Recommendations for Capitol Lake New Zealand Mudsnail Management

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Executive Summary

Closure of Capitol Lake in Olympia, Washington to the public in 2009 was in part due to a New Zealand mudsnail (*Potamopyrgus antipodarum*, NZMS) infestation discovered in the North Basin. This was the fifth watershed in Washington to become infested with NZMS. NZMS are federally and state listed invasive species. They are invasive because they are not native to the US, have broad habitat preferences, and are proliferative. NZMS will survive many different treatments making them hard to eradicate from the environment. At high densities, the NZMS dominate and change the food web with potential cascading effects on protected and native species.

Washington State Department of Enterprise Services (WDES) is exploring ways to manage the Capitol Lake area related to water quality, invasive species, protecting species of interest and large volumes of sediment input from the upper watershed of the Deschutes River. It is WDES's responsibility to employ actions to enable the public to use Capitol Lake because it is part of state-owned land and is designated as State Capitol and Historic Facilities. Management must occur of the federally and state listed protected and listed species of interest as well as invasive species to limit their spread. Incorporating NZMS control and prevention strategies in the proposed Capitol Lake management options after dredging is essential to achieving a successful outcome, especially when informed by monitoring and verification studies (Figure 1).

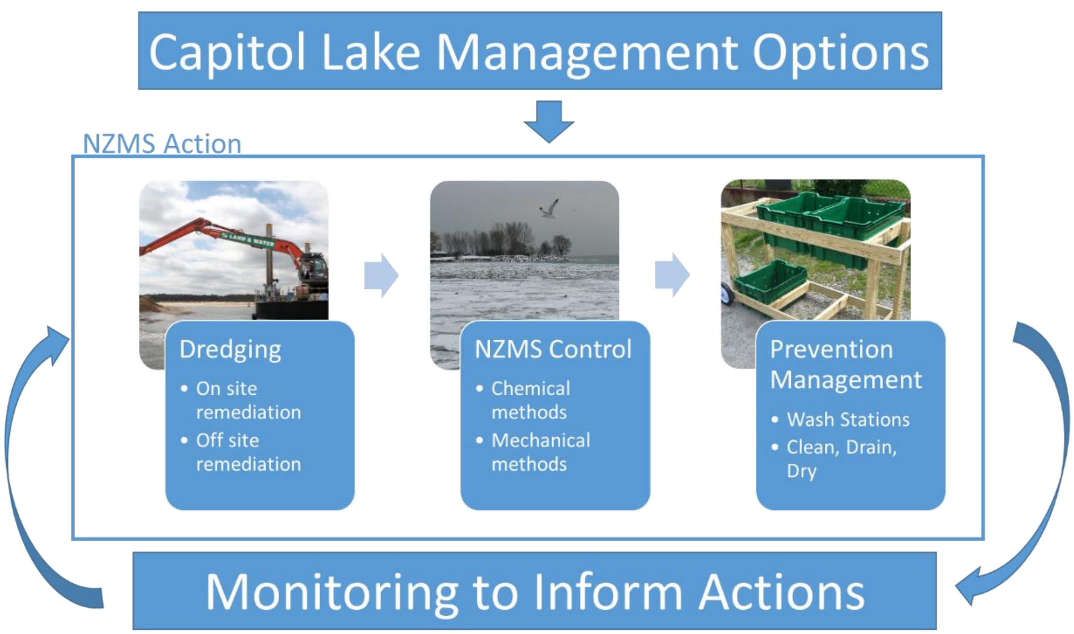

Figure 1. Implementing researched options for NZMS remediation, control and prevention under all of the possible Capitol Lake management options with input from monitoring studies will allow use of the Capitol Lake area by the public with low risk of NZMS transport.

Under all of the options considered to manage the lake, large volumes of dredged material will result. There is the potential that 400,000 cubic yards of dredged material will need to be contained and treated with the removal of the dam. Material kept on site or isolated near Capitol Lake will not need to be treated. Containment and treatment of dredged material that goes off-site could limit the spread of NZMS. Control options have been shown to work at the laboratory scale, but additional research and verification of the treatment at large scale, in-field applications must occur before implementation on large quantities of dredged material. Quantification and quality control standards on treatment process are pertinent to defend the management actions.

None of the Capitol Lake management options will eradicate the NZMS from the area. Removal of the dam to return the area back into an estuary will not eradicate or control the NZMS. NZMS survive in brackish water environments and tolerate ocean salinities. The flows from the Deschutes River are not high enough to keep the NZMS from thriving and spreading. NZMS are equally suited for river and lake environments.

Management and control of the NZMS population in the lake or estuary must occur to keep NZMS populations low, to limit the likelihood of their spread out of Capitol Lake. Eradication is not attainable in the natural environment without high environmental costs. Chemical treatments, such as copper or other pesticides, will decrease the NZMS population. The yearly flushes and additional floodwater from the Deschutes River has transported the NZMS, most likely creating an established population in Budd Inlet, though no surveys have been conducted. If eradication or control is achieved in Capitol Lake, it is necessary to install barriers at the dam to limit the movement of NZMS back into Capitol Lake.

The most important step in controlling NZMS is to implement prevention management. Utilizing decontamination stations at access points around Capitol Lake and other areas in Washington is an effective way to limit and clean mud and plants from transport vectors that harbor NZMS. Decontamination stations are effective prevention tools when properly maintained. Prevention management strategies are useful in slowing the introduction of all invasive and non-native species.

Additional surveys of NZMS including population densities and other invasive species are essential before implementation of lake management options and need to continue on a regular basis to inform management decisions. There is only one density estimate completed on the NZMS from Johannes survey in 2009. The management decisions used on NZMS must be evaluated to be in the best interest with other species of interest that exist in the Capitol Lake area, such as the Brown Bat, Chinook and Coho salmon. Extensive surveys of the fauna of Capitol Lake could confirm the suggestion that natural predation is controlling the NZMS densities.

NZMS are likely to stay in the Capitol Lake area and not disappear. Over time, NZMS have shown that their population densities decrease, but prior to the “bust” they may alter the ecosystem changing the food web and nutrient cycles. The Capitol Lake management actions could make the habitat very favorable for NZMS because the alterations will create a disturbed system and an ecologically new habitat. Utilizing predators of NZMS as a control tool has a high uncertainty of being effective and very little evidence is available to show that it is successful.

Implementation of NZMS control and management strategies with decontamination stations and conducting annual monitoring to inform future management decisions are actions that will reduce the risk of NZMS spread to naïve environments. Monitoring programs need to include adjacent waterways, such as Black Lake, which is between two watersheds that have NZMS infestations (Deschutes River and Chehalis River/Estuary). These actions should be in accordance with federal and state legislation and be the most cost effective ways to manage Capitol Lake. A successful Capitol Lake management plan will have adequate resources dedicated to NZMS management and control.

