, in the case of this snail, is ovate in shape and thin, with an off-center nucleus, and can be used to seal the shell to avoid unfavorable conditions (Zaranko et al. 1997; Richards et al. 2001). The New Zealand mudsnail's shell is dextral (opens to the animal's right), normally with 5 or 6 whorls in adults, and reaching a reported maximum size of 5 to 6 mm in the western U.S., but up to 12 mm long in its native range (Figure 2; Winterbourn 1970; Zaranko et al. 1997). The aperture of the shell is elliptical and its height is less than the height of the spire, or all of the whorls in the shell except for the last whorl (Levri et al. 2007). A unique defining character for this species is that the outline of the spire is concave and attenuate, or narrow, with small protruding whorl at the tip (Zaranko et al. 1997). The shell surface may be smooth or may have a raised periostracal spine with ornamentation (Zaranko et al. 1997; Holomuzki and Biggs 2006). Shell coloration varies from light brown to dark brown or gray. Further descriptive information is available from two sources: U.S. Army Corps of Engineers Aquatic Nuisance Species Research Program (2006) - http://el.erdc.usace.army.mil/ansrp/potamopyrgus_antipodarum.pdf ; and Montana State University (2007) - http://www.esg.montana.edu/aim/mollusca/nzms/index.html.

Distributions of Target AIS

Native Distributions and North American Introductions

The native distribution for zebra mussels is the region around the Black, Caspian, and Azov seas (Stanczykowska 1977). However, they are now also common throughout Europe (Griffiths et al. 1991) and are spreading through North America. Their introduction to North America is thought to have occurred via discharge of ballast water in Lakes St. Clair and Erie from ocean-crossing vessels sometime around 1985 (Hebert et al. 1989). Zebra mussel populations have spread throughout eastern-central North America and are now as far west as California (Benson 2010a).

The quagga mussel is native to the Dneiper River drainage of Ukraine and, like the zebra mussel, has now spread through both Europe and North America (Mills et al. 1996). The first specimens of the quagga mussel recognized in North America came during a survey of zebra mussel genetic variability in the Laurentian Great Lakes in 1989 (May and Marsden 1992). Quagga mussels have rapidly colonized new areas, similar to the spread of zebra mussels, with populations being found in the Mississippi River basin by 1995 (Mills et al. 1996), and they have recently spread to the western United States (Stokstad 2007; Benson 2010b).

Figure 2. Image of New Zealand mudsnails with scale for reference. Photo courtesy of U.S. Geological Survey.

New Zealand mudsnails are native to the two main islands of New Zealand (Winterbourn 1970) and have spread to Europe, Australia, Asia, and North America (Ponder 1988; Davidson et al. 2008). There appear to have been three invasions of North America by this species; two in the Snake River system of southern Idaho in the mid-1980's (Bowler 1991) and another in Lake Ontario that was first recognized in 1991 (Zaranko et al. 1997). Although New Zealand mudsnail populations within their native range and in Australia are comprised of a diverse array of clonal lineages reproducing both sexually and asexually, each invasive population appears to be comprised almost entirely of genetically identical female clones (Dybdahl and Lively 1995; Jokela et al. 1997). This appears to be the case in North America as the invasions of eastern and

western North America are comprised of different clonal lineages: two in the west and one in the east (Dybdahl and Kane 2005; Levri et al. 2008).

Current Distributions in western North America

There have yet to be any reports of established zebra mussel, quagga mussel, or New Zealand mudsnail populations in Alaska. While widespread through the east-central United States, zebra mussels have now also established populations in western States, including Colorado, Utah, and California (Benson 2010a). Quagga mussels have a more limited distribution on the eastern-central States than zebra mussels but have thus far invaded more water bodies in the West. They have now established populations in Colorado, Utah, Nevada, Arizona, and California (Benson 2010b). Many of these quagga mussel populations are present in deep reservoirs of the Colorado River, such as Lake Mead, and its associated aqueduct system that supplies water to southern California (Stokstad 2007). The New Zealand mudsnail has recently been found on Vancouver Island, British Columbia (Davidson et al. 2008). Populations of New Zealand mudsnails in western North America have also been documented in Arizona, California, Colorado, Idaho, Montana, Nevada, Oregon, Utah, Washington, and Wyoming (Gustafson 2009; Benson 2010c). Detailed dot and hydrologic unit code (HUC) maps of invasion sites are available online (Montana State University, 2007). Regularly updated distribution maps are also provided by the U.S. Geological Survey (USGS) and are available at their Nonindigenous Aquatic Species website (USGS 2009) - http://nas.er.usgs.gov/default.aspx.

