Invasive Mussels Update

Economic Risk of Zebra and Quagga Mussels in the Columbia River Basin

Independent Economic Analysis Board

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LIST OF ACRONYMS

AIS	Aquatic Invasive Species
IEAB	Independent Economic Analysis Board of the Northwest Power and Conservation Council
ISDA	Idaho State Department of Agriculture
ITD	Idaho Transportation Department
LMNRA	Lake Mead National Recreation Area
MFWP	Montana Fish Wildlife and Parks
NASQAN	National Stream Quality Accounting Network
NGO	Non-Government Organization
NOAA	National Oceanic and Atmospheric Administration
ODFW	Oregon Department of Fish and Wildlife
PNWER	The Pacific Northwest Economic Region
PSMFC	Pacific States Marine Fisheries Commission
QZAP	Quagga-Zebra Mussel Action Plan for Western Waters
USFWS	U.S. Fish and Wildlife Service
USDI BOR	U.S. Department of the Interior Bureau of Reclamation
WDFW	Washington Department of Fish and Wildlife

EXECUTIVE SUMMARY

This report is an update to IEAB Report 2010-1 titled "Economic Risk Associated with the Potential Establishment of Zebra and Quagga Mussels in the Columbia River Basin." Overall, the information provided in this update suggests that recent efforts to augment ongoing regional prevention efforts are justified economically and should be continued if not expanded.

Since 2010, a number of events have led to increasing concern about the probability of zebra or quagga mussels becoming established in the basin.

- More boats fouled with mussels are being detected at state operated watercraft inspection stations. In 2009, 2010, and 2011, Idaho recorded 3, 8, and 25 boats with mussels. In 2012, 57 mussel-fouled boats were detected, even though the number of boats inspected was about the same as the previous year (ISDA 2012). In Oregon, 5 and 18 boats with mussels were detected and decontaminated in 2011 and 2012, respectively (ODFW, 2012). In Montana and Washington, 4 and 30 fouled boats were intercepted, respectively, during 2012. A total of 109 mussel-infested boats were found during more than 106,000 inspections in the four Northwest states in 2012.
- Research suggests that boat owners are not highly effective in cleaning their own boats (Rothlisberger et al. 2010). This suggests that interception and effective cleaning should help reduce the chance of introductions.
- A recent study found that adult quagga mussels could survive in mainstem Columbia Basin water, suggesting that the low calcium content of these waters may not be as much of a limit on mussel survival as previously thought (Sytsma and Adair, 2013).
- Council staff have obtained and summarized water quality data from selected sites in western Montana. These data, which were not obtained for the 2010 IEAB report, indicate calcium conditions that would likely be favorable for mussel establishment, growth and reproduction. A summary of this information is provided in Table 1 (Tables follow text).

The potential economic and ecological impacts of invasive mussels in the Columbia Basin are becoming more widely recognized

- The ecological effects of invasive species generally are becoming more recognized (Perrings, 2002; Sanderson et al, 2009).
- In the Great Lakes, invasive mussels have "lead to dramatic shifts in trophic dynamics and food web structure that has resulted in fishery collapses and the near elimination of some native species" (LeClair et al. 2012, page 10). Zebra or quagga mussels can foster water quality conditions that lead to toxic algae blooms and resulting low dissolved oxygen levels.

- The potential ecological impacts of invasive mussels may include hosting of pathogens and parasites that are harmful to fish, including salmonids, and the presence of mussels in fish ladders and juvenile bypass facilities could lead to abrasions, injuries and infections (LeClair et al. 2012). Other potential effects not previously discussed include bioaccumulation of toxins (Roper, Cherry and Simmers, 1995; Tatum and Theriot, 1994), and “dead zones,” or hypoxia, caused by the biochemical oxygen demand of waste products.
- Zebra mussels (*Dreissena polymorpha*) have become one of the most common freshwater animals in North America, and have “fundamentally transformed” freshwater ecosystems (Strayer, 2009).
- Once established in open water, mussels may be very difficult or impossible to eradicate as some individuals may not be exposed to a control agent, primarily due to underwater inflows (ISDA 2012).

The outlook for prevention to be successful has improved, and studies suggest that prevention may be underfunded.

- Some of the Pacific Northwest states and British Columbia have passed new legislation aimed at preventing the introduction of aquatic invasive species (AIS) and invasive mussels in particular and regional jurisdictions have increased their prevention efforts. In Oregon, House Bill 3399, passed in 2011, requires all persons transporting watercraft to stop at an AIS watercraft inspection station if an inspection station is observed and open. In Washington, boater surveys have been reduced and efforts to intercept trailered watercraft have increased. In December 2012, British Columbia amended the Controlled Alien Species Regulation to further restrict non-native species. New funding for Lake Mead National Recreation Area (LMNRA) control efforts could reduce the number of infested boats arriving in the Pacific Northwest from that region. Montana increased AIS funding in 2011 and in 2011, a new Administrative Rule made watercraft inspections mandatory for all boaters (MFWP 2013). In 2013, the American Fisheries Society resolved that the Congress of the United States should increase appropriations to fund nonnative aquatic invasive species management efforts, including the Quagga-Zebra Mussel Action Plan (AFS 2013).
- Population genetics data suggest that "introduction of large numbers of zebra or quagga mussels are required to establish sustainable infestations" (McMahon 2012 p. 37). This suggests that prevention may be successful even if small numbers of mussels are introduced into uninfested waters. Some transported mussels are likely to escape detection and cleaning, but that does not mean that prevention efforts are futile.
- Some new sources of information are available regarding the economics of prevention and control. Some sources (Adams and Lee, 2011) generally find that prevention efforts may be underfunded. Another study (Finnoff et al., 2007) suggests that managers may under-value prevention efforts because prevention is viewed as risky. There is perceived risk in that invasion may occur even with prevention efforts. While it is true that mussels may become established

eventually, there is economic value in delaying establishment because preparations can improve and annual damage costs are avoided in the near term.

- Our 2010 report found that "In the short run, prevention buys time that can be used to prepare" (IEAB, 2010, p. 6). Since 2010, preparation efforts such as rapid response plans have been developed or improved, and additional control methods have been developed that offer promise for controlling an infestation. Prevention efforts still buy time to develop strategies that might be very valuable later.

Prevention efforts at the State level might be improved by better enforcement, expanded inspections, and applied research

There still appears to be room for improvement in the State prevention programs. In Oregon, reports from field personnel have indicated that

> while permit compliance has generally risen in 2012 as compared to 2011, it is believed that there are still a fair number of boaters that have not purchased the AIS Prevention Permit (ODFW 2012 p. 7).

Also in Oregon, House Bill 3121 lowered the fines associated with not carrying an AIS Prevention Permit aboard a watercraft when on Oregon waters from $149 to $30 for non-motorized and $50 for motorized watercraft. (Cole 2011)

AIS technicians have recorded the number of watercraft that failed to stop at a highway inspection station. On days when observations were possible, thirty percent of trailered watercraft did not stop at inspection stations (ODFW 2012 p. 4). There is an effort to improve enforcement.

In Washington,

> current AIS program actions are funded only by revenues from resident recreational watercraft owners (AIS Prevention and Enforcement Accounts) even though the statutes regulate all watercraft including commercial, nonresident, and non-motorized watercraft such as canoes and kayaks designed for navigation on waters of the state (LeClair et al. 2012 p. iv).

In Washington, the current AIS sticker fee is $2 for resident boats.

> A moderate increase in resident watercraft registration fees to at least $5 (consistent with Oregon and Idaho fees) is recommended to substantively improve the level of protection necessary to prevent introductions, conduct early detection monitoring, or rapidly respond to a zebra/quagga mussel or other AIS infestation (LeClair et al. 2012 p. iv).

Montana has new AIS funding ($1.58 million over two years for two agencies, FWP and State Lands) and creation of a statewide management area, along with boat searchseizure-quarantine authority, that was passed out of the Montana legislature earlier in 2013 (HB 586). Montana is also planning on updating its ANS management plan.

Nevada does not and cannot by law undertake roadside inspections. Utah has a self-certification program that has drawn some criticism.

More information regarding how to target limited prevention funds is available, but more information is needed to help strategically focus regional prevention efforts. For example, more research is needed regarding the potential for long-term reproductive success, and perhaps more importantly, for successful spawning and juvenile survival of zebra and quagga mussels in the lower Columbia basin and the Willamette River.

Additional watercraft inspection time may be needed to help prevent an introduction. More inspection time might be applied on Sundays, at night, during off-seasons, and at more locations. In 2012, Oregon inspection stations were not open on Sundays. Most inspection stations cease operations about October 1. One study (Wook et. al. 2013) finds that mussel veligers survive longer in the cooler water that would be in boats in the spring and fall off-seasons; this might argue for prevention efforts continuing during those other seasons.

Implementation of management for other possible vectors for introductions is ongoing. For example, Pacific States Marine Fisheries Commission (PSMFC) has developed guidelines and procedures for float plane pilots to inspect and decontaminate their planes. A recent Reclamation manual includes decontamination procedures for vehicles, personal use equipment, and construction equipment (USDI BOR 2012).

The region is likely to experience an infestation, eventually, that would be difficult to eradicate. It would be worthwhile to plan more about the response to such an infestation in terms of how to contain, minimize and delay the spread of the infestation. Advance permitting under both the CWA and ESA could allow for a more rapid and successful response to an infestation.

Also, an infestation by one of the two species may not mean that prevention efforts are no longer useful; the two species have different habitat requirements, and quaggas apparently have two phenotypes in North America with different habitat preferences (Robinson et. al. 2013). Prevention efforts may still be valuable to avoid an infestation by the other species or phenotype.

Changes to the federal Lacey Act and its implementation could help improve prevention

The federal Lacey Act intends to help states by preventing the interstate movement and spread of injurious species, but the Act has provided little visible help thus far. While zebra mussels are included as an injurious species under the Lacey Act, quagga mussels are not listed. Efforts to reform the legislation in Congress, i.e., to add quagga mussels to the injurious species list, have not yet been approved.

There has not been a single case to date in the Northwest states where an attempt to knowingly transport mussels against State and federal laws has been successfully prosecuted. The IEAB knows of only one case where charges may be filed for transporting zebra mussels into Washington State, and the enforcement effort is being led by the state. One problem has been proving that the transported mussels are alive. A successful prosecution and fine could prove to be a deterrent to others.