Introduction

Capitol Lake in Olympia, Washington was found to be infested with New Zealand mudsnail (*Potamopyrgus antipodarum*, NZMS) in the winter of 2009. Washington Department of Fish and Wildlife (WDFW) closed Capitol Lake to the public shortly after the discovery. This was the fifth watershed in Washington to become infested with NZMS (Fuller 2018). WDFW tried three different eradication attempts over the next year with limited success, as a survey completed in 2011 showed high densities of NZMS through the North Basin and into the middle basin of Capitol Lake. The NZMS has created a challenge for the long-term management of Capitol Lake.

Washington State Department of Enterprise Services (WDES) is working on a strategy to manage Capitol Lake for all of the stakeholders, though this has been their goal for about 30 years. WDES is currently hiring an environmental consulting firm (Floyd & Snyder) to conduct a project specific environmental impact statement. This brief is to encourage WDES and Floyd & Snyder to incorporate the management and control of NZMS into all of the Capitol Lake area management options. Three strategies need to be addressed within all of the Capitol Lake management options:

1. Containment and treatment of dredged material
2. Control of NZMS densities to lower the potential risk of transport and environmental damage
3. Implementation of prevention actions to lower the risk of NZMS and other invasive species being transported out of the area and other invasive species being introduced into Capitol Lake.

Monitoring the effect of the implemented strategies will be critical in evaluating the success of the project. Monitoring should also be used to make informed management decisions and options for treatment and eradication adjusted as shown to be needed. Options for eradication, management, and prevention are discussed, but it will be important for stakeholders more familiar with all of the issues and intricacies surrounding Capitol Lake to choose what is best for the area.

The NZMS as an Invasive Species

NZMS discovered in the United States in 1987 from an established population at Snake River, Idaho (ANS 2007; Johannes 2011; Benson et al. 2018). They are native to New Zealand and are invasive in Europe, Australia, Canada and the United States (ANS 2007; Benson et al. 2018). Federal legislation considers NZMS an invasive species (ANS 2007) and Washington State prohibits them under RCW 77.135.010(13) (Meacham 2001; Pleus 2016). The goal of the federal NZMS management plan is to prevent and delay the spread of NZMS to new areas and reduce the impacts of existing and new population (ANS 2007), which dictates federal and state agencies directives. Considered a “management class 2” in Washington State’s management plan, NZMS must have management actions that mitigate the impact, control the population size and prevent dispersal to other water bodies (Meacham 2001). Washington Department of Enterprise Services (WDES) has the responsibility to manage Capitol Lake and Washington Department of Fish and Wildlife (WDFW) has the responsibility to administer the invasive species statutes. Since these are both government entities, the federal and state laws apply to these agencies and dictate their management actions.

NZMS are categorized as invasive species because they have broad environmental tolerances. They are able to survive a large range of temperatures (0-30°C), conductivity and salinity ranges (>25 µS/cm and freshwater to brackish water), flows (0-100 cm/s), colonize different substrates, and do not prefer pristine or disturbed habitat (ANS 2007; Alonso and Castro-Diez 2008; Stockton 2011; Alonso and Castro-Diez 2012). NZMS are clonal, but successful clones can have broad environmental tolerances (Dybdahl and Lively 1995; Jacobson and Forbes 1997; Dybdahl and Drown 2010). They either fill unoccupied niches in environments or compete with native invertebrates in that ecological niche changing the dynamics of the ecosystem (Alonso and Castro-Diez 2008). This snail has a solid operculum ensuring its survival from desiccation and chemical treatment (Richards et al. 2004). NZMS are easily transported; examples of transport vectors include aquaculture products and aquatic ornamental plants, transport tanks and pipes, recreational vehicles and sport fishing gear, and birds and fish (ANS 2007; Alonso and Castro-Diez 2008; Stockton 2011).

Capitol Lake Management Options Pertaining to NZMS

Capitol Lake has been closed to the public since 2009. WDFW conducted three treatments to eradicate the NZMS from the lake between 2009 and 2010 (Johannes 2010a; LeClair and Cheng 2011; Johannes and Aitkin 2011), which were not successful as the NZMS densities in 2011 were high in some areas sampled (Milne 2017). Instituting a long-term management plan for both protected species and invasive species in Capitol Lake is essential for WDES.

In all of the Capitol Lake management options, NZMS management requires more definition. The following are some of the general options that have been proposed (Hayes et al. 2008; Floyd & Snider 2016) and how NZMS management would most likely occur.

- Status Quo - no change from existing conditions and NZMS are not managed or controlled and continue to be transported into the marine waters with high probability of being transported to other areas;
- Managed Lake – Dam remains with various up lake management strategies and NZMS are managed and controlled to limit their densities within lake and prevention strategies are employed to minimize the likelihood of spread to other areas;
- Estuary - 5th-Avenue Dam removal resulting in a dynamic, steady-state tidal mudflat environment and partially restored estuary, where NZMS are still present in the environment thus additional prevention and management of NZMS would continue as in the managed lake options; and
- Hybrid of the Above- There have been several conceptual designs, but management and prevention of NZMS will need to occur.

Status quo, leaves the lake closed to the public and no further management is to be conducted, though due to constant input of sediment from the Deschutes River, Capitol Lake will be dredged periodically (Hayes et al. 2008). The other options require dredging the lake, removing plants and sediments from the lake, which has the high probability of harboring NZMS. In the options that require removal of the dam to create an estuary environment, it will create a suitable habitat for NZMS. Hayes et al. (2008) did an extensive assessment of the fauna of Capitol Lake and the impact of the management options, but this was prior to the establishment of NZMS.

Within these lake management options or others future options, WDFW and WDES need to assess and control for NZMS in dredged material and establish a management or eradication program for NZMS. As these are taxpayer-funded entities and Capitol Lake is public, it is their responsibility to employ actions to enable the public to use Capitol Lake. Keeping the lake closed in status quo is not an option; there are viable management and control options available for use at Capitol Lake. A successful Capitol Lake management plan will have adequate resources dedicated to NZMS management and control.

Dredged Material Containment

Processing dredged plant or soil material containing NZMS removed from Capitol Lake area is required. An estimated 400,000 cubic yards of material would be initially dredged and about 35,000 cubic yards annually dredged. Dredged material that stays on site would not have to be treated. This material would still harbor NZMS and contribute to the population already in the area, but until the NZMS are eradicated from Capitol Lake, there is no additional risk from the dredged material. The dredged material should be contained and kept isolated to lower the risk of transport of NZMS from the area.