Ecology and Life History

Although they are all members of the phylum Mollusca, the closely related zebra and quagga mussels (Class Bivalvia, Order Veneroida) differ significantly from the New Zealand mudsnail (Class Gastropoda, Order Prosobranchia) in a number of life history characteristics and morphological features that profoundly affect their dispersal abilities. Information pertaining to reproduction, larval stages, adult forms, and general ecology for each of the three species is discussed below. Due to their overall similarity, zebra mussel and quagga mussel information are presented together, with differences between the two species identified as they arise.

Zebra and Quagga Mussels

Zebra and quagga mussels are found in freshwater lakes and rivers where water temperatures range from 0° to 25° C, dissolved oxygen is greater than 90% saturation, and there is at least 10 mg/L dissolved calcium for shell production (Miller et al. 1992; Whittier et al. 2008). Adults of both species are commonly immobile, living affixed to a wide array of solid objects by the byssal threads. The ability to attach using byssal threads is the primary reason that these species can be such an economic burden, as the mussels use them to cling to various materials, clogging intake pipes at industrial and municipal water plants, causing problems for fire prevention and irrigation systems that use raw water, fouling cooling systems on motorized boats, and causing issues with lock and reservoir systems. Zebra mussels have been found attached to plastic, concrete, wood, fiberglass, iron and polyvinyl chloride pipes, rocks, logs, aquatic plants, shells of native bivalves (causing their eventual demise), and exoskeletons of crayfish (Miller et al. 1992). Unlike these invasive species, native freshwater mussels in North America burrow into sand and gravel and do not attach to hard surfaces as adults.

Both zebra and quagga mussels are highly effective filter feeders. They filter a broad size range of particles from the water column, from 0.7 to 40 µm and occasionally larger (Ten Winkel and Davids 1982; Sprung and Rose 1988). Rejected particles such as clays, silt, and non-edible algae

are enveloped in mucus and expelled as pseudofeces, which settle to the bottom. The filtering process and associated bio-deposition of feces and pseudofeces have been speculated to improve water clarity (Ten Winkel and Davids 1982; MacIsaac 1996). Zebra mussels have even been used in bio-manipulation programs in The Netherlands to remedy poor water quality because of these filtering abilities and the fact that they can feed year round (Reeders and Bij de Vaate 1990). However, this efficient filter feeding, when combined with the ability to establish at very high densities, can dramatically disrupt ecosystem functions. For example, juvenile sockeye salmon are dependent on plankton as a food source in lakes (Quinn 2005). Therefore, a zebra or quagga mussel invasion that removes this food source from the water column could threaten the stability of sockeye salmon populations.

The life history of zebra and quagga mussels can be described as having two main stages: larval and adult (Ackerman 1995). Under natural thermal regimes in the Pacific Northwest, adult mussels release eggs during spring and summer, although reproduction can occur continually in thermally polluted areas (Miller et al. 1992; Claxton and Mackie 1998). Females, which can produce over 1 million eggs per season, become reproductively active at 12 months of age or less. By comparison, native mussels usually become reproductively active at age 5 (Miller et al. 1992). Gametes are released into the water column where external fertilization occurs (Ackerman et al. 1994). Fertilized eggs hatch into planktonic larvae known as trochophores (pre-shell) and develop into veligers that are covered in a D-shaped shell-like velum, which can stay in the water column for up to one month (Ackerman et al. 1994; Nichols and Black 1994). The larvae of zebra and quagga mussels are non-parasitic free-swimmers that complements their ability to be successful colonizers. These qualities can be contrasted with native North American bivalves that have parasitic larval development and require an intermediate host for dispersal (McNabb 1993; Ackerman et al. 1994). As zebra and quagga mussel veligers settle to the substrate, more organs form, including the foot and gill filaments. At this stage, mussels can still move about using their foot to swim near the bottom or crawl on surfaces.

The mussel is considered to be a postveliger following metamorphosis, which occurs at some time between 18 and 90 days after fertilization when it anchors to a surface using its byssal threads (Ackerman et al. 1994). At this time the velum is absorbed, the gills, mouth, and hard shell develop, the foot increases in size, there is a reorientation in the mantle cavity, and the clam-like shape is replaced with a more triangular mussel shape. The onset of sexual maturity can occur at sizes as small as 5 mm (Ackerman 1995). Movement of juveniles and adults is common and achieved by purposefully releasing from their original substrates and moving on their own or by clinging to moving substrate such as aquatic vegetation (Ackerman et al. 1994).