Invasive Mussels Update

Economic Risk of Zebra and Quagga Mussels in the Columbia River Basin

In the 2010 report, titled “Economic Risk Associated with the Potential Establishment of Zebra and Quagga Mussels in the Columbia River Basin” the Independent Economic Analysis Board worked with invasive mussel experts to estimate potential costs of zebra or quagga mussel establishment in the Columbia basin. The report also identified potential infestation scenarios based primarily on calcium concentrations. This report updates the 2010 report by reporting on progress in the science and prevention of invasive mussels in the region.

1. Updated Information Regarding Conditions Required for Mussel Survival and Establishment

The Pacific Northwest region (including Wyoming and Alaska) is one of the last regions of the U.S. that is not infested with mussels and no tributary of the Columbia River has tested positive for either zebra or quagga mussels.

The region is very much concerned about the potential for a population of invasive mussels to become established in Columbia basin waters. These highly invasive and destructive pests could result in control and management costs amounting to tens of millions of dollars annually with potentially larger ecological damage costs. The region has invested billions of dollars to maintain and increase native fish, primarily salmon and steelhead trout, and this investment could be at risk.

Despite recent research, there is still some uncertainty about the ability of invasive mussels to become established in the Columbia mainstem and many of its tributaries. Mussels require calcium to build their shells. In river basins where calcium concentrations are known to be high, such as in the Snake River basin and now, in the Upper Columbia River basin in western Montana, there is little doubt that invasive mussels could survive and become established. There are some areas where water quality appears to be very favorable for mussels, and in other areas, not favorable. A better understanding of where mussels could become established could help focus regional prevention efforts.

There is still uncertainty about whether mussels could reproduce, especially in the lower Columbia and Willamette rivers. Veligers (mussels in their planktonic larvae stage) may have higher calcium requirements than adults (Willet and RNT Consulting 2013), and calcium concentrations in the mainstem Columbia River tend to be lower in summer when temperature is suitable for spawning. Figure 2 reproduces a chart of temperature and calcium concentration on the Mainstem Columbia near Quincy, Oregon, from the 2010 report. More research regarding the potential for long-term reproductive success, primarily, the potential for successful spawning and juvenile survival, is needed.

Established populations of invasive mussels reproducing in upstream locations would send large numbers of veligers downriver into waters with lower average calcium concentrations. In this situation, the downstream waters might experience damaging populations even if these mussels could not reproduce at the lower calcium levels. To become a nuisance, the veligers from upstream merely need to float downstream, settle, survive and grow.

In this situation, water travel times could be an important determinant of how far downstream mussel populations could attain damaging levels. The time from fertilization to settlement is generally 15 to 40 days, though it may be longer when temperatures are sub-optimal (Cohen and Weinstein 2001). Reservoirs and water storage slow travel times. Therefore, the presence of reservoirs might help to diminish the size and extent of downstream populations.

Zebra and quagga mussels have significantly different habitat preferences. Quagga mussels may have higher calcium requirements (Jones and Ricciardi 2005), and they may survive better than zebra mussels in deep water (Karatayev 2012). The two species may have different reactions to ambient acidity. Robinson et al (2013) notes that there are two distinct phenotypes of quagga mussels in North America that have significantly different habitat preferences. These studies raise a question about how to manage regional prevention efforts if only one phenotype of one species becomes established. If a population of quaggas were to become established, it might still be economical to continue prevention efforts because zebras and the other quagga phenotype might colonize areas that the established mussels will not. Generally, there is more information about zebra mussel habitat preferences than for quaggas.

The 2010 IEAB report did not discuss the potential role of temperature in limiting the establishment of mussels. Zebra mussel adults prefer a minimum mean summer water temperature of 64 degrees Farenheit (about 17.8 C) (Willet and RNT Consulting, 2013). The temperature required to initiate zebra mussel spawning may be as high as 60 degrees F (15.5 C) (McMahon, 2012). The previous IEAB report shows that, at some locations on the lower mainstem, calcium levels are often low and unfavorable at times of the year when these spawning water temperatures are attained. In some upstream and higherelevation basin locations, summer water temperatures may be too low to support reproducing populations. This factor argues against the long-term viability of populations at these locations. Water temperature could be a factor that, with other factors, could be used to decide if prevention efforts are worthwhile.

Quagga mussel veligers do not survive long in the summer when ambient hot temperatures in residual waters of boats reach 86 to 97 degrees Farenheit. Mussel veligers can be expected to survive in residual waters of trailered boats much longer in the cooler months of the year, up to 27 days (Choi et al. 2013). This suggests that the Northwest states' prevention efforts should continue in the spring and fall months even though fewer recreational boats may be crossing state lines at that time.

The previous IEAB report did not discuss the potential role of acidity in limiting establishment of mussels. However, a graph of pH over time at Quincy, Oregon, near the Beaver Army Terminal, was provided (Whittier, 2010). That figure is reproduced as Figure 2 below. Willet and RNT Consulting (2013) show "uncertainty of veliger survival" at a pH as low as 7.1 to 7.5; the graph in Figure 1 shows that pH at Quincy is normally somewhat alkaline, within a range of 7.5 to 8.2. Thus the pH level in the lower Columbia River appears to be favorable for the chance of veliger survival and mussel establishment.

Flow velocity is important in determining where mussels can become attached (Chen et al. 2011). Structural designs that allow high velocities might help avoid some mussel control costs. This could be important for fish bypass systems. There are fish passage criteria limits to velocities in fish bypass systems, however. Passage can be impaired and high velocities may impinge juvenile salmonids and/or lamprey on fish bypass screens.

2. Potential Economic Damages at PUD Facilities

The 2010 IEAB report did not include much information about the three mid-Columbia public utility district (PUD) hydropower projects (Grant, Chelan, and Douglas County PUDs). The PUDs report their AIS activities to FERC, and all are actively engaged in monitoring, public awareness and to a lesser extent, boat inspections.

PUD No. 2 of Grant County reports performing boat inspections on major holidays and weekends during the boating season (May-Sept) following WDOE and FERC approval of their Aquatic Invasive Species Control and Prevention Plan, which will "[p]erform inspections at least once per month; target 25% of boaters using launch during each inspection day" (PUDGC, 2010 p. 19).

PUD No. 1 of Chelan County (2012) reports educational activities such as AIS signage, monitoring for mussels beginning in 2012, and preparation for early detection and rapid response. PUD No. 1 of Douglas County (2012) reports early detection efforts using plankton tows.[1] In general, these limited actions cannot be expected to provide much additional prevention help relative to the state programs that are currently active or planned. New information about potential damages at these facilities is not available.

3. The Potential Role of the Federal Lacey Act

Recent research has investigated the potential for the federal Lacey Act to provide help in preventing mussel introductions. Currently, quagga mussels are not listed as an injurious species under the Act. White and Otts (2013 p. 85) describe the potential role of the Lacey Act in controlling the spread of invasive mussels:

> The Lacey Act contains two key provisions. Title 16 prohibits wildlife trafficking and elevates the violation of state, tribal, or foreign wildlife laws to federal offenses. Title 18 prohibits the importation and interstate transportation of listed injurious species, including zebra mussels.
>
> The Lacey Act is an important component of this federal-state partnership, but it may not be the most effective tool in the toolbox. First, with respect to violations of Title 16, the Lacey Act is only as strong as the underlying state law and a number of evidentiary challenges may arise during a prosecution to prevent a conviction. Second, only federal prosecutors can file and pursue Lacey Act cases, leaving state officials at the mercy of underfunded and understaffed federal agencies and offices. Although a few Lacey Act Title 18 (injurious species) violations have been prosecuted by the FWS and the U.S. Department of Justice, no high-profile cases have been filed to date involving either zebra or quagga mussels in the Western states White and Otts (2013 p. 101).

Federal legislative efforts to reform the injurious species listing process were recently considered. On May 30, 2012, New York representative Louise Slaughter (R) introduced the Invasive Fish and Wildlife Prevention Act of 2012 (H.R. 5864). Senator Kristen Gillibrand (D – NY) introduced a companion bill, S. 3606, on September 20, 2012.These bills, which were reintroduced in 2013 as HR 996 and S. 1153, would “establish an improved regulatory process for injurious wildlife” by authorizing the FWS to develop regulations specifying criteria for injurious species listings and assessing the risks of those species being imported to the United States. H.R. 5864 also grants the USFWS the authority to take immediate action to temporarily designate a nonnative wildlife species as injurious upon a determination that an emergency exists. As of June 2013, these bills had not moved out of committee.

H.R. 1823, the “Protecting Lakes Against Quaggas Act of 2013,” was introduced by Nevada representatives Joseph Heck and Mark Amodei on April 30, 2013. This bill would add the entire genus Dreissena to the injurious species list in Title 18 of the Lacey

[1] A plankton tow is a fine mesh net used, in this instance, to monitor for veligers

Act, thereby including both quagga and zebra mussels. The Council has gone on record as supporting this legislation.

The USFWS has proposed that adding species to the injurious list be exempt from NEPA compliance. The agency announced July 31 that it would reopen the comment period for an additional 60 days for those seeking to submit comments on the proposed categorical NEPA exclusion for listing injurious wildlife (ACWA 2013).

4. Changes at the State Level

The 2010 IEAB report and the 2010 Quagga-Zebra Mussel Action Plan were supportive of additional funding for prevention of invasive mussels. However, state prevention efforts continue to be limited by funding constraints. Watercraft AIS fees have been able to make up some state funding cuts. The federal appropriation for Interior to improve prevention by targeting inspections of moored boats leaving Lake Mead should help, but federal funding to support additional inspection stations in the Pacific Northwest has been negligible.

The 2007 law (RCW 77.15.293) in Washington requires that anyone transporting watercraft must stop and allow the watercraft to be inspected by the department's enforcement or WSP officers for the presence of aquatic invasive species wherever check stations are present and posted as active. The legislature increased funding for boat inspections in 2011, but state funding for all AIS programs fell from a maximum of $831,000 in 2007 to a projected level of $357,000 in 2013 (LeClair et al., 2012, p. 3). Washington is considering new legislation for 2014 that would increase funding for AIS prevention.

In Oregon, House Bill 3399, passed in 2011, requires all persons transporting watercraft to stop at an AIS watercraft inspection station if the inspection station is observed and open. A user fee on watercraft was created to implement the AIS Prevention Program. Revenue generated from AIS Prevention Permits for 2012 totaled $731,474. In 2012, the AIS Prevention Program funded three full-time positions (one OSMB AIS coordinator and two ODFW AIS technicians), nine seasonal or part-time positions (seven ODFW AIS technicians) and partial funding for one ODFW Invasive Species Coordinator and one OSMB accounting technician (ODFW 2012).