Any material moved off site would have to be treated and testing completed to ensure NZMS were dead or removed. Several mechanical control options that kill or remove NZMS are filtration, incineration, freezing, or desiccation (ANS 2007). Chemical treatment with pH changes will work, but concentrations will be high and material will need to be neutralized depending on intended use after treatment (Stockton-Fiti and Moffitt 2017; Barenberg and

Moffitt 2018). Organic material deactivates many chemicals, so chemical treatment of dredged material will need high concentrations to mitigate the deactivation of the organic material. Conducting large scale testing and verification of mortality for the chosen method for treating the dredged material must occur, as there is no published work stating that it is effective with large volumes of dredged material. The following are mechanical options that will work to kill NZMS, but the method used on large amounts of dredged material will be at the discretion of engineers or planners.

Freezing the NZMS to a temperature less than -3°C for 2 h will kill NZMS (Richards et al. 2004). Complete freeze of the dredged material will be necessary to be 100% effective. Further processing of the material such as sieving out snail shells before use at another location could be required. Freezing does not destroy DNA; additional removal steps to lower the risk are necessary if material is applied in an ecological rehabilitation project. DNA in the soil would increase the likelihood of false positives as the use of eDNA for monitoring increases (Goldberg et al. 2013).

Heating dredged material to temperatures greater than 40°C will kill NZMS (Richards et al. 2004); incineration would ensure mortality. Incineration of soil, as they do with contaminated soil from hazardous waste sites, will remove NZMS and any other invasive species of concern such as the purple loosestrife (*Lythrum salicaria*). It will destroy all DNA and the clean dredged material is usable for any reclamation project.

Desiccation will take a long time, studies demonstrate that NZMS remain dormant and survive desiccation for up to 50 days on wet substrates at 20-25°C and 72 h at 9°C on dry substrates; desiccation time is dependent on humidity and temperature (Richards et al. 2004). Complete desiccation of the material is necessary to ensure NZMS mortality. Degradation of DNA occurs with time exposure to sunlight. Desiccated dredged material would have degraded DNA and sieving out the NZMS is unnecessary, though shells are present. With this treatment method, second hand application could be limited.

Removing plant material and then suction dredging the top layers of soil is another option (ANS 2007). Material from the suction dredge would need to be filtered with a sieve small enough to catch the NZMS (>100 µm). A sieve of 100 µm will catch all neonates (baby snails), juveniles, and adults (Nielson et al. 2012). This might not be feasible due to time and cost as the filter may plug easily at this small of mesh size. Additional sieving or treatment may need to occur. Dredged material will contain eDNA, but time to degradation of DNA not filtered is short and material could be used for any reclamation project.

Disposing dredged material into Puget Sound is another option, but the NZMS would likely survive the salinity increase (Hoy et al. 2012). However, it is unknown how the combination of pressure, salinity, temperature, and food availability will effect the NZMS survival. Levri et al. (2008) found NZMS could not survive at depths greater than 40 m in Lake Ontario. This warrants additional research if chosen as the treatment method.

Disposal of dewatered material in a landfill will be effective. Methods and disposal requirements should be followed per the landfill directions in compliance with Environmental Protection

Agency guidelines. Inspection of landfill containment systems will ensure that the landfill will contain and control the NZMS.

Placing dredged material prior to treatment or during treatment on top of an impenetrable platform that has a contained water collection system is essential in ensuring the NZMS do not crawl away, infest the land, and cause more problems. Equipment used in the dredging activity and any hauling of contaminated material are transport vectors. Cleaning and decontamination is necessary before transport or used only on site (ANS 2007). Conducting risk analysis for overland transport and implementing safety measures will keep NZMS from being dropped, blown out, or transported by equipment into other areas (ANS 2007).

Controlling NZMS within the Management Options

In the various Capitol Lake management options, NZMS management and control must occur. The proposed dam removal and creation of an estuary does not eliminate the NZMS from the area and environment. Prevention strategies must be in place prior to reopening the area to the public to ensure NZMS transport does not occur to other locations.

NZMS Survive and Flourish in an Estuary Environment

In some of the proposed Capitol Lake management options, an estuary environment is favored. The estuary environment will support NZMS survival. NZMS can survive in fresh and brackish water (ANS 2007), however recent research has shown NZMS can survive much higher salinities comparable to ocean salinity levels (LeClair and Cheng 2011; Hoy et al. 2012). They are found in the brackish waters and estuaries of the Columbia River and Chehalis River (Bersine et al. 2008; Litton 2017; Fuller 2018). Most of the populations in the western US of NZMS are of the same genotype; therefore, the snails in Capitol Lake are going to be similar to those in Young's Bay Columbia River and survive in an estuary (Dybdahl and Drown 2011; Hoy et al. 2012). Young's Bay Columbia River has high densities of NZMS since 1996 (Bersine et al. 2008). NZMS from the Columbia River Estuary are tolerant of salinity levels equal to that of ocean levels. Laboratory testing shows that 23% mortality of freshwater NZMS was achieved after 24 days (with acclimation to ocean salinity) and 30 to 63% survival occurred to acute exposure to ocean salinity levels (Hoy et al. 2012). Tolerance to salinity by the NZMS is dependent on temperature and rate of acclimatization to the higher salinity (LeClair and Cheng 2011).

LeClair and Cheng (2011) suggest that the response of NZMS to high salinity at colder temperatures warrants additional study. Conducting additional monitoring on Budd Inlet to determine if NZMS are present is prudent. If the NZMS are not present in the inlet, this could be valuable information regarding the salinity tolerance of the Capitol Lake NZMS and the dispersal activities of the population.

Dam Removal

Removal of the dam to make Capitol Lake entirely an estuary will have little effect on the NZMS. After the removal of the dam, the flow of water may be more variable, turbidity will increase potentially impeding growth of periphyton and filamentous algae, which will initially decrease the density of NZMS (Oasis Environmental 2011). However, NZMS will rebound when turbidity decreases and food sources stabilize with the new flow regime, as observed in the Bear River, Idaho (Oasis Environmental 2011). Flow regimes higher than 100 cm/s will ensure that NZMS survival is low (Stockton 2011). Obtaining these high velocities in a river is extremely difficult; as the river widens the velocity slows.