Some differentiation in habitat usage is apparent between zebra and quagga mussels. In Lake Ontario, for example, both mussels co-exist at depths from 8 to 110 m while only quagga mussels are found at 130 m depth (Mills et al. 1993). In portions of Lake Erie, quagga mussels are found in densities 14 times greater than zebra mussels in waters below 40 m depth. Quagga mussels are also more likely than zebra mussels to colonize soft or sandy substrates.

New Zealand Mudsnails

The New Zealand mudsnail has been recorded from a variety of habitats including rivers, streams, creeks, ponds, lakes, springs, and estuaries within its native range in New Zealand (Winterbourn 1970). It is a detritivore-herbivore that will feed on plant and animal detritus, green algae, and diatoms (Haynes and Taylor 1984), and thrives in disturbed systems that have increased filamentous green algae production and sedimentation (Suren 2005). It has been recorded in fresh and brackish water (Winterbourn 1970). It reportedly will bury itself in the

sediment during cold or dry periods (Duft et al. 2003); however, it does not survive in systems that seasonally dry and does not survive freezing (Hylleberg and Siegismund 1987).

The life history of New Zealand mudsnails is well suited for invasion, as they give birth to live young (viviparous), can reproduce sexually (diploid) or asexually (parthenogenic triploid), and have an annual life cycle (Lassen 1979). Sexual maturity is reached at a size of 3.5 mm and females have an estimated annual fecundity of 230 young while carrying between 50 and 100 embryos at various developmental stages within the brood pouch (Winterbourn 1970; Lassen 1979). As previously mentioned, invasive populations have all found to be parthenogenetic reproducing clonal females. While male New Zealand mudsnails are occasionally found in North America (Wallace 1979), they are considered to be irrelevant abnormalities because no sexual (diploid) females have been identified (M. Dybdahl, Washington State University, personal communication).

New Zealand mudsnails can spread by both active and passive dispersal methods. Haynes et al. (1985) found that these snails exhibit positive rheotaxis and can move upstream in flowing waters. They have also been observed to readily enter the drift following disturbance and to raft on floating vegetation mats (Richards et al. 2001). Also of interest is their ability to survive passage through the intestinal tract of fish and give birth shortly thereafter, which could expedite their movement to new areas (Haynes et al. 1985; Bruce et al. 2009).

Another key to the invading success of the New Zealand mudsnail is an ability to tolerate a wide variety of aquatic environments. Populations in North America exist in lakes, in shallow spring-fed streams, in rivers, and in brackish estuarine environments. They are found in several of the Laurentian Great Lakes at a depth range between 4 and 45 m on silt and sand-type sediments (Zaranko et al. 1997; Levri et al 2007). Their first appearance in North America was from the upper region of the Middle Snake River of Idaho where they were found on filamentous algae, macrophyes, and rocks (in riffle sections) between the water surface and 10 cm depth, and quickly became the dominant molluskan fauna (Bowler 1991). They have also been found at the freshwater-marine interface from multiple locations in the Pacific Northwest (Bersine et al. 2008; Davidson et al. 2008).

Environmental and Experimental Tolerances

To predict the environmental variables favorable to AIS invasion and transport, it is important to understand their tolerances to different environmental stressors (Table 2). Although many of these values were obtained through laboratory studies, natural variation among populations may exceed the thresholds presented here. As an example, zebra mussels have a salinity (S) tolerance ≤ 5 parts-per-thousand (‰) in North American populations and can only survive ≤ 0.5‰ S in estuaries on the Atlantic coast of the Netherlands, but have been shown to survive up to 12‰ S in inland seas of Eurasia (Mills et al. 1996). McNabb (1193) provides further information pertaining to limnological parameters required by colonizing zebra mussels, including pH (≥7), turbidity (≤ 50 Nephelometric Turbidity Units – NTU's), and eutrophy (Total Phosphorus <0.25 mg L^{-1} or Total Nitrogen <4.0 mg L^{-1}).

Understanding thresholds and parameters allows for the development of invasion risk assessment models, as was recently done for zebra and quagga mussels using calcium concentration in stream waters in the contiguous United States (Whittier et al. 2008). Calcium is necessary for basic metabolism function and shell construction in dreissenid mussels, and is required at higher concentrations than for many other freshwater mussels. EPA water chemistry calcium

Table 2. Environmental tolerance ranges for zebra mussels (ZM), quagga mussels (QM), and New Zealand mudsnails (NZMS). Ranges based primarily on laboratory studies.