In Idaho, Invasive Species Prevention Sticker Rules (IDAPA 26.01.34) were enacted by the Legislature in 2009. They require all boats to have an Invasive Species Sticker to launch and operate on Idaho's waters. The sticker program is administered by the Idaho Department of Parks and Recreation. Revenue generated by this program is deposited in the Idaho Invasive Species Fund.

The Montana legislature passed the Aquatic Invasive Species Act in 2009. The legislation authorizes state agencies to designate infested waters as Invasive Species Management Areas, where they can restrict boat movement, require boaters to inspect and clean boat exteriors, and levy fines for noncompliance. The legislation establishes a state fund to increase AIS control and prevention measures and to increase public education. Representative Mike Cuffe's legislation, House Bill 586, passed in 2013. It increased appropriations for AIS prevention and added inspection stations for trailers destined for Flathead Lake. The Bill established a statewide invasive species management area and authorized the use of quarantine measures and check stations at key state entry points. As of June 10, 2013, inspection crews had inspected 4,130 boats.

There are significant differences among the Northwest states in how boat inspections are accomplished. In the State of Washington, "The department uses three types of watercraft management actions for the prevention of AIS introductions, including zebra/quagga mussels. These include boater surveys, integrated watercraft safety/AIS inspections, and mandatory watercraft check stations." (LeClair et al p. 21) It appears that boater surveys were phased out by 2012. In 2011, 1,040 mandatory check station AIS inspections were performed. In the State of Montana, it also appears that effort has shifted from "roving inspection crews" to include both roadside check stations and roving crews.

In 2012, the State of Idaho "operated 15 watercraft inspection stations on highways and major roads. Many of these stations were operated with the assistance of local governments and conservation districts. The data collected at the inspection stations during the previous (2009-2011) boating seasons have allowed staff to prioritize routes into the state for the 2012 season. Some stations were moved or adjusted to strategically maximize contact with out-of-state and high-risk boats." Over 47,000 boat inspections were conducted in 2012.

The inspection efforts of each state as of 2012 are summarized below:

> **Idaho** has 15 roadside watercraft inspection stations for aquatic invasive species (AIS) plus 11 port of entry stations. Their boat inspection stations are open over 8 months this year (February through September), 7 days per week from 7 am until 7 pm.
>
> **Montana** has 65 AIS inspectors working throughout the state at border crossings and major highway routes as well as 5 roving inspection crews that move around to various busy boat access and fishing sites. Montana's eight roadside boat inspection stations operate from mid-May through October.
>
> **Oregon** currently has five roadside boat inspection stations operating Tuesday - Saturday typically from May 1 to October 1 (in Ashland, Gold Beach, Klamath Falls, Lakeview, and Ontario). The Ashland station will operate from mid-February to October 1. Motorists hauling boats in Oregon are now required to stop at these inspection stations to have their watercraft inspected for AIS under a 2011 law.
>
> **Washington** uses roving inspection stations throughout the state focusing on border crossings and major highway routes to inspect boats for the presence of AIS. All commercially hauled watercraft is stopped and inspected at one of eight Port of Entry locations. WDFW provides free inspection at any WDFW Regional Office and works at training other entities in the state to help conduct boat inspections (Council Staff 2013).

A summary of 2013 direct spending for watercraft inspection and decontamination as well as mussel monitoring, prepared by Council staff based on information provided by state AIS coordinators, is provided in Table 2.

The constitutionality of watercraft inspections is a significant concern. Kondo, Cotter and Otts (2013) conclude:

> Watercraft inspection programs advance a compelling state interest. States are seeking to protect their water bodies from an invasive species that is harmful to native ecosystems and imposes significant costs on water users. Supreme Court jurisprudence interpreting the Fourth Amendment, the Commerce Clause, and the right to travel establish that constitutional rights are not absolute. The government may infringe, to some degree, if there is a compelling government interest. While it can be a challenge to strike the proper balance, watercraft inspection programs should generally prevail. Watercraft inspectors conduct rather limited searches, examining only the exterior of the boat and other places where mussels are likely to be present. Inspectors are not authorized to look in vehicles or closed dry compartments where personal effects may be stored. In addition, most inspections do not result in lengthy delays that significantly restrict a boater's ability to travel. On balance, <u>watercraft inspection programs should withstand constitutional scrutiny, as they involve minimum intrusions and infringements on boaters' privacy and freedom of movement while advancing states' legitimate interests in preventing significant economic and environmental harm</u>. [Emphasis added.]

5. Regional Coordination Efforts

Active coordination among the four Northwest States, with the Province of British Columbia, federal agencies, and among state agencies within states have all contributed to the regional prevention effort.

The 100th Meridian Initiative Columbia River Basin Team has met regularly since 2003. These Team meetings are attended by state, federal and tribal natural resource agencies and NGO's and are chaired by the PSMFC. These meetings help to coordinate regional AIS monitoring, prevention and educational activities, develop partnerships, identify funding sources and development of the "Columbia River Basin Interagency Invasive Species Response Plan: Zebra Mussels and Other Dreissenid Species." The Plan's goal, developed with funding from the USFWS, is to maximize the delineation and control of dreissenid mussel populations if they are introduced in Columbia River Basin waters. In the Fall of 2008 the plan was signed by the 4 Columbia River states, USFWS and Columbia River InterTribal Fish Commission, with the Province of British Columbia signing in Fall 2009 and NOAA signing in Fall 2011.

Robinson et al. (2013) show that most of British Columbia has a "high risk" of mussel establishment. In December 2012, the British Columbia provincial government amended the Controlled Alien Species Regulation to further restrict non-native species. No invasive zebra or quagga mussel, alive or dead, is allowed to remain on boats or related equipment. Failure to clean mussels off boats or equipment could result in a fine of up to $100,000. Conservation Officers and Natural Resource Officers will be trained on the amended regulation. Canadian Border Service Agency staff and federal Fisheries and Oceans Canada officers may also be invited to participate in this training. Recently, the Province has also prepared an economic and ecological risk assessment.

ISDA partnered with the Idaho Transportation Department (ITD) to initiate an education and outreach campaign for oversized load commercial haulers that bring boats through (and to) Idaho (ISDA 2012). Through the oversized load permitting process, ITD notifies ISDA when a commercially-hauled oversized watercraft is destined for Idaho. ISDA then contacts the boat transporter directly to inform the hauler of state laws related to possessing and transporting invasive species in Idaho. This coordination mechanism is being developed in other states to identify and inspect potentially contaminated large watercraft.

For commercially-hauled vessels, Washington reports that “Idaho does not presently have the statutory authority to detain AIS contaminated watercraft that are being transited through their state” (LeClair et al, 2012 p. 30). Idaho state officials have opined that they cannot legally detain a contaminated trailer that is destined for another State, because this would inhibit interstate commerce. Thus Idaho passes commercially-hauled fouled boats off to WA and other states for decontamination; this is viewed as effective coordination between states.

Coordination with federal agencies that have management oversight over boat inspections and decontamination at contaminated waterbodies could significantly reduce the number of infested boats arriving at Columbia Basin borders. Coordination with the National Park Service at Lake Mead National Recreation Area (LMNRA) has been a continuing problem for the Pacific Northwest states. The FY 2012 and 2013 Interior Appropriation bills provided the U.S. Department of Interior with $1 million of funding towards the implementation of mandatory operational inspection and decontamination stations at Federally-managed or inter-jurisdictional water bodies considered to be of highest risk, as called for in the February 2010 Quagga-Zebra Mussel Action Plan (QZAP) for Western U.S. Waters.

The USFWS’ 2012 plan for allocating this $1 million in funding, as described to the Council by David Britton of USFWS Southwest Region, includes funding to Lake Mead NRA specifically for quagga mussel prevention efforts, including one coordinator ($88K), education and outreach ($46.8K), repair and maintenance of existing decontamination stations ($58.5K), two new decontamination stations ($117K), and watercraft inspection training ($30K). Also included in the $1 million was $117,000 for interdiction Rangers at Lake Powell.

Due to the severe threat posed by invasive quagga and zebra mussels to the waters of the Pacific Northwest, the Council recognized there is a compelling need to define and implement a region-wide prevention and response strategy. Toward that end, on May 15, 2013, the Council partnered with The Pacific Northwest Economic Region (PNWER), Portland State University (PSU), and the Pacific States Marine Fisheries Commission (PSMFC) to jointly sponsor a regional workshop in Vancouver, WA entitled "Preventing an Invasion: Building a Regional Defense Against Quagga and Zebra Mussels." The purpose of the workshop was to bring together about 80 individuals representing Canadian and Pacific Northwest irrigation and water districts, water suppliers, legislators, state and federal agencies, tribal sovereign nations, nonprofit organizations, recreational watercraft interests, consortiums, and others to develop a set of action items to address challenges and barriers to preventing the introduction of invasive quagga and zebra mussels to the Pacific Northwest.

Toward that end, a Northwest Defense Against Mussels Declaration of Cooperation was prepared by the workshop sponsors in June 2013. The Declaration of Cooperation, which is intended to be signed by workshop participants, is a statement of the good faith and commitment of all parties to implement the high priority actions identified at the workshop. The Declaration of Cooperation represents a public statement of workshop participants' commitment and intent to: a) support and participate in a Northwest Defense Against Mussels; b) strive to identify opportunities and solutions whenever possible; c) seek efficiencies through regional cooperation and collaboration; and d) contribute assistance and support within resource limits to prevent the introduction and establishment of invasive mussels in the Pacific Northwest (Council Staff, 2013a).

Expanded inspections in states bordering the Columbia basin have been helpful to the region. Wyoming and California inspections have been intercepting boats before they get to the Northwest. Redundancy across States may be a good thing, especially because most regional state inspection stations are closed at night.

6. How States are Targeting Prevention

The immediate concern for the region is the level of effort and expenditure and location of prevention efforts. Adjustments to prevention efforts happen annually, if not more frequently. In Montana,

> Each spring, inspection station sites are selected based on angler pressure, boater movement, estimated risk of AIS introduction, logistics, and input from other agencies and stakeholder groups. Based on this input, FWP shifted some resources from roving crews at popular water bodies to seasonally-permanent stations at border entry points during the 2012 field season. There were still several roving crews, but the majority of the 2012 effort was focused on eight border and strategic highway stations (MFWP, 2013, p. 1).

In Oregon,

> The 2013 watercraft inspections will change slightly; ODFW will relocate two of the watercraft inspection teams (Hines and La Grande to Lakeview and Ontario)

> to better protect Oregon's southern and eastern borders. Additionally, ODFW plans to add one watercraft inspection team to Gold Beach and add extra inspectors at the Ashland inspection station. To continue with enforcement activities during 2013, more inspection station compliance enforcement will be planned to make sure the threat of watercraft transporting AIS are intercepted and prevented from entering the state (ODFW 2013 p. 9).