The Deschutes River has not achieved these velocities to achieve low likelihood of NZMS survival. Maximum discharge in the Deschutes River over the last 10 years was about 6000 cubic feet per second in 2016 (USGS and USDOI 2018). At the USGS station 12080010 Deschutes River at E St Bridge at Tumwater, WA the depth was 33 feet deep at the maximum discharge and the width of the river was 65 feet (USGS and USDOI 2018). The velocity of the river was 84.5 cm/sec at the maximum discharge observed in the last 10 years. This is not a high enough velocity to ensure low NZMS survival. The station is in an area that is highly channelized, but downstream the river is wider, which will result in slower velocities. Removal of the dam and allowing for natural release of water into Budd Inlet will spread the water over the landscape and result in velocities less than 100 cm/sec, which will ensure a medium to high likelihood of NZMS survival (Stockton 2011).

Control Options for Capitol Lake Area

Continued management of NZMS in the Capitol Lake area needs to occur with all lake management options. Dredging will not eradicate NZMS from the Capitol Lake area. Application of control options to reduce the NZMS population will lower the risk of transport when Capitol Lake is open to the public. Possible control options for Capitol Lake could include a periodic chemical application, or drawdown of water to do a complete freeze or desiccate the mud and lakebed.

Chemical applications have proven effective to kill NZMS. The negatives include not 100% effective or if effective on NZMS, the chemical is brutal to native species, including species of interest and protected species. Application of pH changes to either basic levels, or copper containing pesticides as control options in lakes warrants additional research (Watton and Hawkes 1984; ANS 2007; Oplinger and Wagner 2009; Barenberg and Moffitt 2018). Desiccation and freezing may not be permitted because of effect on native fauna or impossible due to the flow of the Deschutes River and temperatures in the winter.

If eradication is achieved in upstream areas installation of copper, electrical, or velocity barriers will prevent NZMS from moving upstream from Budd Inlet (Stockton 2011). Barriers will limit the infestation potential and keep Capitol Lake free of NZMS as part of control efforts. Installation of copper barriers at fish hatcheries to limit the establishment of NZMS was successful (Hoyer and Myrick 2012). The type of barrier chosen for use at Capitol Lake will be dependent on engineering controls available for the area installed.

Since NZMS are upstream of Capitol Lake in the Deschutes River (Johannes 2013; Johannes 2015), there is a risk of them spreading down into Capitol Lake from this upstream source. The best solution would be to monitor the populations to determine if downstream spread is occurring and institute NZMS prevention management strategies.

NZMS Prevention Management

Prevention management of NZMS at Capitol Lake needs to occur under all of the proposed management options (with and without the dam) to reduce the risk of new populations in Capitol Lake and to stop the spread of NZMS out of Capitol Lake. When the lake is open to the public, utilization of prevention protocols is essential to stopping the transport of NZMS into other areas that are not infested. While there are 15 watersheds infested with NZMS (Table 1), it is best to keep them out of other watersheds to minimize control management costs (Fuller 2018). Prevention management strategies for NZMS include putting decontamination stations for gear cleaning at all access points. These decontamination stations include education and outreach material to explain the reasons for and proper use of stations. There are two options for decontamination stations. One option is to have a station that includes cleaning, draining and rinsing contaminated gear. This station will provide bristle brushes, boot picks, and clean water; maintenance should occur bimonthly. The second option is to have chemical treatment of gear once it is devoid of organic material (mud and plants). This station would have a chemical bath in addition to the items in option 1. A good chemical for disinfection is Virkon Aquatic (Stockton and Moffitt 2013) with maintenance occurring weekly. Maintenance of the stations is imperative for it to be effective.

Table 1. Management actions implemented by WDFW for watersheds/drainages. Capitol Lake and Ringold hatchery are the only area closures. *Ringold hatchery was reopened after management actions occurred.

	Management Action		
Watersheds/drainages	**Area Closure**	**Educational Outreach**	**Unknown**
Deschutes	X	X	
Duwamish		X	
Grays Harbor		X	
Lake Washington		X	
Lower Chehalis		X	
Lower Columbia		X	
Lower Columbia-Clatskanie		X	
Lower Cowlitz			X
Lower Skagit			X
Lower Snake-Asotin		X	
Middle Columbia-Lake Wallula		X	
Puget Sound		X	
Snohomish		X	
Upper Columbia-Priest Rapids	X*	X	
Willapa Bay		X	

Education and outreach are not enough to control the spread of NZMS. Currently 15 watersheds in Washington State contain populations of NZMS, with the most recent find in 2018 in the Lower Skagit watershed (Table 1; Fuller 2018). WDFW has put up signage at these areas, but has not instituted closure of the areas or installed decontamination stations (Table 1; Pleus and Schultz 2015). Continued spread into other drainages is evidence that only signage at infested areas is not enough to limit the spread of NZMS. California and Oregon are other states that only utilized education and outreach, but have new watersheds infested with NZMS yearly (Fuller 2018).

Montana implemented gear decontamination stations in 2009 (Davis and Moeltner 2010) and have had one new locality (but same watershed as other NZMS populations) in 2013 reported as infested (Fuller 2018). Idaho and Wyoming have also implemented gear decontamination stations at popular fishing sites where NZMS exist (ISAN 2014). Idaho has had one new watershed infested and Wyoming has had no new infestations since 2010; Washington has had nine new watersheds infested since 2010 (Fuller 2018).

Budd Inlet NZMS Prevention and Management

The likelihood of the Capitol Lake NZMS already being in Budd Inlet is high. There are flushing events that occur many times every spring, transporting sediment, debris, and plants throughout the lower Budd Inlet. NZMS can passively travel downstream through the outlet of Capitol Lake on floating algae and other plant mats or within the drift of the water column (Alonso and Castro-Diez 2008; Stockton 2011) and survive the salinity of the inlet (Le Clair and Cheng 2011; Hoy et al. 2012). Implementing monitoring studies in Budd Inlet will be valuable in determining management actions.

NZMS will most likely inhabit the mud or plant mats in an estuary, so implementation of clean, drain, dry procedures for boats removed from Budd Inlet will limit NZMS spread and other invasive species. Care and maintenance of fishing and wading gear to remove mud, plants or attached organisms after visiting Budd Inlet is advisable to limit the risk of spreading invasive species. Buy-in from the public is necessary to achieve success of these prevention strategy goals.

Surrounding Area NZMS Prevention and Management

WDFW shares education and outreach material focused on NZMS and other invasive species to the public through their website, fishing regulations, and public contact venues. It is the responsibility of the public to prevent the spread of invasive species. Implementation of decontamination stations in areas of high value for environmental reasons or public use will minimize the likelihood of invasive species introduction including NZMS. Decontamination stations will assist the public in preventing the spread, educate them about different invasive species, and equip them with a tool to prevent the spread through fishing gear vectors. The Clean, Drain, Dry initiative promoted for use to prevent Dreissenid mussels is advantageous in preventing the introduction of many other invasive species including the NZMS.