Attribute	Range	Source
	Salinity	
ZM	Mortality at ≥5‰ S	Spidle et al. 1995
QM	Mortality at ≥5‰ S	Spidle et al. 1995
NZMS	Survival up to 30‰ S, active below 17.5‰ S	Winterbourn 1970; Hylleberg and Siegismund 1987
	Water temperature – cold	
ZM	Lethal at -1.5°C for individuals	McMahon et al. 1993
	Lethal at -3.0°C for clusters	McMahon et al. 1993
QM	Does not survive freezing	R. McMahon personal communication
NZMS	Does not survive freezing	Hylleberg and Siegismund 1987
	Water temperature – hot	
ZM	Lethal at 35°C	Spidle et al. 1995, McMahon et al. 1993
QM	Lethal at 30°C	Spidle et al. 1995
NZMS	Stopped reproduction at ≈ 24°C	Dybdahl and Kane 2005
	Lethal at 35°C	Quinn et al. 1994
	Desiccation tolerance – high humidity	
ZM	Survive 3-15 days (temperature dependent)	Ricciardi et al. 1995
QM	Survive 3-10 days (temperature dependent)	Ricciardi et al. 1995
NZMS	Survive for ≥50 days (on damp surfaces)	Winterbourn 1970
	Desiccation tolerance – low humidity	
ZM	Survive 1-10 days (temperature dependent)	Ricciardi et al. 1995
QM	Survive up to 3 days	Ricciardi et al. 1995
NZMS	Survive up to 30 hours	Winterbourn 1970

concentration survey data were used in the model to predict areas of high (mean > 28 mg L^{-1} and 25th percentile > 12 mg L^{-1}), low (12 mg L^{-1} < 75th percentile < 20 mg L^{-1} or 75th percentile < 21 mg L^{-1} and maximum < 28 mg L^{-1}), and very low risk (75th percentile <12 mg L^{-1}). A comparison of predicted invasion areas with known invasion areas showed a high degree of similarity. Alonso and Castro-Díez (2008) provide a review for the New Zealand mudsnail, showing that their wide tolerance range to physio-chemical factors, high competitive ability

(especially in human altered ecosystems), and reproductive rate have allowed them to be successful invaders.

Zebra mussels, quagga mussels, and New Zealand mudsnails share some environmental tolerances while being distinctly different in others (Table 2). While zebra and quagga mussels have very low tolerance (>5‰) to saline waters (Spidle et al. 1995), New Zealand mudsnails have been found in environments up to 26‰ salinity (Winterbourn 1970) and may tolerate higher salinities, as has been shown in short-term experiments where they survived a 7-day exposure at 30‰ salinity (Hylleberg and Siegismund 1987). While zebra mussels are able to tolerate temperatures just below freezing in certain situations (McMahon et al. 1993), neither quagga mussels nor New Zealand mudsnails survive temperatures below freezing (R. McMahon, University of Texas at Arlington, personal communication; Hylleberg and Siegismund 1987). Lethal upper temperatures for quagga mussels is around 30°C (Spidle et al. 1995), while zebra mussels and New Zealand mudsnails survive up to 35°C (McMahon et al. 1993; Quinn et al. 1994), however experimental testing has shown that the New Zealand mudsnails stop reproductive activities at around 24°C (Dybdahl and Kane 2005).

Of particular importance is the ability of these AIS to tolerate desiccation during overland transport. Experimental studies have shown that the three species of interest could survive short trips (1-2 days) in the correct temperature range (~20° C) with low humidity conditions (Winterbourn 1970; Ricciardi et al. 1995). In high humidity conditions at this same temperature, and on damp surfaces, quagga mussels could survive 3-10 days (Ricciardi et al. 1995), zebra mussels could survive 3-15 days (Ricciardi et al. 1995), and New Zealand mudsnails could survive up to 50 days (Winterbourn 1970). It should be noted the median and maximum survival times for all three of these invaders are well within what might be the expected travel time for a trailered boat being brought to Alaska from Canada or the Lower 48 States.

Dispersal Vectors

Understanding both natural and anthropogenic dispersal vectors is critical to stopping the introduction of AIS to new areas. Movement of AIS within a body of water such as a lake or stream can occur by active and passive dispersal (Ribi 1986; Siegismund and Hylleberg 1987; Carlton 1993; Ackerman et al. 1994). Transport to other bodies of water, however, is dependent upon active dispersal, mainly by anthropogenic vectors. Recreational boats and trailers are of particular importance because they provide suitable attachment substrates in the short-term (a means of dispersal from infested to uninfested waters) and can be inspected for the presence of AIS (Carlton 1993; Johnson et al. 2001). Other documented dispersal vectors include recreational fishing equipment, floatplanes, firefighting equipment, and other anthropogenic mechanisms (Carlton 1993; Hosea and Finlayson 2005; Zook and Phillips 2009).