In Washington, boat surveys were used to generate helpful data.

> Combined boater origin and movement data will be used to assist the department in identifying the highest risk travel vectors into Washington State, and enable future interdiction and enforcement efforts to be focused on those vectors (LeClair et al 2012 p. 31).

Washington's program has been somewhat different from the other states. Education and inspections have been provided in conjunction with watercraft safety education, and inspections have been provided at port of entry sites. WDFW has been working on drafting new legislation for 2014 that would establish stable funding for AIS and would enable expanded boat inspections.

In Idaho,

> Idaho's inspection stations are placed on major highways at or near the Idaho state line. This strategy is taken to maximize contact with boats that are travelling into the state from impacted states. The inspection stations on the southern and eastern borders of the state intercepted the majority of the mussel-fouled boats.
>
> Commercially-hauled boats are considered a high-risk pathway. More than half of the mussel-fouled boats intercepted in Idaho during 2012 were commercially-hauled (ISDA 2012 p. 4).
>
> Boats that have been in mussel-infested states recently (within the last 30 days), watercraft coming from another state (especially commercially hauled boats), boats that show a lot of dirt, grime, or slime below the waterline or boats that have standing water on board are considered "High-risk" (ISDA 2012 p. 6). [2]

From this discussion, it seems the states have different approaches to targeting prevention efforts. It is possible that more science-based targeting and regional coordination could improve prevention. Pacific Northwest states work to target prevention funds, but there is not one scientifically-based method for doing so. Some inspection activities are probably redundant with stations in neighboring States.

Wells et al. (2010) have provided a generalized framework for prioritizing mussel prevention in the Columbia Basin based on water quality and boater use. A summary of

[2] This definition of high-risk may be used by other states also

their results is attached to this report as Table 3. Their data is organized by State and by calcium level for convenience. Refinements to this framework might be accomplished based on: 1) a reference regarding what points of entry are used by non-resident boaters for which water bodies; 2) knowledge of locations and events that are relatively likely to be attended by non-resident boaters; and 3) specific types of activities that attract different types of boaters at different times and seasons. USGS and Washington State University personnel are currently working on developing such refinements.

7. Incentives and Unintended Effects in Prevention

Prevention efforts include these elements:

1. Interception of trailered boats, inspection, and quarantine and cleaning, if necessary
2. Education to influence behavior such that the risk of introduction is reduced
3. Enforcement and penalties regarding actions that risk introductions
4. Boat fees to raise revenues for prevention efforts (Washington does not currently have boat fees)
5. Coordination amongst all the jurisdictions
6. Research to determine the effectiveness of the above elements.

Prevention efforts include several economic incentives that can influence compliance and risk of introduction. It is important that these aspects of prevention do not work independently of the other, and some may have unintended consequences.

While most boaters have heard the “Clean, Drain, and Dry” message and participate in draining and cleaning their watercraft, others are driven more by simple economic motives. Potential penalties provide an incentive to cooperate with interceptions. Increased penalties also provide a stronger incentive to obey state laws. However, boat fees, interception costs and potential penalties could influence boater behavior regarding decisions about how often and where to travel and use boats. Indeed, the costs of compliance could influence some high risk boaters to find boating opportunities where compliance costs are not required, or costs can be avoided, or travel elsewhere where they may not be detected and inspected.

Timar and Phaneuf (2009) developed a framework that combines a recreation demand model of boating behavior with a discrete duration model describing the spread of an aquatic invasive to understand how boater behavior responds to policy changes. This integrated approach allows invasion risk probabilities to be linked directly to boating behavior, policy levers, and behavior changes arising from policy shocks. They show that explicitly accounting for behavioral responses can dramatically change predictions for the effectiveness of particular policies, in some instances leading to increases in invasion risks at some Wisconsin locations.

8. Update on Mussel Control Agents

There has been new information provided about potential mussel control agents since our last report. Zequanox®, a biological control product, was registered by USEPA for use in industrial and commercial water systems in the fall of 2011 (ISDA 2012).

Marrone Bio (2013) provides a summary of Zequanox® applications in commercial power systems to date.

> For the USBR, at the Davis Power Plant cooling water subsystems on the Lower Colorado River, 90 percent reduction in settlement was achieved;
>
> For Oklahoma Gas and Electric, in 2 cooling system forebays at the Sooner Power Plant, mortality was 98 to 99 percent;
>
> For Ontario Power Generation, for the DeCew II Falls Generating Station cooling system, mortality reached 94 percent 28 days after treatment;

In March of 2013, New York, Pennsylvania, Connecticut and Vermont all issued Certificate of Pesticide Registrations for using Zequanox® to control mussels in enclosed systems and infrastructures (PRWEB, 2013). There are currently no products registered for use in natural systems. However, USEPA "approval for using Zequanox in natural water systems is currently in process" (Marrone Bio 2012)

Marrone Bio found that Zequanox® was highly effective at controlling invasive zebra mussels in Deep Quarry Lake located in DuPage County, Illinois. Zequanox was applied within barrier systems in three locations throughout the lake. Results showed that treated sites experienced an average mussel mortality of 97.1 percent compared with 11.2 percent mortality in the control (i.e., untreated) sites (Marrone Bio 2012).

ISDA (2012) provides some case studies where mussel eradication was attempted in natural systems. In two cases, eradication attempts were unsuccessful, possibly because some individual mussels may have been protected by incoming groundwater seeps or springs.

A variety of other chemicals, primarily chlorine-based products, are registered for control of zebra and quagga mussels in closed water systems. However, most of these products are toxic to fish and other aquatic organisms.

Claudi and Prescott (2013, 2013a) present results of an experiment using UV light to prevent veligers from settling on downstream surfaces; for example, in cooling water systems. They found that "UV treatment of raw water with a continuous average dose of 100 mW-s/cm² appears to prevent all downstream settlement of quagga mussel veligers at the Hoover Dam cooling water circuit of Unit A1" (Claudi and Prescott 2013 p. 15). The same authors "describe an experiment designed to test the efficacy of various UV dose levels required to prevent downstream settlement of quagga mussel veligers" (Claudi and

Prescott, 2013a p. 3) This experiment found that "veliger settlement past the UV lights was decreased by 98% to 99% in all four experiments" (Claudi and Prescott, 2013a p. 31). These experiments and others at different locales suggest that UV treatment could provide practical control of invasive mussels in some closed and low-flow systems without chemical contamination.

Claudi (2013) reports that RNT Consulting is currently completing a report for the California Department of Water Resources regarding the use of copper-based algaecides for invasive mussels, and a publication on the use of a calcite index for predicting mussel spread, which was presented at the International Conference on Aquatic Invasive Species in April. Current research is focused on the use of UV and on the use of copper ion generator for settlement prevention. The use of copper-based algaecides, however, would be problematic in salmon-bearing streams of the Columbia Basin.

Moffit et al. (unpublished document) tested the efficacy of using elevated pH and a commonly used aquaculture disinfectant on quagga mussel veligers. Aqueous solutions of pH 12 were created with NaOH or $Ca(OH)_2$ and tested at 15 and 22°C, and three concentrations of Virkon® Aquatic were tested at 22°C. Mortality of veligers was faster in warmer temperatures and in solutions of $Ca(OH)_2$. Complete mortality occurred in solutions of $Ca(OH)_2$ within a 10 minute exposure, and within a 30 minute exposure in the solution prepared with NaOH. Solutions of 5 g/L of Virkon® Aquatic killed all veligers within 10 minutes. The authors conclude that all three chemicals show promise as disinfectants, and use of $Ca(OH)_2$ or NaOH to elevate the pH of disinfecting solutions may provide an economical and environmentally acceptable way to disinfect large surfaces or tanks.

9. Economic Aspects

The contents of the various economic articles below have been summarized from their abstracts, often with little change to the abstract text.

In three studies discussed below (Connelly et al. 2007; Warziniack et al. 2011; Thomas 2010), the costs of ecological effects of invasive mussels were apparently not included in the authors' economic models and findings. The IEAB report suggests that, because of the high value of fishery and aquatic resources in the Columbia Basin, and because no controls exist for mussels in open natural systems, the ecological costs of a Columbia basin invasion could be much larger than other costs; this provides support for the view that additional prevention efforts are warranted.

Strayer (2009 p. 135) reports that "we know little about the extent to which large outreach programs about zebra mussels have changed public knowledge, attitudes, or behaviors, and there are still substantial gaps in policies to curb the establishment, spread, and impacts of species like zebra mussels." Mueting and Gerstenberger (2011) find that boaters are becoming more aware of their role in spreading invasive mussels.

Adams and Lee (2011) use a bio-economic model to compare costs and risks of a mussel invasion in Florida with and without the emerging control technologies such as Zequanox. Although calcium may be a limiting factor in parts of the State, results suggest that

> without investment in prevention, there is a very high probability that Florida waterways will be infested with zebra mussels by year 2025, and expected environmental damages and management costs are high. Slow response due to poor detection methods or insufficient control efforts will lead to a moderate probability of a significant infestation. Rapid reaction and enhanced prevention efforts are expected to greatly reduce the probability of ZM infesting Lake Okeechobee by 2025, and to generate much higher expected net benefits (Adams and Lee, 2011, p. 21).

Mehta et al. (2007) focus on the economics of detection. Managers may increase their chances of finding a species at a smaller population level by devoting more resources to detection. This should make subsequent control measures less expensive and more effective. However, detecting new invasive species is difficult and uncertain; many factors such as low population densities reduce the likelihood of successful detection, and there is a chance of false detections. The authors present a model that includes the trade-off between prevention, detection and control by incorporating a detection stage. The analysis illustrates that the optimal detection strategy depends on ease of detection, and the unique biological relationships of each species.

Finnoff et al. (2007) state that it is reasonable to expect that a manager "would use more prevention relative to control," but this is not typically done.

> Managers frequently wait until after invaders have arrived and then scramble to limit the damages. We demonstrate quantitatively how managers perceived to be cautious or averse to risk tend to shy away from prevention relative to control. This counterintuitive result arises because control is a safer choice than prevention because its productivity is relatively less risky: it works to remove existing invaders from the system. In contrast, the productivity of prevention is more uncertain because prevention only reduces the chance of invasion, it does not eliminate it. In invasive species management, if managers act as though they are risk averse, their caution can backfire when it leads to more control rather than prevention. The social consequences of this choice are a greater probability of future invasions and lower social welfare. Our results suggest that social welfare is highest when managers were willing to "take a risk" with prevention (Finnoff et al. 2007 p. 216).