The closest NZMS infestation to Capitol Lake is in the Chehalis River near Cosmopolis, WA. This is a one-hour drive, 50 miles from Capitol Lake, so there is potential to fish or visit both locations in the same day. This location was reported infested in 2013 (Fuller 2018) and WDFW did not close the area to the public, but utilized education and outreach prevention strategies in the area. WDFW needs to be consistent with their messaging and actions for NZMS infestations statewide.

History of NZMS in Capitol Lake

NZMS were first discovered in Capitol Lake, Washington on October 22, 2009 at the north basin of Capitol Lake at Marathon Park (Johannes 2010a). WDFW was notified of the NZMS introduction November 16 after Deixis Consultants positively identified them as NZMS (Johannes 2011). On November 18, 2009, US Fish and Wildlife Service surveyed four sites around Capitol Lake and only found NZMS at Marathon Park area (Johannes 2011). WDFW surveyed Marathon Park and positively identified the snails as NZMS. WDFW closed Capitol Lake to the public and posted informational signs as their first response to the NZMS introduction on November 24, 2009 (Johannes 2010a). An additional survey conducted by WDFW on November 24, 2009 of Capitol Lake (no locations listed), Blake Lake Ditch, and Percival Creek and Johannes (2011) reports no results. WDFW conducted additional searches on December 3, 2009 in the Deschutes River at three sites and found no NZMS (Johannes 2011).

On December 9, 2009 a 2-foot drawdown of Capitol Lake was conducted (Johannes 2010a), and five sites of Percival Creek and the north basin boat launch at Capitol Lake were sampled, with only the north basin boat launch samples being positive for NZMS (Johannes 2011). Cheng and LeClair (2010) report that the surveys indicated “patchy distribution of snails throughout the lake with some areas of very high density, and that the adjoining waterways were not infested.” Multiple sites or transects near the north basin boat launch were sampled by WDFW and assessed by Deixis Consultants on December 10, 11 and 14, 2009 to determine the status of the NZMS after the management action of freezing the lakeshore (Johannes 2010a; Cheng and LeClair 2010). Both studies reported that in the area sampled there was 1.8% survival after freezing; i.e. mortality of the freezing management action was 98.2%.

In March 2010, WDFW conducted a backflush of saltwater from Budd Inlet into Capitol Lake with very little mortality occurring at the north and south sample sites located in the north basin (LeClair and Cheng 2011). Johannes (2011) reported that WDFW found NZMS in 2010 at the junction between the north and middle basins of Capitol Lake.

Another freeze attempt was conducted Feb 23, 2011, but was not successful because the mud did not freeze due to snow cover (Johannes and Aitkin 2011). Deixis Consultants was hired to do a large survey of Capitol Lake, which took place over 3 days June 20, 21, and 22, 2011 (Johannes 2011). This study showed that 29 of the 30 sites had NZMS present; indicating that NZMS were in the north and middle basin of Capitol Lake, but had not infested the area around the I-5 bridge at the south end of the lake. In 2016, Capitol Lake Improvement and Protection Association funded a project for Deixis Consultants to analyze the 2011 samples for densities of NZMS, and

Dr. Dave Milne wrote a report dated January 10, 2017 presenting the density data from this study. Densities ranged from 86 to 17,198 NZMS per square meter (Milne 2017).

Additional surveys completed in 2010, 2013 and 2015 by Deixis Consultants assessed the presence of additional NZMS populations within a 5-mile radius of Capitol Lake. In 2010, there were no additional NZMS populations (Johannes 2010b). In 2013, site 55 (Deschutes River at Tumwater Historical Park, Deschutes River, Thurston County, Tumwater) was discovered to be positive for NZMS; this is upstream of Capitol Lake (Johannes 2013). This introduction seems to be separate from the Capitol Lake NZMS, i.e. not a spread or continuation of the Capitol Lake population moving upstream, as NZMS were not found under the I-5 bridge when sampled on June 26, 2015 (Johannes 2015).

Despite recommendations by Deixis Consultants to WDFW and WDES, additional surveys of Capitol Lake have not been completed (Johannes 2015). Conducting a survey of Budd Inlet will complete the picture of the NZMS infestation. Density estimates of the NZMS population may be crucial in defending and implementing control actions.

NZMS Controversy

Environmental Damage of the NZMS

Impacts of NZMS vary widely with the ecosystem that they invade. NZMS tend to colonize an area at higher densities compared to most native invertebrates (Hall et al. 2003; Hall et al. 2006; Alonso and Castro-Diez 2008). Introduced populations consume most of the primary production of the habitat and can dominate secondary production of the invertebrate community (Hall et al. 2003; Hall et al. 2006; Alonso and Castro-Diez 2008; Maret et al. 2008; Moore et al. 2012; Bennett et al. 2015; Rakauskas et al. 2016). Change in the flow of primary production up to the higher trophic levels changes the dynamics of the food web in the ecosystem (Hall et al. 2003; Hall et al. 2006; Rakauskas et al. 2016). However, their invasion success seems to be dependent on the health of the invaded habitat. NZMS will establish in areas that are in the early stages of succession, but have a hard time competing with an intact native community (Alonso and Castro-Diez 2008; Maret et al. 2008; Alonso and Castro-Diez 2012; Bennett et al. 2015).

NZMS biofouling and economic impact is not as severe as other aquatic invasive species, namely zebra and quagga species, but they are a species that are invasive and harmful to the environment at least short term. Prevention or management actions are essential to controlling the spread of invasive species (ANS 2007; Davis and Moeltner 2010). Habitat areas that are diverse and have an abundance of species is a healthy ecosystem, whereas, habitats that are made up of monocultures are less resilient to climate change or mild disturbances (Yachi and Loreau 1999; Chapin III et al. 2000; Maret et al. 2008; Hooper et al. 2012; Bennett et al. 2015). The likelihood of losing native species is greater in the presence of invasive species (Chapin III et al. 2000; Maret et al. 2008; Moore et al. 2012; Bennett et al. 2015).

Federal and State Response to NZMS

Currently, 19 states have NZMS infestations and 10 of those in the western US (Table 2; Benson et al. 2018). Most states are following prevention protocols (Table 2), which are preventing the spread by employing decontamination activities such as the clean, drain, dry campaign and utilizing education and outreach material regarding how to limit their spread, as prevention is the best tool for management (ANS 2007; ISAN 2014).

Table 2. Management actions of western states with drainages infested with NZMS.