Recreational Boats and Trailers

As noted above, zebra mussels and quagga mussels can survive extended periods out of water, especially if local conditions are cool and humid. For these two species the general recommendation for quarantine time for a boat moving from infested to uninfested waters is a minimum of 30 days after cleaning all equipment and draining all possible sources of standing water (100th MI 2009). However, New Zealand mudsnails have the potential to survive up to 50 days out of water (Ricciardi et al. 1995; Winterbourn 1970), and a recommended quarantine time has not been developed for this species. Recreational boats and trailers are therefore potential vectors for these mollusks, even after long overland trips. For example, a boat and trailer traveling from the Great Lakes to the Kenai Peninsula, Alaska, can easily complete the journey

within these time frames. In a comprehensive review of dispersal mechanisms for zebra mussels, Carlton (1993) found them in or on nearly all surfaces of recreational watercraft. AIS have also been found indirectly attached to boats and trailers on vegetation or in mud (Davidson et al. 2008). The U.S. Army Corps of Engineers Zebra Mussel Information System reports that boats in infested waters for as few as one or two days may have mussels attached to them (U.S. Army Corps of Engineers 2002). However, another survey of transient recreational boaters (boats in the water for one week or less) found that a week did not appear to be long enough to allow for fouling of hulls (Johnson et al. 2001). The majority of AIS transported with transient boats were found on aquatic vegetation entangled on the boats or trailers. This survey also discovered that boats placed in water for short durations were more likely to transport larval zebra mussels than adults, which has positive implications as larval mussels have lower survival rates than adult mussels during transportation. Regardless of transport time and weather conditions encountered by a trailered boat, the passage into Alaska of recreational boats from other regions infested by invasive mollusk populations would increase the risk of colonization events. Further information about quarantine time is available from the 100th MI watercraft quarantine estimator - http://www.100thmeridian.org/emersion.asp.

Wading Boots and Fishing Equipment

Fishing equipment, including felt-soled wading boots, have been shown to be important vectors for AIS spread (Hosea and Finlayson 2005). In California, the only known population of New Zealand mudsnails had existed in the Owens River on the eastern slope of the Sierra Nevada Mountains (Bowler 2001). Transport via fishing gear or waders is believed to have then spread New Zealand mudsnails from the Owens River to other streams and rivers in the surrounding area and to the western slope of the Sierras. Other fishing equipment, such as nets, cages, and bait-bucket water, has also been implicated in the movement of AIS (Carlton 1993). The ban of felt soles on wading boots is being considered in many places to curb the spread of AIS. While fishing equipment companies have identified many options and are developing additional felt-free alternative products, bans are already in place in New Zealand as of 2008 (New Zealand Fish and Game 2008), and will be regulated throughout Alaska starting in 2012 (under Alaska State regulation 5 AAC 47.030).

Other Potential Vectors

Although the focus of this document is to assess the potential introductions of AIS into Alaska through recreational boating, it is important to realize that there are many other transportation vectors that could spread these species. Industrial pumps and other equipment used in infested waters, such as fish stocking trucks, fire trucks, and water-dumping firefighting aircraft, can spread AIS (Bowler 1991; Carlton 1993; McNabb 1993). Commercial movement of aquaculture products (fish eggs, live fish) from infested facilities or agriculture products watered from infected waterways could also be vectors (Bowler 1991; Bruce et al. 2009). Any solid object that is moved to a new location after being left in infested water for some time (for example channel marker buoys and floats, oil and gas exploration and drilling rigs, or scientific research gear) could transport AIS to new locations (Carlton 1993). There is a potential for floats (pontoons) on amphibious planes to harbor AIS (Carlton 1993; Pleus et al. 2007). The spread of some AIS, for example New Zealand mudsnails, can be enhanced through dispersal by fish, as they can survive passage through the gastrointestinal tract of some fishes (Haynes et al. 1985; Bowler 1991; Bersine et al. 2008). Mechanisms for distribution of mollusks between water bodies include reservoir systems, canals, and irrigation pipes (Haynes et al. 1985; Stokstad 2007). Other natural means for transfer of mollusks among water bodies include twisters (tornadoes),

insects, and birds (Coates 1922; Rees 1965; Lassen 1975; Haynes et al. 1985; Ribi 1986; Richards et al. 2004).