Ricciardi et al. (2011) suggest that invasive species should be managed using concepts similar to those applied to natural disasters because:

- Both invasions and natural disasters can generate enormous environmental damage,

- Similar to natural disasters, the frequency of damaging events is inversely proportional to their magnitude,
- the annual combined economic cost of invasions worldwide exceeds that of natural disasters, and
- management of invasions—like that of natural disasters—requires international coordination of early-warning systems, immediate access to critical information, specialized training of personnel, and rapid-response strategies.

Homans and Smith (2013) appeal to the literature on conventional pollution to guide their conceptualization of the invasive species problem. They show how costs and benefits should be estimated to guide decisions and use examples from the literature to illustrate how market transactions can be used to estimate benefits. The roles of adaptation, mitigation, and species population growth are detailed, and they investigate conditions under which investing in biocontrol methods might be economically justified.

Connelly et al. (2007) update information regarding the economic impact of zebra mussels on North American drinking water treatment and electric power generation facilities from 1989 to 2004. Over one-third (37%) of surveyed facilities reported finding zebra mussels in the facility and almost half (45%) have initiated preventive measures to prevent zebra mussels from entering the facility operations. Almost all surveyed facilities (91%) with zebra mussels have used control or mitigation alternatives to remove or control zebra mussels. The authors estimated that 36% of surveyed facilities experienced an economic impact. Expanding the sample to all facilities in the study area, they estimated $267 million in total economic costs for electric generation and water treatment facilities through late 2004, since 1989. Annual costs were greater ($44,000/facility) during the early years of zebra mussel infestation than in recent years ($30,000). Ecological costs were probably not considered in this analysis.

Warziniack et al. (2011) use a bioeconomic computable general equilibrium (CGE) model to measure welfare changes from a dreissenid invasion into the Columbia River Basin and from policy measures designed to reduce the risk of invasion into the basin. Threat of invasion is modeled using a production constrained gravity model of boater movement and a probability function dependent on boater arrivals. Welfare effects of the impacts of a dreissenid invasion are evaluated in terms of compensating variation measures. The bioeconomic model suggests the annual welfare losses (i.e., costs or loss of benefits) of a dreissenid invasion in the Columbia River Basin could be around $64 million. It does not appear that economic values related to fish and wildlife losses are included in this estimate.

Hortch and Lewis (2009) use hedonic pricing techniques to estimate the economic costs of a milfoil infestation in Wisconsin. Hedonic pricing techniques use observed land or rental prices, usually with statistical analysis, to infer the value of amenities or other land characteristics. This technique could be useful for estimating some of the ecosystem costs of a mussel invasion.

Thomas (2010) builds a bioeconomic model to simulate a mussel invasion and associated control costs for a Colorado water supply system, and compares the prevention costs of a state boat inspection program to the expected reduction in control costs to infrastructure. Results suggest that preventative management is effective at reducing the probability that mussels invade, but the prevention costs may exceed the benefits of reduced control costs. Ecological costs may not be included in this analysis. “The risk of invasion, the spatial layout of a system, the type of infrastructure, and the level of control costs associated with a system are key variables in determining net benefits of preventative management” (Thomas, 2010, abstract).

Robinson et al (2013) provide damage estimates for a potential establishment of zebra and quagga mussels in British Columbia using “transferable damage estimates from peer reviewed and gray literature sources and facility count data for B.C.” Damage estimates are provided for hydropower, water supply, and recreation facilities. Total potential damages for these facilities are estimated to be $21.6 million annually, in Canadian dollars.

Ricardo deLeon, Mussel Control Program Manager of the Metropolitan Water District of Southern California MWDSC), stated that Lake Havasu on the lower Colorado River is the primary water source for 19 million Southern Californians, including residents of Los Angeles. Aquatic weed problems, as well as mussel-encrusted pipes and water intake trash racks, are constant O&M and budget problems. He estimates about $12 million was spent initially to install special mussel control equipment at MWDSC facilities, and operations and maintenance of mussel control activities have cost the District about $4.5 million annually (2013).

10. A Revised Simple Economic Risk Model

Figure 3 below is an update to the Figure 2 provided in our 2010 report. It shows how the expected value of damages from invasive mussels might be calculated, and it shows how controllable factors could influence the expected value of damages. The expected value of damages is the product of three probabilities and a damage estimate for the established population. In comparison to the 2010 report, the probability of successful rapid response has been added. The damage estimate and any cost estimates should both be long-term, and they should be annualized or net present value of costs.

If all three of the probabilities in Figure 3 are equal to 1, then the expected value of damages is equal to the damages caused by the established population. If any of the probabilities equal zero, then the expected value of damages is also zero.

Controllable factors are prevention, detection, rapid response, control and management programs. The expected value of damages changes if any of these controllable factors change. This framework can be used to evaluate when any investment in a controllable factor might be justified. If the cost of the controllable factors is less than the reduction in the expected value of damages, then the controllable factors are economically justified. If there is close to a zero probability of an introduction, however, then the expected value of damages is close to zero and there is no potential economic justification for changing any controllable factors. Similarly, if there is a small potential for survival, reproduction and establishment, then there is also a small value to prevention, detection or rapid response actions.

Consider the potential economics of an introduction in the upper Snake River Basin. Evidence presented in the previous report and this report suggest that mussels will spread into the lower Snake River and will have substantial economic costs for water users, hydropower, fish passage, hatcheries, as well as substantial ecological impacts in the Hells Canyon and downstream in the lower Snake River, and some economic costs will extend into the mainstem Columbia River.

Suppose, for example, that the annual expected “damages caused by the established population” is $100 million. Without any prevention, detection or rapid response efforts, the introduction and non-detection probabilities in Figure 3, even within a short time frame, are probably close to 1. Many infested boats are being intercepted, the ability to detect and eradicate an introduced population is probably poor, and water quality conditions in the upper Snake River appear to be very favorable for establishment.

Suppose that $5 million annually is currently being spent on prevention efforts. If these efforts reduce the annual chance of an introduction by 50 percent, then the subsequent reduction in expected value of damages is about $50 million annually, or ten times the prevention costs. In this example, the existing level of prevention appears to be economically justified. An analytical approach similar to that developed here could be used to allocate available funds to the most beneficial program elements.

11. Acknowledgements

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Figures and Tables

Figure 1. pH Columbia River at Quincy near Beaver Army Terminal, 1996 to 2004

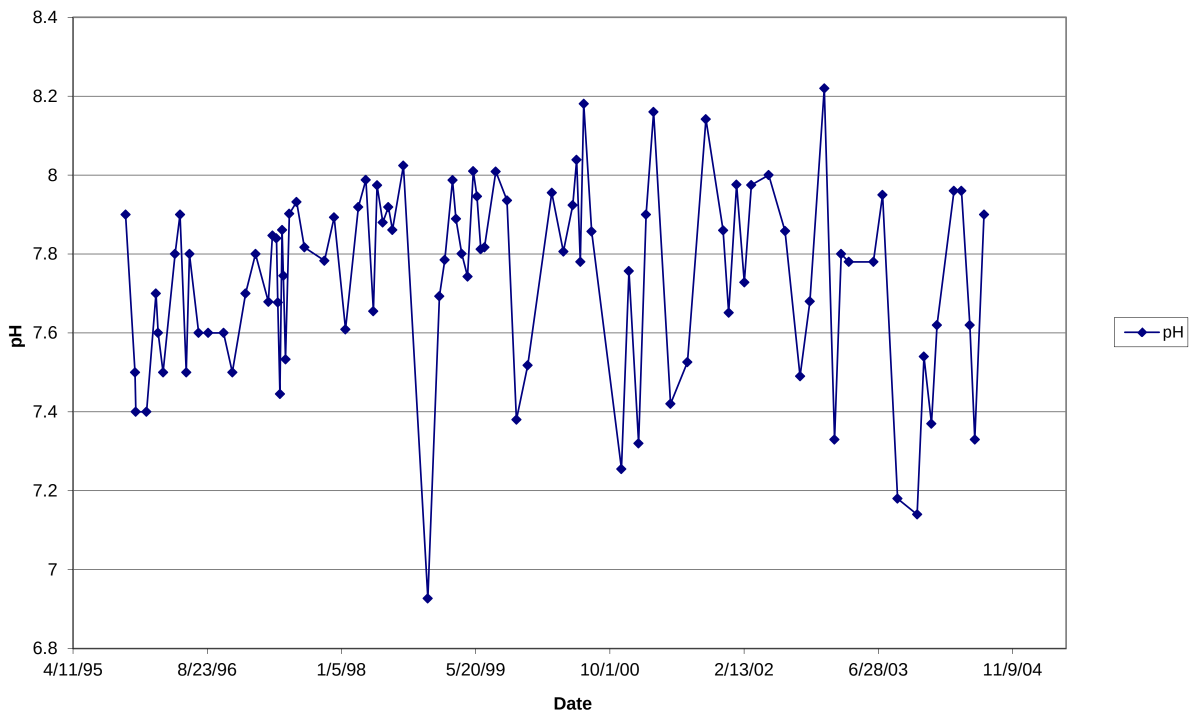

Figure 2. Calcium and Temperature, Quincy OR, Near Beaver Army Terminal, 1995 to 2000, from NASQAN (Whittier 2010)