States	**No. Infested Drainages**	**State Management Action**		
		Clean, Drain, Dry	*Decontamination Station*	*Area Closure*
AZ	25	X		
CA	330	X		X
CO	45	X		X
ID	437	X	X	
MT	75	X	X	X
NV	10	X		
OR	104	X		
UT	262	X		
WA	105	X		X
WY	73	X	X	

There is no change in federal or state's regulatory approach with NZMS, but focus and funding are on preventing and managing the spread of zebra (*Dreissena polymorpha*) and quagga (*Dreissena bugensis*) mussels, as Dreissenid mussels have a higher ecological and economic cost (Davis and Moeltner 2010). Some states passed legislation to ban felt soles on wading gear as an attempt to control this transport vector (ISAN 2014). Felt soles are not the only transport vector; NZMS infest other materials (Stockton and Moffitt 2013). Decontamination and cleaning of gear or mud from shoes and feet or fishing gear is the best way to limit the spread of NZMS. Current movement in some of the federal regions is to reframe NZMS messaging to minimize language about NZMS specific impacts and focus on how prevention strategies will limit the spread of all invasive species (Draheim 2015). However, NZMS have only been in the Western US for about 30 years and it could take more time to realize the impacts of this invasive species on other protected and endangered species (Richards and Arrington 2006).

These snails are hard to eradicate from natural areas, especially without killing the native fauna. In the natural environment, many states employ similar methods as Washington, by employing education and outreach material, area closures, and decontamination activities (Table 1; ANS 2007; ISAN 2014; City of Boulder 2018). Putah Creek in central California, Dry Creek and Boulder Creek Colorado, and Darlington Spring Creek, a tributary of the Madison River in Montana were closed to the public when NZMS were found (Richards and Arrington 2006; City of Boulder 2018). Dry Creek and Boulder Creek Colorado locations remain closed to the public, but the California and Montana sites are now open to the public after eradication efforts were impeded due to NZMS infestation of other areas in the same watershed (Richards and Arrington 2006). Some states such as Montana have enforced gear cleaning post water activity (Table 1; Davis and Moeltner 2010; ISAN 2014).

NZMS eradication from facilities is easier, because flow of water is easily controlled and there is less concern of impacts on native species. States that have NZMS infestations at facilities, such as hatcheries, have closed them and worked on eradicating the NZMS from the facility. NZMS were observed at Ringold Hatchery in Washington in 2014. WDFW's response was to implement containment and not release any fish from the hatchery until management actions occurred. Management actions included purging of fish and decontaminating trucks. Educational signage was deployed in the area (Pleus & Schultz 2015). States such as Utah, California, Colorado and Montana have completely shut down hatcheries, implemented control measures to eradicate the NZMS from the facility and then after the NZMS were eradicated, the facilities were opened with strict biosecurity measures (ANS 2007; Davis and Moeltner 2010; Stockton 2011).

Closure of NZMS areas can have high economic costs to surrounding industries. A case study by Davis and Moeltner (2010), calculates that a year-round closure of a fishing area could result in $2 to 5 million loss in expenditures to the local community per year of closure and they highlight that prevention of spread is essential to mitigating all costs. Closure of Capitol Lake has cost DES and delayed the implementation of lake management options. With the infestation of NZMS in Capitol Lake, extra cost and actions will be needed to reduce the spread of NZMS.

Eradication of NZMS by the Environment

NZMS along with other invasive species populations exhibit "boom and bust" cycles, which is an initial high density during early establishment and then population densities decrease to a moderate, sustainable level (Moore et al. 2012; Bennett et al. 2015). However, there are many variables that can affect the timing and severity of the cycle (Simberloff and Gibbons 2004; Moore et al. 2012). There are cases where these cycles can lead to an extinction event in a location, but it is rare and the population must be isolated; and if predator mediated extinction occurs the predator must be at an advantage (Simberloff and Gibbons 2004; Carlsson et al. 2009). The Capitol Lake NZMS population will go through "boom and bust" cycles as a whole lake or in different areas; having access controlled and limited with prevention management strategies will make a bust cycle more likely lead to an extirpation.

Even with populations of NZMS going through "boom and bust" cycles, there is one example of NZMS extirpated from a watershed without human eradication attempts. In 2004, NZMS were observed in the Upper Green-Slate drainage in Wyoming, but subsequent sampling through 2014 resulted in no detection (Fuller 2018). This population was likely found near the time it was introduced and the population could not become established. Recent work on Polecat Creek has shown that the large populations cited by Hall et al. (2003) have declined, but are still present (Wise and Krist 2017). After a "bust" period, there are still NZMS in the ecosystem, but usually at lower densities (Moore et al. 2012; Bennett et al. 2015). Gerard et al. (2018) reviews the NZMS population over a 14-year period and notes the "boom and bust" cycle, attributing the decline in density with time to a trematode. Trematodes keep the NZMS densities lower in their native range and have escaped them in their invasive range (Simberloff and Gibbons 2004; Gerard et al. 2018). Even with the trematode acting as a disease/parasite, the NZMS populations are still within the stream causing ecological impacts (Gerard et al. 2018).

Due to clonal reproduction, it is alleged that NZMS will eventually die out due to being genetically identical, especially with the added pressure of predation (Milne 2017). Some of this assertion is accurate, NZMS are parthenogenic (females reproduce asexually, clonal reproduction) in habitats that they invade. However, their genotypic diversity can be high in clonal populations as the NZMS can be diploid or triploid asexual individuals (Dybdahl and Lively 1995). The NZMS in the United States and Europe are less genetically diverse compared to clonal populations in New Zealand (Dybdahl and Drown 2011). Invasive clones seem to have a large amount of phenotypic plasticity (ability to have traits that thrive and make survival possible in many environments) that assisted NZMS from one clonal line to survive at least 140 years in Great Britain (Dybdahl and Drown 2011). Implementation of prevention methods will ensure that additional introductions do not occur. This will keep the genetic diversity low and is essential in slowing the evolution rate of the NZMS (Alonso and Castro-Diez 2012).

Species that have overcome biological resistance of the habitat, which includes competition, predation, and disease, as they are trying to establish are assured long-term successful establishment (Alonso and Castro-Diez 2008). Establishment of NZMS in Capitol Lake occurred before 2011, as there are large densities throughout the lake (Johannes 2011; Milne 2017). Predators of NZMS were present through the NZMS introduction to establishment; therefore, predators already within the system are not going to eradicate the NZMS (Alonso and Castro-Diez 2008; Bennett et al. 2015).