Detection of AIS and Decontamination Methods for Watercraft and Trailers

Detection

Fouled watercraft and trailers have the potential to spread AIS to waterways across North America by means of repeated introductions in waters easily reached from areas of existing populations (Carlton 1993; Lodge et al. 1998; Johnson et al. 2001; Drury and Rothlisberger 2008). As such, known populations should be important focal points for monitoring and removal activities. Desiccation studies have shown that the three AIS of interest in this analysis can survive for extended periods of time (Table 2) in damp environments, such as those found in engine cooling systems and bilges of boats, under trailer fenders, around rollers, and in other crevices (Winterbourn 1970; Ricciardi et al. 1995). Therefore, any transportation of watercraft between infested and non-infested waters is a concern. The following list provides suggested locations to check for AIS on watercraft and trailers based on reviews of AIS transport (Carlton 1993; Zook and Phillips 2009). Many of these locations are included on watercraft inspection checklists for other jurisdictions and should be a part of any protocol that is developed for Alaska.

Exterior surfaces (at or below water line).—Hull, transducer, speed indicator, through-hull fittings, trim tabs and plates, zincs, centerboard box and keel (sailboats), foot-wells, rudders, and pontoons (catamarans).

Propulsion system.—Lower unit, cavitation plate, cooling system intake, propeller and propeller shaft, bolt heads, engine housing, jet intake, paddles and oars, exhaust outlets, hydraulic cylinders, propeller guards, transducers, and trolling plates.

Interior area.—Bait and live wells, storage areas, splash wells under floorboards, bilge areas, water lines, ballast tanks, and drain plug.

Equipment.—Anchor, anchor and mooring lines, PFD's, swim platform, wetsuits and dive gear, inflatable craft, down-riggers and planing boards, water skis, wake boards and ropes, ice chests, fishing gear, bait buckets, stringers.

Trailer.—Rollers and bunks, light brackets, cross-members, license plate bracket, and fenders.

Decontamination

Once AIS become established in a waterbody, eradication, if possible at all, can be extremely difficult and prohibitively expensive. It is therefore imperative to address other aspects of their spread that can be more effectively and efficiently controlled, such as identifying and decontaminating fouled recreational boats and their associated equipment. Several methods for decontamination have been proposed and tested for zebra mussels, quagga mussels, and New Zealand mudsnails.

Desiccation, in particular drying with heat, has been proposed for use on recreational boating equipment (Richards et al. 2004). More recently, the use of hot water sprays has been suggested as an effective method of decontaminating boats (Morse 2009). It was found that sprays of ≥ 60°C for 10 seconds or ≥ 80°C for 5 seconds were 100% lethal for zebra mussels. Other suggested methods included combinations of hot water sprays and desiccation. Rothlisberger et al. (2010) found that transport of high-risk macrophyte AIS can be prevented through visual

inspection and hand removal, but high pressure sprays were necessary for removal of small bodied AIS organisms. Further protocols and standards for the use of hot water sprays for decontamination can also be found in the Recommended Uniform Minimum Protocols and Standards for Watercraft Interception Programs for Dreissenid Mussels in the Western United States (Zook and Phillips 2009), which were recently adopted by the Western Regional Panel of the Aquatic Nuisance Species Task Force (J. Heys, USFWS, personal communication). This document covers the standards for temperature, soak time, water volume, and pressure, and also discusses attachments for hard to reach or sensitive areas, storage tanks, and cooling systems.

Methods for decontamination of fishing equipment, such as waders, nets, and boots, for New Zealand mudsnails and other AIS include the use of household disinfectants, freezing, or desiccation as well as visual inspection and cleaning (Dwyer et al. 2003; Richards et al. 2004; Hosea and Finlayson 2005; Schisler et al. 2008). As noted above, known populations should be important focal points. Accordingly, it is important for those trailering boats to take preventive measures before leaving the vicinity of infested waters. Other programs, such as Protect Your Waters (ANS Task Force 2010) provide recommended actions for boaters before they leave boat landings to reduce the likelihood of transporting AIS, including removing animals, plants, and mud from boats and trailers, and draining all water from the boat, motor, live wells, bilge, and bait buckets. Because the act of decontamination itself can present some risk of further spreading the invasive species that are removed from the infested gear, any efforts to further develop decontamination options should include a prevention plan following the format of Hazard Analysis and Critical Control Points (HACCP), as recommended by USFWS (2008).