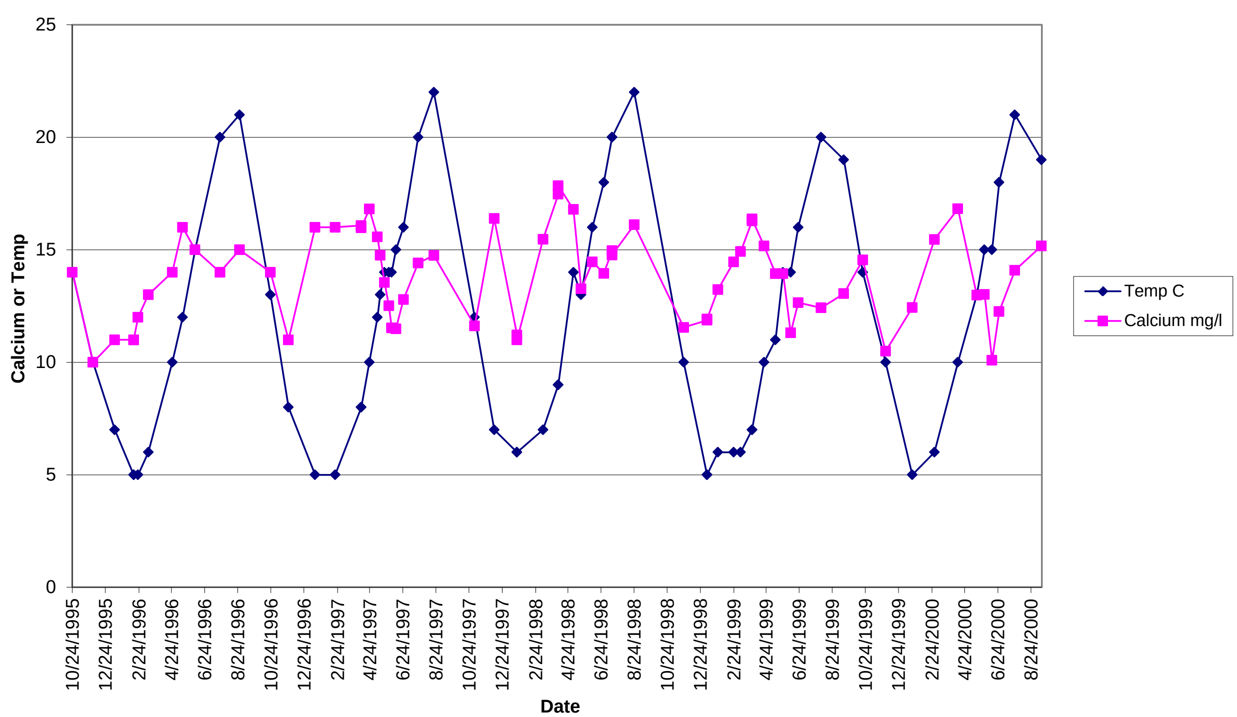

Figure 3. Flow Diagram for Expected Value of Damages from an Invasive Mussels

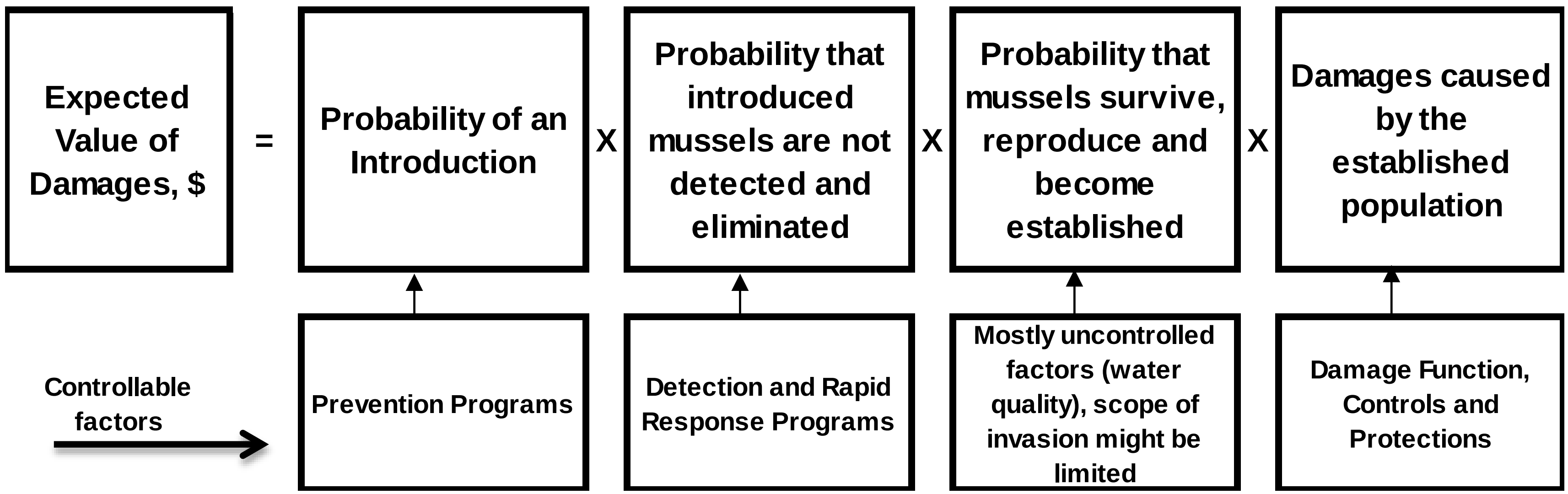

Table 1.
Summary of Data on Calcium and pH Levels in Selected Western Montana Rivers

USGS Station	Period of Record	Range of Calcium Levels, in mg/l	Average Calcium Level, in mg/l	pH Range, std. units	Average pH, std. units
Kootenai R below Libby Dam near Libby, MT	1967-2004	23-82	37	7.0-8.7	7.9
Clark Fork near Galen, MT	1988-2012	23-110	53	7.5-9.2	8.5
Clark Fork near Drummond, MT	1993-2012	21-83	52	7.8-8.7	8.3
Blackfoot River near Bonner, MT	1986-2012	14-38	26	7.5-8.7	8.3
Clark Fork above Missoula, MT	1989-2012	14-83	31	7.5-8.8	8.2
Clark Fork below Missoula, MT	1978-1995	11-47	30	7.1-8.8	8.0
Flathead River at Columbia Falls, MT	1963-70, 1979-94	19-32	25	6.9-8.5	7.7
Flathead River at Perma, MT	1984-2009	23-32	25	7.5-8.5	8.2
Willow Creek at Opportunity, MT	2003-2012	18-47	35	7.4-9.0	8.0
Lost Creek near Galen, MT	2003-2012	49-122	85	7.9-8.7	8.3
Flathead Lake samples (2)	Aug. 2009	23-26 mg/l			
Whitefish Lake sample	Aug. 2009	23 mg/l			

Source: Council Staff. Generally, calcium levels above 15 mg/l may be suitable for mussels, levels over 25 mg/l are very likely to be suitable (IEAB, 2010)

Table 2.
State spending for watercraft inspections, decontamination and mussel monitoring, 2013

State	Program element	2013 Funding
Washington	Mussel monitoring (DNA, supplies, staffing)	$133,145
	WDFW AIS staffing at check stations	$ 14,855
	WDFW Enforcement officer staffing at check stations	$ 90,000
	WA TOTAL	**$238,000**
Oregon	Watercraft inspection program (coordinated by ODFW with state funding from the Oregon State Marine Board AIS boat permit revenue)	$450,000
	Waterbody monitoring for mussels (coordinated by Portland State University utilizing state funding from Oregon State Marine Board AIS boat permit revenue)	$ 50,000
	OR TOTAL	**$500,000**
Idaho	Watercraft inspection program	$958,445
	Mussel monitoring (DNA, supplies – not including staffing)	$ 74,000
	ID TOTAL	**$1,032,445**
Montana	Watercraft inspection program	$400,000
	Mussel monitoring (DNA, supplies, staffing)	$ 72,500
	MT TOTAL	**$472,000**
	REGION TOTAL	**$2,242,445**

Table 3.
Estimated Risk of Establishment, from Wells et al (2010), By State and Estimated Calcium Level, PNW States Only

State	Water Body Name	[Ca2+] mg/L	pH	Risk Category	Ramcharan Model 1.
Idaho					x= NO DATA
Salmon Falls	Creek Reservoir	83.2	8.15	High	Presence
Oneida Narrows	Reservoir	59.7	7.76	High*	Presence
Snake	River	57.5	8.03	High	Presence
Blackfoot	River	53	8.1	High*	Presence
Alexander	Reservoir	52.1	7.97	High*	Presence
Willow	Creek	50.2	8.18	High	Presence
Magic Reservoir,	Outflow	49.8	7.85	High	Presence
Bear	Lake	47.7	8.11	High	Presence
Snake River,	American Falls Res.	47.5	8.19	High	Presence
Ririe	Reservoir	46.9	7.96	High	Presence
Snake River,	Lake Walcott	46.2	8.27	High	Presence
Snake River, Milner	Lake	45.7	8.49	High	Presence
Blackfoot	Reservoir	43.7	8.38	High	Presence
Snake River,	Bliss Reservoir	43.3	8.21	High	Presence
Snake River,	Upper Salmon Falls Res.	40.3	8.23	High	Presence
Murtaugh	Lake	39.8	8.14	High	Presence
Snake River,	Gem State Reservoir	37.4	8.09	High	Presence
Snake River,	Palisades Reservoir	37.3	7.99	High	Presence
Stone	Reservoir	34.4	8.25	High*	Presence
Deadwood	Reservoir	33.7	7.21	High	Absence
Kootenai	River	33.1	7.79	High	Presence
Owyhee	River	32.6	8.21	High	Presence
Mud	Lake	31.9	7.96	High	Presence
Snake River,	Brownlee Reservoir	31.3	8.13	High	Presence
Chesterfield	Reservoir	27.4	8.63	High*	Presence
Mann Lake,	Inflow	26	7.95	High*	Presence
Snake River, C.J. Strike	Reservoir	24.2	8.39	Medium	Presence
Little Wood	Reservoir	23.8	7.91	Medium	Absence
Clark Fork	River	23.6		Medium*	X
Mormon	Reservoir	23.5	8.21	Medium*	Presence
Little Wood	River	23.4	7.93	Medium	Absence
Lake	Pend Oreille	23.4		Medium	Absence

Big Lost	River	22	8.18	Medium	Presence
Pend Oreille	River	20.1	7.92	Medium	X
Lake	Lowell	19.8	8.17	Medium	Presence
Salmon	River	19.1	8.62	Medium*	Presence
Paddock Valley	Reservoir	17.8		Medium*	
Mann Creek	Reservoir	16.9	7.68	Medium	Absence
Mann	Creek	16.7	7.77	Medium	Absence
Island Park	Reservoir	15.8	8.09	Medium	Absence
Bruneau	River	13.6	7.96	Low	Absence
Henry's Fork, N.F. Snake	River	12.3	7.87	Low	Absence
Mountain Home Res	outflow	11.4	7.42	Verylow	Absence
Payette	Lake	11	8.3	Verylow*	Absence
Boise	River	10.9	7.67	Verylow	Absence
South Fork Boise	River	10.6	8.1	Verylow*	Absence
Anderson Ranch	Reservoir	10.3	7.68	Verylow	Absence
Crane Creek	Reservoir	9.5	7.33	Verylow*	Absence
Lucky Peak	Reservoir	9	7.36	Verylow*	Absence
Hayden Lake,	inflow	8	7.55	Verylow	Absence
Priest	Lake	7.6	7.46	Verylow	Absence
Alturas	Lake	7.4	7.22	Verylow*	Absence
St. Joe	River	6.4	7.19	Verylow	Absence
Little N.F. Coeur d'Alene	River	6.3	7.5	Verylow*	Absence
Killarney	Lake	6.2	6.94	Verylow	Absence
Deadwood	Reservoir	6.2		Verylow	Absence
Black	Lake	5.8	7.05	Verylow	Absence
Wilson	Creek	5.8	7.32	Verylow*	Absence
Black Canyon	Reservoir	5.7	7.55	Verylow*	Absence
Benewah	Lake	5.6	8.42	Verylow	Absence
Clearwater	River	5.4	8.2	Verylow	Absence
Deadwood	River	5.2	7.3	Verylow	Absence
Redfish Lake,	outflow	4.7	7.21	Verylow	Absence
Hauser	Lake	4.6	6.91	Verylow	Absence
St. Maries	River	4.3	7.27	Verylow	Absence
Horsetheif	Lake	3.9	6.83	Verylow*	Absence
Lochsa	River	3.7	7.36	Verylow	Absence
Cascade	Reservoir	3.6	7.4	Verylow	Absence
Pettit	Lake	3.2	7.31	Verylow	Absence
Payette	River	3.1	7.37	Verylow	Absence