Predators of NZMS that are native to Capitol Lake or Budd Inlet include some invertebrate feeding fish, such as juvenile flounder (*Platichthys stellatus*), perch, and juvenile Chinook salmon (*Oncorhynchus tshawytscha*) (LeClair and Cheng 2011). NZMS are not easily digested by these fish and are transport vectors (Bersine et al. 2008; Bruce et al. 2008; Brenneis et al. 2011; LeClair and Cheng 2011; Rakauskas et al. 2016). Brenneis et al. (2011) demonstrate that the signal crayfish feed on the NZMS and successfully digests the NZMS. The damselfly *Argia vivida* (present in Washington) and dragonfly *Aeshna walkeri* (not present in Washington) will consume NZMS more than sporadically or accidentally (Bennett et al. 2015; ISU 2018). Tidewater goby (*Eucyclogobius newberryi*) eat and digest the NZMS (Hellmair et al. 2011), which is native to California. Other potential predators include waterfowl and Peamouth minnow (Beacham and McDonald 1982; ANS 2007).

Many of these species were in Capitol Lake at the time of NZMS establishment and have not stopped their spread throughout the lake. Additional monitoring is necessary to understand fully the distribution of NZMS; there is only one density estimate taken in 2011. Signal crayfish eat a generous amount of NZMS, but they are generalist feeders, so when NZMS population are at low densities, the crayfish will switch to other prey items and the NZMS population will rebound (Twardochleb et al. 2012). The signal crayfish were present in Capitol Lake at the time of the NZMS introduction and they did not control or prevent its establishment (Hayes et al. 2008).

Signal crayfish as a predator of NZMS is not an effective control tool (Twardochleb et al. 2012; Bennett et al. 2014). Predators as a control tool may be effective, but there is low certainty of success and is likely to be specific to the environment implemented. Introduction of additional species, not native to Capitol Lake can cause even larger problems than they solve especially without proper risk/benefit analysis and strict quarantine screening (Messing and Wright 2006).

Review of Milne (2017) Preliminary Report

Dr. Milne (2017) analyzes the density distribution of NZMS from Johannes 2011 survey and discusses that state of NZMS in Capitol Lake. There are three main points that he draws attention to:

1) NZMS were in Capitol Lake prior to their first observation in 2009 and did not spread to outlying areas
2) NZMS are harmless in the environment
3) There is no evidence that NZMS damage freshwater ecosystems.

Due to these arguments, Milne concludes that Capitol Lake should be re-opened to full public use immediately and no control, including drawdowns to freeze the lake, should be conducted. The presented data is informational and contributes to the condition of Capitol Lake, as Johannes did not include density estimates in his report (Johannes 2011).

Milne (2017) argues that NZMS were in Capitol Lake between 2001 or 2005 using two different snail movement rates by back calculating from Johannes survey sites with no NZMS to the site with the highest NZMS densities. With these conclusions and Johannes 2010, 2013, and 2015 reports, which reports that no NZMS were found within a 5-mile radius of Capitol Lake, Milne concludes that NZMS did not spread to outlying areas prior to the lake closure. Johannes indicated that the snails arrived in 2009 when first observed (Johannes 2013, 2015). Both authors made assumptions that need further investigation. The assumptions are the rate of spread, direction of spread, timing of spread, and failure to include a lag period for NZMS to establish in the area before spread (Simberloff and Gibbons 2004; Alanso and Castro-Diez 2008; Kappes and Haase 2012).

I took the liberty of using the same method as Milne (2017) and used the same density numbers, 270 days a year of movement at 1.0 m/day as was the average NZMS movement reported by Kappes and Haase (2012). However, I assumed non-directional spread and I assumed that the north basin boat launch was the introduction site because Cheng and LeClair (2011) mention that there were large densities of NZMS in that location. For the first year only 135 days of spread was modeled to account for lag time or summer introduction. My results indicate that the introduction of NZMS was in 2007 (Figure 2). I am assuming many inputs in these calculations and there is not enough data to know when the NZMS were introduced into Capitol Lake with high certainty.

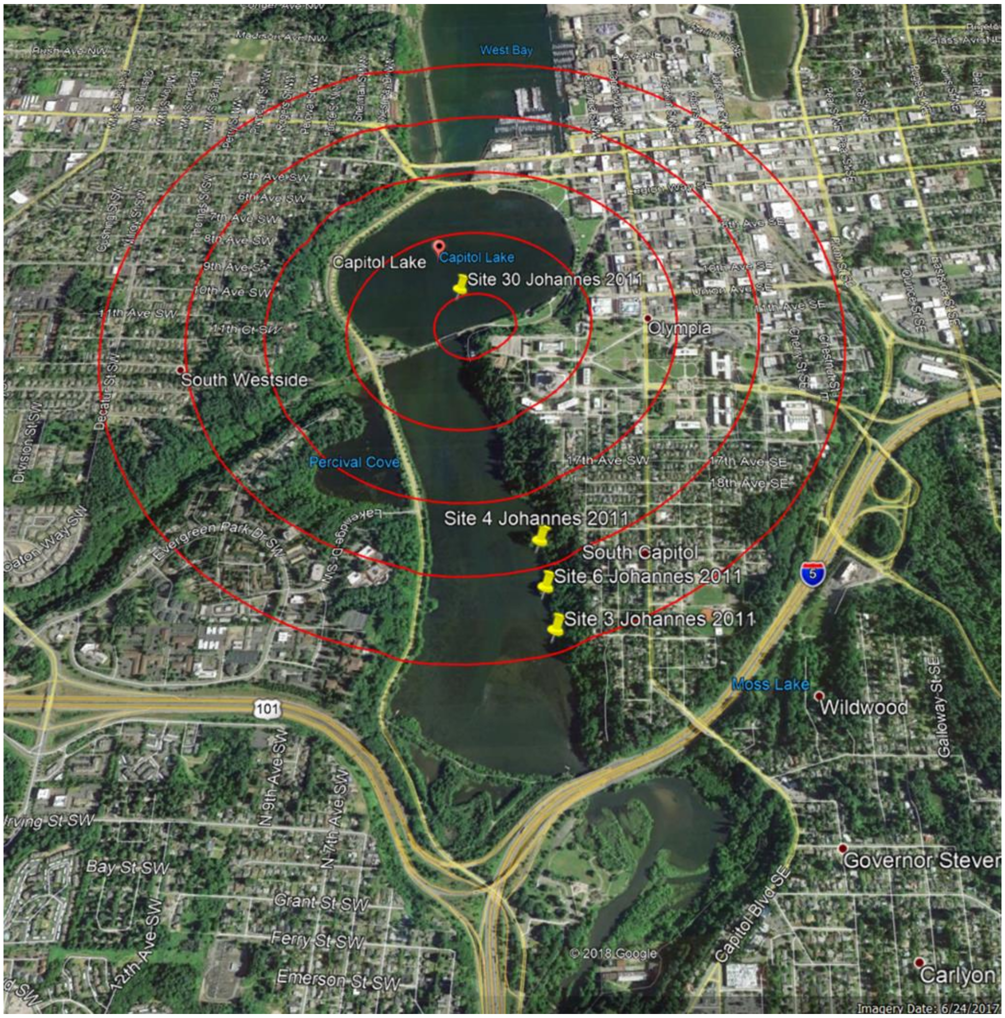

Figure 2. Hypothetical model of NZMS spread in Capitol Lake using data from Johannes 2011 density data (Milne 2017) assuming NZMS moved 1 m/day for 270 days per year, but used non-directional movement (circles instead of arrows) and site of introduction was where large densities of NZMS were reported in 2009 by Cheng and LeClair (2011) and the most active access point, the north basin boat launch.