Alaska Roadway Detection and Interception Points

Human activities have aided the dispersal of Dreissenids and other AIS across much of the continental United States and into southern Canada. Examination of AIS dispersal patterns illustrate that virtually any water body within a few days travel of a contaminated area is at risk of invasion (Griffiths et al. 1991). As such it is crucial that at inspection points, like border crossings, known vectors, such as boats and trailers, should be inspected and, if invasives are found, not allowed to pass until decontaminated. Individual inspection findings, or patterns of findings, from one location can inform the decisions and activities undertaken at other locations, particularly along the same road system. A shared reporting and alert system among neighboring inspection points, with critical personnel identified, should be developed to facilitate timely notice of invasive mollusks or other AIS if they are detected.

The main intercept areas for detection of freshwater AIS entering Alaska on boats and trailers would be along the U.S.-Canada border, specifically at Customs checkpoints. The Alcan Portal should be a primary inspection point, as the majority of traffic that passes into interior Alaska arrives via this route. However, it is important to note that there are numerous other roadway points of entry into Alaska including the border crossings at Poker Creek (Taylor/Top-of-the-World Highway), Haines (Haines Highway), Skagway (Klondike Highway), and Hyder (Glacier Highway, Canada), as well as boat traffic on the Yukon River, and via the Alaska Marine Highway ferry system and marine barges. Ultimately, successfully safeguarding Alaska from invasion of AIS would require that inspection and prevention measures for recreational watercraft be undertaken by trained personnel at all points of entry. In those cases where AIS are found, complete removal and decontamination options may exist on-site or may require travel to another location to access the needed equipment.

Current Border Crossing Operations in Alaska

Most border crossings and vehicle inspections, including AIS inspections, are the responsibility of State agencies for the lower 48 States. However, in Alaska all of the land-based ports of entry are shared with Canada. As such, agencies responsible for monitoring various AIS and other prohibited species or goods include Customs, USFWS, and U.S. Department of Agriculture, though representatives of some State agencies participate in training activities.

Recent contact with Customs agents confirmed that there is awareness of the AIS threat to Alaska and that some AIS monitoring activities are occurring. Customs Agricultural Specialists are assigned to Portals on the Alaska, Klondike, and Haines Junction (Dalton Cache Alaska) highways. During the past few summers, boats have been inspected for zebra mussels at port of entry stations where Agriculture Specialists have been posted (T. Keough, Customs, personal communication). The inspections have consisted of exterior examination of boat hulls, exhaust pipes, and other structures for noticeable attachment by AIS. However, currently there are no set protocols at these port of entry stations for AIS inspections or on-site decontaminations. Previous training sessions and materials for the Agriculture Specialists have been provided by USFWS personnel, Customs agents, and Watercraft Inspection Training contractors arranged through the Pacific States Marine Fisheries Commission. Plans are in place for USFWS LE and ADFG staff to provide AIS training to Customs personnel for the 2010 summer season.

Conclusions and Recommendations

It is evident from the information presented above that invasive mollusks are extremely well adapted for dispersal using recreational watercraft and trailers as a vector and to colonize new aquatic habitats they encounter. It is also evident that many of these invading species, even as adults, can be quite small and thus difficult to detect and identify on boats, in engine cooling systems, on trailers, and other equipment. For this reason, it is recommended that all such gear be cleaned as a routine matter regardless of whether invasive species are actually observed.

If invasive mollusks are detected or suspected on boats or other equipment, specific actions must be taken to kill and remove them; otherwise, they will persist. Establishing an effective AIS monitoring and prevention program for watercraft entering Alaska via the road system should be a high priority and will require several components. First and foremost, it will require trained agents to be stationed at ports of entry points, particularly during the late spring and summer months. It will also require a plan for dealing with invasive mollusks if they are detected. This may entail on-site decontamination by one of the means outlined above, with a re-inspection to verify that all AIS have been removed; or decontamination at a location in Canada, again with re-inspection when they return to the border crossing. In the case of zebra mussels, a species specifically prohibited from importation under the Lacey Act, allowing entry without clear evidence of having removed the mussels is illegal. Finally, notification protocol with appropriate contact information for informing other interested parties of detection events as they occur will be important. For the latter two components, it is worth noting that the Western Regional Panel of the National ANS Task Force has recommended to its member States (which include Alaska) that they implement trailered boat inspections according to the 100th MI guidelines which include both a standard survey form and a searchable database (Western Regional Panel on Aquatic Nuisance Species 2010).