N.F. Payette	River	2.2	7.07	Verylow	Absence
N.F. Clearwater	River	1.8	8.39	Verylow*	Absence
Montana					
Powder	River	153	8.03	High	Presence
Musselshell	River	115	8.08	High	Presence
Bighorn	River	89.9	8.08	High	Presence
Clark Fork	Muddy Creek	83.2	8.12	High*	Presence
Teton	River	73.5	7.32	High	Presence
Ruby	River	73.3	8.24	High	Presence
Beaverhead	River	71.5	7.92	High	Presence
Judith	River	64.2	8.01	High	Presence
N.F. Musselshell	River	64	8.09	High	Presence
Sun	River	59.5	8.21	High	Presence
Smith	River	56.5	8.16	High	Presence
Ruby River	Reservoir	53.5		High*	X
Red Lodge	Creek	53.3	7.35	High*	Presence
Norwegian	Creek	50.1	7.22	High	Presence
Marias	River	49.2	7.83	High	Presence
Lake	Fort Peck	47	8.59	High*	Presence
Tongue River	Reservoir	46.9	7.43	High	Presence
Garden	Creek	45.9	8.34	High*	Presence
Milk River		43.8	8.13	High	Presence
Tiber	Reservoir	43	8.17	High	Presence
Mission	Lake	42.4	8.05	High	Presence
Gallatin	River	42.2	7.94	High	Presence
Jefferson	River	40.5	8.18	High	Presence
Missouri	River	39.8	8.16	High	Presence
Douglas	Creek	39.6	8.11	High*	Presence
Cooney	Reservoir	38.7		High*	X
Battle	Creek	37	7.91	High*	Presence
Beaver	Creek	37	8.02	High*	Presence
Jocko	River	37		High*	presence
Lodge	Creek	35.8	9.03	High*	Presence
Tenmile	Creek	35.5	7.65	High	Presence
Helena Valley Regulating	Reservoir	35		High*	X
Clarks Fork of Yellowstone	River	34.9	7.5	High	Absence
Holter	Lake	34		High*	X

Nelson	Reservoir	34		High*	X
Ashley	Lake	33.8	8.16	High*	Presence
Clark Fork	River	33.2	7.91	High	Presence
Lake	Koocanusa	33	7.74	High*	Presence
Hauser	Reservoir	32		High*	X
Post	Creek	32		High*	X
S.F. Sun	River	31.7	8.33	High*	Presence
Gates of the Mountain	Reservoir	30		High*	X
Willow	Creek	29.4	7.03	High	Absence
Birch	Creek	29.2	7.17	High	Absence
S.F. Flathead	River	29	7.87	High	Presence
Lake	Helena	29		High*	X
Kootenai	River	28.6	8.1	High*	Presence
Nevada	Creek	28.5	8.1	High*	Presence
Canyon Ferry	Reservoir	28.3		High	X
Blackfoot	River	28.1	7.09	High	Absence
Lake	Alva	28		High*	X
Thompson Falls	Reservoir	27	8.33	High*	X
Echo Lake		27		High*	X
Yellowstone	River	26.8	8.14	High	Presence
Rock Creek		26.7	7.3	High	Absence
Noxon	Reservoir	26		High*	X
Soda Butte	Creek	25.6	7.99	High	Presence
Upper Marsh Ck, Flaming Gorge Res.	inflow	25		Medium*	X
Fresno	Reservoir	24.1		Medium	X
Flathead	River	24	8.21	Medium*	Presence
Cabinet Gorge	Reservoir	24	8.21	Medium*	Presence
Flathead	River	24	8.21	Medium*	Presence
Cabinet Gorge	Reservoir	24	8.21	Medium*	Presence
Butte	Creek	23.5	8.37	Medium*	Presence
Whitefish	Lake	23	7.58	Medium*	Absence
Harrison	Lake	22		Medium*	X
Sophie	Lake	22		Medium*	X
Swan	Lake	22		Medium*	X
Flathead	Lake	21.6	8.02	Medium	Absence
Hungry Horse	Reservoir	21.2	8.01	Medium*	Absence
Ennis	Lake	21		Medium*	X

E.F. Rock Creek	21	6.16	Medium*	Absence
Ennis Lake	21		Medium*	X
Thompson Lake, inflow	19		Medium	Presence
Boulder River	18.9	7.01	Medium	Absence
Salmon Lake	17		Medium*	X
Big Hole River	16.1	7.46	Medium	Absence
Placid Lake	16		Medium*	X
Lake Mary Ronan	15.9	7.38	Medium*	Absence
Lake McDonald, outflow	15.2		Medium	Absence
Bitterroot River	14.8	6.77	Low	Absence
Madison River	13.5	7.91	Low	Absence
Seeley Lake	12		Low*	X
W.F. Clearwater River	11.7	7.4	Verylow*	Absence
St Regis River	10	7.5	Verylow*	Absence
Bull Lake	8.3	8.14	Verylow	Absence
Painted Rocks Reservoir	7	8	Verylow*	Absence
Oregon				
Warm Springs Reservoir	56	8.08	High*	X
Malheur Reservoir	44.6	8.37	High	Presence
Owyhee River	43	7.97	High	Presence
Bully Creek Reservoir	41.7	7.76	High	Presence
Malheur River	39.6	8.36	High*	Presence
Umatilla River	34.6		High*	X
Prineville Reservoir	33.4	7.72	High	Presence
Snake River, Hells Canyon Reservoir	31	8.2	High*	Presence
Owyhee Reservoir	28.2	7.55	High	Absence
Paulina Lake	28	8.25	High	Presence
East Lake	25.5	7.25	High	Absence
Powder River	25.2	7.73	High	Absence
Crooked River	24.3	7.9	Medium	Presence
Mann Lake	24.3	8.7	Medium*	Presence
Crooked River	24.3	7.9	Medium	Presence
Ochoco Reservoir	20.1	8.4	Medium*	Presence
Buckeye Lake	19.2		Medium*	X
Applegate Reservoir	18.1	7.75	Medium	Absence
Columbia River, Lake Umatilla	17.8		Medium	X
Columbia River, Lake Wallula	17.4		Medium*	X
John Day River	17.3	7.79	Medium	Absence

Hart Lake	17.2	8	Medium*	Absence
Unity Reservoir	17.1	9.6	Medium*	Presence
Columbia River, Lake Celilo	17	8.07	Medium	Absence
Thief Valley Reservoir	15.6	7.31	Medium	Absence
Harney Lake	15	8.93	Low	Presence
Platt1 Reservoir	14.3	7.29	Low*	Absence
Wallowa Lake	14	8.09	Low*	Absence
Magone Lake	14	8.7	Low*	Presence
Upper Cow Lake	13.8	7.8	Low*	Absence
Antelope Flat Reservoir	13.6		Low*	X
Blue Lake	13.3	7.14	Low*	Absence
Cold Springs Reservoir	13.2	7.41	Low	Absence
Beulah Reservoir	12.8	7.9	Low*	Absence
Emigrant Lake	12.6	7.02	Low	Absence
Agate Reservoir	11.2	7.28	Verylow	Absence
Walton Lake	11.2	8.3	Verylow*	Absence
Lake Billy Chinook	11	9	Verylow*	Presence
Delintment Lake	10.6	8	Verylow*	Absence
Simtustus Lake	10.4	8.9	Verylow*	Presence
Hyatt Reservoir	10	7.34	Verylow	Absence
Lake Oswego	10	7.8	Verylow*	Absence
Cliff Lake	9.9		Verylow*	X
North Twin Lake	9.7	8.2	Verylow	Absence
Antelope Reservoir	9.3	8	Verylow*	Absence
McKay Reservoir	9	7.78	Verylow	Absence
Rock Creek Reservoir	8.9	6.98	Verylow*	Absence
Phillips Lake	8.9	8.2	Verylow*	Absence
Chickahominy Reservoir	8.1	7.7	Verylow*	Absence
Cottonwood Reservoir	7.8	7.8	Verylow*	Absence
Fish Lake	7.5	7.2	Verylow*	X
Klamath Lake	7.3	7.57	Verylow	Absence
Agency Lake	7	7.46	Verylow*	Absence
Howard Prairie Lake	6.9	7.56	Verylow	Absence
Dorena Reservoir	6.9	7.63	Verylow*	Absence
Willamette River	6.8	7.12	Verylow	Absence
South Twin Lake	6.7	8.3	Verylow*	Absence
Deschutes River	6.5	7.91	Verylow	Absence
Cottage Grove Lake	6.4	6.77	Verylow*	Absence