If NZMS were in Capitol Lake in 2001, then WDFW should consider themselves fortunate that the NZMS population from Capitol Lake did not spread to other outlying areas. However, this argument is meaningless because NZMS are in Capitol Lake and actions must occur to limit their spread to other areas. After identification of NZMS in 2009, WDFW enacted prevention and management protocols as per state and federal guidelines (Meacham 2001; ANS 2007). Both federal and state legislation consider NZMS as a risk to the environment and prohibits the importation, possession and transportation of NZMS (ANS 2007). However, there are prevention management strategies that WDFW can implement rather than closing down the lake to the public, such as utilizing decontamination stations.

Milne (2017) points out that NZMS are harmless to the environment. He gives examples of genetics, predation, and "boom and bust" cycle of densities as arguments for showing that the

NZMS is harmless to the environment. He also argues that since there is not a large economic or ecological impact with NZMS that they are harmless to the environment. Milne may have justifiable evidence, but delisting NZMS off the invasive species list starts at the federal level with the ANS Task Force. Meanwhile, WDFW must manage the risk of NZMS spreading to other areas.

Conclusions

NZMS may have a low environmental impact compared to other aquatic invasive species, but there are rules and regulations supporting the management and prevention of their introduction and spread. It is WDFW and WDES responsibility to the public to use consistent messaging and provide access to state owned areas. As Capitol Lake management options and actions move forward, it is imperative to implement NZMS prevention and control tools. These prevention and control tools will be valuable for preventing the spread of many invasive species. Implementing active management principles, including using monitoring to determine the success of management actions, will be crucial to the success of the project.

All Capitol Lake management options include removing NZMS contaminated dredged material, which must be disposed of properly to limit the spread to other areas. Best options for treating the dredged material include incineration, freezing, desiccation, or ocean application. Verification studies to ensure the method is effective for the Capitol Lake scenario must occur prior to implementation. The Capitol Lake area will still harbor NZMS, even as an estuary or with the dam removed. Control of the NZMS within the lake have included freezing and increasing salinity, but other methods, such as increased pH or use of copper products, could be successful.

Regardless of the management action chosen for Capitol Lake, the area must be open for public use. Implementing prevention tools for NZMS at Capitol Lake, such as gear decontamination stations, and implementing management actions, such as chemical treatment, will reduce the risk of spread to other areas. Monitoring the Capitol Lake area including Budd Inlet will increase understanding of the NZMS population and determine the effect of management actions. Informed management actions will be essential to implementing cost effective solutions.

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Appendix A: Resume Kelly Stockton-Fiti

Kelly Stockton-Fiti, M.S. from KASF Consulting is the owner of KASF Consulting, and has over 10 years of experience conducting extensive research on aquatic invasive species biology and management. Ms. Stockton-Fiti experience includes activities such as identification, prevention, management and evaluation of the effects of chemicals and biological agents on survival of all life stages of invasive aquatic mollusks. She co-hosted conferences and workshops on New Zealand mudsnails and other invasive mollusk species. She has partnered with federal, state, and private scientists to investigate control applications on invasive mollusks. Ms. Stockton-Fiti publishes her work, which focuses on different control methods for aquatic mollusk species.

Kelly Stockton-Fiti

EDUCATION:

2011. Masters of Science, Fisheries Resources (University of Idaho)

2005. Bachelor of Science, Biology; Minor in Microbiology (Colorado State University)

WORK EXPERIENCE:

2015-Present. Owner / Research Scientist. KASF Consulting LLC.

2012-2015. Research Scientist. Marrone Bio Innovations. Davis, CA

2011-2012. Aquatic Ecologist. GEI Consultants, Inc., Denver, CO.

KNOWLEDGE AND SKILLS:

- ❖ Plans, designs, construct and perform experiments for different clients' needs specifically related to their research objectives and timetable. Example projects include:
  - ➢ Determining the toxicity of antifreeze to quagga mussels
  - ➢ Investigation of the Edwards protocol's effectiveness on zebra and quagga mussel veligers
  - ➢ Mortality Responses of Quagga Mussels to KCl Solutions Prepared in Different Source Waters
  - ➢ Use of UV Radiation Technology to Prevent Settlement of Quagga Mussel Larvae
  - ➢ Investigation of the KRIA Industrial Ionizer on the Mortality of the Invasive Quagga Mussel
- ❖ Knowledge and utilization of scientific theory, principles, practices, methods specifically of:
  - ➢ Water quality monitoring and standards analysis through use of meters and testing kits in regards to state and federal laws and regulations and experimental research needs
  - ➢ Fish and mollusk toxicology testing
  - ➢ Aquatic invertebrate and vertebrate monitoring, identification, collection, ecology, management and conservation, aquaculture, and many capture techniques such as electroshocking, gill nets, seines, hook and line, traps, kick-nets, hess and surber samplers
  - ➢ Calibration, maintenance and repair of instruments and equipment

- Safe laboratory practices including handling of hazardous waste and organisms
- Integrated Pest Management and application of pesticides
- Microbiology lab techniques, disinfectants, media preparation, Safety Data Sheets, use and development of Standard Operating Procedures

- Project management, supervisory and leadership abilities demonstrated through job duties, hosting conferences and workshops, training coworkers and work-studies, mentoring of undergraduates, and acting as president, committee chair person, or other positions in many clubs
- Excellent communication skills demonstrated through scientific writing for publication and presentations, customer service activities, and volunteer activities

SELECTED PUBLICATIONS:

Stockton-Fiti, K.A. and C. M. Moffitt. 2017. Determining the toxicity of antifreeze to quagga mussels. Technical Report for US Fish and Wildlife Service.

Stockton-Fiti, K.A. and C. M. Moffitt. 2017. Safety and efficacy of Virkon® Aquatic as a control tool for invasive mollusks in aquaculture. Aquaculture 480: 71-76.

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