Zook and Phillips (2009) also provide a comprehensive set of guidelines for developing an effective program and discuss options for organizations with different financial resources, legal authorities, and other situations. An effective prevention, detection, monitoring, and

decontamination program for freshwater mollusks at the Alcan Portal and other ports of entry to Alaska will require extensive coordination with the appropriate Customs agents, State and Federal Agricultural Specialists, and ADFG personnel. Successfully stopping the road invasion of freshwater mollusks will require trained inspectors at all ports of entry, a consistent and thorough inspection process, an easily used and accessible system for reporting inspection findings, and clear options for either on- or off-site decontamination. Public outreach will be an important component of the overall effort to prevent AIS invasion of Alaska waters, but is not sufficient by itself. Finally, there are many vectors of AIS dispersal to Alaska waters besides vehicles traveling the road system, including angler gear, floatplanes, and firefighting equipment. Some of these vectors may be subject to effective regulation through other means than border inspections, but others may not.

As a portent to the future, Customs agents stationed at the Alcan portal identified three boats in one party during a recent boating season that were contaminated with zebra mussels (T. Robson, Law Enforcement, USFWS, personal communication). Customs agents, in concert with USFWS, Law Enforcement, denied these boats entry into the U.S, as these mussels are a prohibited species under the Lacey Act. The boats reportedly returned to Whitehorse, Yukon Territory, where they were decontaminated. They returned to the Alcan portal the following day and, after a second inspection, were allowed entry. Follow-up information indicated that the boats had been purchased from the Great Lakes area. This incident demonstrates that dedicated and focused monitoring, prevention, and decontamination programs must be implemented to ensure that Alaska stays free of AIS.

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Appendix 1. Freshwater mollusks native to Alaska

This list is a compilation of mollusk species native to Alaska based on Clarke (1981), Freshwater Molluscs of Canada, and the Alaska Natural Heritage Program (2009) invertebrate species list.

Class Gastropoda (Snails)
- Subclass Prosobranchia (Gill-breathing snails)
  - Order Heterostropha
    - Family Valvatidae (Valve snails)
      - *Valveta lewisi* – Fringed valvata
      - *Valvata mergella* – Rams-Horn valvata
      - *Valvata sincera* - Mossy valvata

- Subclass Pulmonata (Lung-breathing snails)
  - Order Basommatophora
    - Superfamily Lymnaeacea
      - Family Lymnaeidae (Pond snails)
        - *Fossaria modicella* – Rock fossaria
        - *Fossaria obrussa* – Golden fossaria
        - *Fossaria truncatula* – Attenuate fossaria
        - *Lymnaea atkaenis* – Frigid lymnaea
        - *Lymnaea stagnalis* – Swamp lymnaea
        - *Radix auricularia* – Big-eared radix
        - *Stagnicola arctica* – Arctic pondsnail
        - *Stagnicola caperata* – Wrinkled marshsnail
        - *Stagnicola elodes* – Marsh pondsnail
    - Superfamily Physacae
      - Family Physidae (Tadpole snails)
        - *Aplexa elongata* – Lance aplexa
        - *Physa jennessi* – Obtuse physa
        - *Physa sibirica* – Frigid physa
        - *Physa skinneri* – Glass physa
        - *Physella gyrina* – Tadpole physa
    - Superfamily Planorbidae
      - Family Planorbidae (Rams-horn snails)
        - *Gyraulus crista* – Star gyro
        - *Gyraulus deflectus* – Flexed gyro
        - *Gyraulus parvus* – Ash gyro
        - *Helisoma anceps* – Two-ridge rams-horn
        - *Menetus opercularis* – Button sprite
        - *Planorbella subrenata* – Rough rams-horn
        - *Planorbella trivolvis* – Marsh rams-horn
        - *Promenetus exacuous* – Sharp sprite
        - *Promenetus umbilicatellus* – Umbilicate sprite

Class Bivalvia (Clams and Mussels)
- Order Unionoida
  - Superfamily Unionacea (Freshwater mussels)
    - Family Margaritiferidae (Pearly River-mussels)
      - *Margaritifera falcata* – Western pearlshell
    - Family Unionidae (Pearly mussels)
      - *Anodonta beringiana* – Yukon floater
      - *Anodonta kennerlyi* – Western floater
- Order Veneroida
  - Superfamily Corbiculoidea
    - Family Pisidiidae (Fingernail & Pea clams)
      - *Pisidium casertanum* – Ubiquitous pea clam
      - *Pisidium conventus* – Arctic-alpine pea clam
      - *Pisidium idahoense* – Great northern pea clam
      - *Pisidium compressum* – Ridged-beak pea clam
      - *Pisidium ferrugineum* – Rusty pea clam
      - *Pisidium lilljeborgi* – Lilljeborg's pea clam
      - *Pisidium milium* – Quadrangular pea clam
      - *Pisidium variabile* – Triangular pea clam
      - *Sphaerium nitidum* – Arctic-alpine fingernail clam