Morgan	Lake	6.4	8.1	Verylow*	Absence
Penland	Lake	6.1	8	Verylow*	Absence
North Fork	Reservoir	5.7	7.48	Verylow*	Absence
Henry Hagg	Lake	5.6	7.07	Verylow	Absence
Willow Valley	Reservoir	5.5	7.2	Verylow*	Absence
Hills Creek	Lake	5.3	8.1	Verylow*	Absence
Fern Ridge	Reservoir	5.2	7.8	Verylow*	Absence
Tenmile	Lake	5.1	7.26	Verylow*	Absence
White	River	5.1	7.4	Verylow*	Absence
Lost Creek	Lake	5	7.3	Verylow*	Absence
Goose	Lake	4.9	9.3	Verylow*	Presence
Hemlock	Lake	4.9		Verylow*	X
Gerber	Reservoir	4.8	7.3	Verylow	Absence
Willow	Lake	4.8	7.7	Verylow*	Absence
Dexter	Lake	4.7	7.6	Verylow*	Absence
Devils	Lake(Lincoln)	4.7	7.8	Verylow	Presence
Selmac	Lake	4.7		Verylow*	Absence
Haystack	Reservoir	4.6	7.2	Verylow*	Absence
Pine Hollow	Reservoir	4.5	7.4	Verylow*	X
Lookout Point	Lake	4.5	7.4	Verylow	Absence
Timothy	Lake	4.5	7.64	Verylow	Absence
Foster	Reservoir	4.4	7.2	Verylow*	Absence
Thompson Valley	Reservoir	4.4	7.6	Verylow*	Absence
Wolf Creek	Reservoir	4.4		Verylow*	Absence
Sandy	River	4.3	7.5	Verylow	Absence
Loon	Lake	4.2	7	Verylow	Absence
Smith	Reservoir	4.2	7.2	Verylow*	Absence
Fall Creek	Reservoir	4.1	7.58	Verylow	Absence
Green Peter	Lake	4	7.3	Verylow*	Absence
Suttle	Lake	4	8.08	Verylow*	Absence
Eel	Lake	3.6	7.4	Verylow*	Absence
Cougar	Reservoir	3.5	6.84	Verylow	Absence
Detroit	Lake	3.5	7.51	Verylow*	Absence
Lemolo	Lake	3.5	7.53	Verylow*	Absence
Wickiup	Reservoir	3.5	7.6	Verylow*	Absence
Fish	Lake(Jackson)	3.5		Verylow	Absence
North Ten Mile	Lake	3.4	7.1	Verylow*	Absence
Siltcoos	Lake	3.4	7.48	Verylow	Absence

Davis Lake	3.3	7.87	Verylow*	Absence
Gold Lake	3.2	7.3	Verylow*	Absence
Blue River Reservoir	3.2	7.49	Verylow	Absence
Tahkenitch Lake	3	7.01	Verylow	Absence
Odell Lake	3	7.79	Verylow*	Absence
Mercer Lake	3	7.87	Verylow*	Absence
Lake of the Woods	2.5	7.14	Verylow	Absence
Diamond Lake	2.5	7.36	Verylow	Absence
Triangle Lake	2.4	7	Verylow*	Absence
Crescent Lake	2.4	7.2	Verylow*	Absence
Elk Lake	2.2	7.95	Verylow*	Absence
Craine Prairie Reservoir	2.2	9.8	Verylow*	Presence
Clear Lake	2.1	7	Verylow*	Absence
Munsel Lake	2.1	7.05	Verylow*	Absence
Miller Lake	2.1	7.2	Verylow*	Absence
Lava Lake	2.1	7.9	Verylow*	Absence
Cultus Lake	2	7.5	Verylow*	Absence
Woahink Lake	1.9	7.1	Verylow*	Absence
Sparks Lake	1.4	7.01	Verylow	Absence
Hosmer Lake	1.2	7.1	Verylow*	Absence
Washington				
Wannacut Lake	225	8.25	High*	Presence
Pearrygin Lake	41.5	8.35	High*	Presence
Coldwater Lake	40.3	6.87	High	Absence
Spectacle Lake	37.8	8.75	High	Presence
Palmer Lake	36	8.35	High	Presence
Spokane River inflow	35.3	8.43	High	Presence
Lower Crab Creek	33.9	8.33	High	Presence
Sprague Lake	31.8	8.68	High	Presence
Moses Lake	30.5	8.18	High	Presence
Waitts Lake	30.2	7.38	High	Absence
Potholes Reservoir outflow	28.3	8.14	High	Presence
Methow River	21.5	7.99	Medium	Absence
Priest Rapids Lake, outflow	20.9	7.69	Medium	Absence
Columbia River, FDR Lake	20.9	7.93	Medium	Absence
Priest Rapids Lake, outflow	20.9	7.69	Medium	Absence
Columbia River, FDR Lake	20.9	7.93	Medium	Absence
Williams Lake	20.5	7.39	Medium	Absence

Yakima River	inflow	20.5	7.88	Medium	Absence
Williams	Lake	20.5	7.39	Medium	Absence
Yakima River	inflow	20.5	7.88	Medium	Absence
Loon	Lake	19.4		Medium*	X
Loon	Lake	19.4		Medium*	X
Lake Washington,	inflow	18.8	7.77	Medium	Absence
Lake Washington,	inflow	18.8	7.77	Medium	Absence
Columbia River,	Lake Wallula	18.6	7.87	Medium	Absence
Yakima	River	18.6	7.91	Medium	Absence
Columbia River,	Lake Wallula	18.6	7.87	Medium	Absence
Yakima	River	18.6	7.91	Medium	Absence
Columbia River,	Lake Wanapum	18.1	8.02	Medium	Absence
Columbia River,	Lake Wanapum	18.1	8.02	Medium	Absence
Billy Clapp	Lake	17.9		Medium*	X
Billy Clapp	Lake	17.9		Medium*	X
Banks	Lake	17.8	7.9	Medium	Absence
Banks	Lake	17.8	7.9	Medium	Absence
Columbia River,	Hanford Reach	17.1	8.05	Medium	Absence
Columbia River,	Hanford Reach	17.1	8.05	Medium	Absence
Columbia River,	Lake Celilo	16.8		Medium*	X
Columbia River,	Lake Celilo	16.8		Medium*	X
Columbia River,	Lake Bonneville	16.5	8.11	Medium*	X
Columbia River,	Lake Bonneville	16.5	8.11	Medium*	X
Clear	Lake	16.4	8.47	Medium	Presence
Clear	Lake	16.4	8.47	Medium	Presence
Horsetheif	Lake	16.2		Medium*	X
Lake	Crescent	15.9	6.94	Medium	Absence
Blue	Lake	15.6	8	Medium	Absence
Rolland	Lake	15.6		Medium*	X
Snake River,	Lake Wallula	13.6	7.95	Low	Absence
South Twin	Lake	13	7.45	Low*	Absence
Buffalo	Lake	12.5	8.55	Low*	Presence
Nooksack	River	12	7.57	Low*	Absence
Lake	Cushman	11.6	7.55	Verylow	Absence
Touchet	River	10.8	7.7	Verylow	Absence
Silver	Lake	10.4	7.49	Verylow	Absence
Spokane	River	10.2	7.71	Verylow	Absence
Entiat	River	9.7	7.91	Verylow	Absence

Deer	Lake	9.3	7.5	Verylow*	Absence
Palouse	River	8.5	7.96	Verylow	Absence
Cowlitz	River	8.1	7.47	Verylow*	Absence
Skagit	River	7.8	7.5	Verylow	Absence
Diamond	Lake	7.5	7.9	Verylow	Absence
Rimrock	Reservoir	7.4	7.59	Verylow*	Absence
North Twin	Lake	7.2	7.05	Verylow*	Absence
Lake	Wenatchee	7	7.33	Verylow	Absence
Tieton River	outflow	7	7.62	Verylow*	Absence
Lake	Chelan	6.9	7.73	Verylow	Absence
Kachess	River	6.2	7.53	Verylow*	Absence
Kachess	Reservoir	6.1	7.53	Verylow*	Absence
Mineral Lake,	outflow	5.8	7.64	Verylow*	Absence
Riffe	Reservoir	5.4	7.43	Verylow*	Absence
Spirit	Lake	5.3	6.93	Verylow	Absence
Alder	Lake	5.1	7.45	Verylow*	Absence
Newman	Lake	4.8	7.8	Verylow*	Absence
Cle Elum	Reservoir	4.7	7.08	Verylow	Absence
Cle Elum	River	4.7	7.53	Verylow*	Absence
Wenatchee	River	4.7	7.6	Verylow	Absence
Grays	River	4.3	7.24	Verylow	Absence
North Fork Sauk	River	4.3	7.36	Verylow*	Absence
Keechelus	Reservoir	4.1	7.35	Verylow*	Absence
Swift Creek	Reservoir	3.9	7.39	Verylow*	Absence
Liberty	Lake	3.9	7.5	Verylow*	Absence
Yale	Reservoir	3.8	7.23	Verylow*	Absence
Bumping	Reservoir	3.8	7.55	Verylow*	Absence
Black	Lake	3.8		Verylow*	X
Omak	Lake	3.5	9.55	Verylow*	Presence
White	River	1.7	7.29	Verylow*	Absence
Soap	Lake	1.6	9.6	Verylow*	Presence
Wyoming					
Cheyenne	River	249	7.82	High	Presence
Big Sandy River,	Big Sandy Res. outflow	141	8.2	High*	Presence
Keyhole	Reservoir outflow	135	8.2	High	Presence
Seminoe	Reservoir outflow	120	8.23	High	Presence
Salt River,	Palisades Reservoir inflow	64.1	8	High*	Presence

Bighorn River	62.9	8.17	High	Presence
Boysen Reservoir	54.1	8.31	High	Presence
Bighorn Lake inflow	52.6	8.31	High	Presence
Flaming Gorge Reservoir	52.4	8.34	High	Presence
North Platte River	50.9	8.79	High	Presence
Sulphur Creek Reservoir outflow	44.3	8.51	High*	Presence
Woodruff Narrows Reservoir inflow	44.2	8.48	High	Presence
Green River, Fontenelle Reservoir	43.6	8.06	High	Presence
Bear River, Woodruff Reservoir	43.5	8.3	High	Presence
Wind River	37.2	8.18	High	Presence
North Platte River, Pathfinder Res. inflow	36.5	8.16	High	Presence
North Platte R, Seminoe Res. Inflow	33.2	8.14	High*	Presence
Lamar River	18.8	7.9	Medium	Absence
Lamar River	18.8	7.9	Medium	Absence
Snake River, Jackson Lake	17.3	7.71	Medium	Absence
Snake River, Jackson Lake	17.3	7.71	Medium	Absence
Buffalo Bill Reservoir inflow	16.4	7.78	Medium	Absence
Buffalo Bill Reservoir Inflow	16.4	7.78	Medium	Absence
Yellowstone Lake	11.6	7.25	Verylow	Absence
Meeks Cabin Reservoir	9.6	7.45	Verylow	Absence
Bull Lake	6.4	7.54	Verylow	Absence
Yellowstone River	5.5	7.52	Verylow	Absence
Jenny Lake outflow	3.7	7.87	Verylow	Absence
Grassy Lake Reservoir	2.9	7.3	Verylow	Absence
Shoshone Lake inflow	2.9	7.44	Verylow*	Absence
Fremont Lake	2.4		Verylow	X
Halfmoon Lake	2.3		Verylow*	X

1. The Ramcharan et al. (1992) model is a discriminant function:

   $A = 1.246 * pH + 0.045 * [Ca2+ \text{ as mg/L}] - 11.696$
   Mussels present if $A > -0.638$. This model correctly predicted the presence or absence of D. polymorpha with 92.7% accuracy.

*means 1 or 2 data points