Inventory of aquatic invasive species and water quality in lakes in the Lower Truckee River Region: 2011

by

Dr. Sudeep Chandra and Timothy J. Caldwell
Aquatic Ecosystems Analysis Laboratory
Department of Natural Resources and Environmental Science
University of Nevada – Reno
1000 Valley Road MS 186
Reno, NV 89512

TABLE OF CONTENTS

DISCUSSION

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

The introduction of invasive species to aquatic ecosystems can be detrimental to the natural ecology of lakes and be responsible for regional and widespread economic loss. For example, the Laurentian Great Lakes have suffered plant invasions by Eurasian water milfoil (*Myriophyllum spicatum*) and zooplankton such as the Spiny waterflea (*Bythotrephes longimanu)*, both have altered natural ecosystem function, and displaced native species (Mills et al. 1994; Riccardi and MacIsaac 2000). More recently, zebra (*Dreissena polymorpha*) and quagga (*Dreissena bugensis*) mussels have entered the Great Lakes (Riccardi and MacIsaac 2000), and have continued to spread throughout the United States (Ludyanski et al 1993; Stockstad 2007) causing ecosystem wide consequences (Hecky et al. 1994; Ludyanski et al. 1993), and economic loss (Leung et al. 2002; Pimentel et al. 2000).

The introduction and establishment of aquatic invasive species throughout the Truckee River region of California and Nevada is of growing concern to resource managers. Recent research from the region, conducted largely within Lake Tahoe, suggests that invasives cause both ecological and economic impacts (Kamerath et al. 2008; Vander Zanden et al. 2003). For example, the recent introduction of Asian clam (*Corbicula fluminea*) is thought to facilitate increases in algal blooms in the southeastern part of the lake and have a variety of negative effects (Sousa et al., 2008). While, invasive plants such as water milfoil (*Myriophyllum spicatum*) can alter nearshore habitats and facilitate the invasion of other species such as warmwater fishes which have drastic impacts on lake ecology (Kamerath et al. 2008). The invasion of species which is facilitated by previous non-natives has been described as “invasional meltdown” and can cause catastrophic shifts in ecosystems (O.Dowd et al. 2003)

The majority of the lakes in the Truckee River Watershed have resisted invasion by many of the exotic species (Rammer and Chandra 2010). However, as aquatic nuisances continue to spread to the western United States (e.g. dreissenid mussels in Lake Mead; Stockstad 2007) they are a risk to lakes and a concern to resource managers in the Truckee River watershed. Dreissenids have been known to significantly impact water quality, resulting in large scale economic damage by clogging water intake pipes and reducing recreational activity when they establish. Given the ability of dreissenids to spread between systems and the extensive boat traffic (a common vector for aquatic invasions) in the Truckee River watershed, the potential for the establishment of invasive mussels could be significant (Wittmann et al. 2009; Umek et al. 2009).

Researchers have attempted to predict the potential of dreissenid invasion using varying parameters such as ecosystem depth, substrate size and other physiochemical factors (Bossenboeck et al. 2001; Drake and Bossenboeck 2004, Whittier et al. 2008). For example, Jones and Riccardi (2005) used depth, substrate size, and calcium concentration to model the distribution of dreissenids in the St. Lawrence River, and suggest that all 3 variables play a role in zebra mussel colonization, while only depth and sediment size are important for quagga mussel establishment, indicating that zebra mussels are more dependent on water calcium levels. The concentration of calcium in the waters of the Truckee River region is low (Rammer and Chandra 2010) and suggests that mussels may not be as likely to invade these ecosystems. However, with the recent invasion of Asian clams to the ultra-oligotrophic and low calcium waters of Lake Tahoe and Donner Lake (Rammer and Chandra 2010), mussels may be able to survive if transported to the Truckee River watershed (Chandra et al. 2009) since the concentration of calcium in the sediment pore-water (i.e. water in interstitial space) can be higher than that in the water column (Rammer and Chandra 2010) and could facilitate dressenid invasion, this mechanism deserves further examination. Currently, boat inspection stations have been put in place along the Truckee River to minimize the risk of transporting species. However, it is important to have information on the current locations of invasive species throughout the watershed, and continue to document recent invasions.

The objective of this project is to identify water bodies within the Truckee River region (Donner Lake, Stampede Lake, Boca Reservoir, Prosser Reservoir, Marlette Lake, Martis Creek Lake, Rye Patch Reservoir, Spooner Lake, Lahotan Reservoir) that have already established invasive invertebrate and plant communities, and to identify and document recent invasions. Additionally, we plan to test the hypothesis that bivalve invasion is dependent not only on calcium concentration in the water column but on the concentration of calcium in sediment pore-water. This is year two of the project and builds upon data collected in 2010 (Rammer and Chandra 2010). Specifically, our goals were to

1. Use the method developed by Rammer and Chandra (2010) to continue shoreline surveys for invasive invertebrates (Dreissenid mussels, New Zealand mudsnail, Asian clam, and crayfish) and invasive plant (Hydrilla and Eurasian water milfoil) species.
2. Sample lakes for the DNA of dreissenid mussel veligers to document invasions using zooplankton net hauls.
3. Quantify the concentration of calcium in the water column of each lakes.
4. Collect sediment pore-water from Donner Lake's “clam patch” and from other locations around the lake to determine if the concentration in the sediment pore-water can influence bivalve introduction.

METHODS

Study Sites

During the fall of 2011 seven lakes that represent the major recreational water bodies in the Truckee River Watershed region were chosen for invasive species assessment (Table 1). These include six lakes in California (Independence Lake, Boca Reservoir, Stampede Reservoir, Prosser Reservoir, Martis Creek Lake, Donner Lake), and one lake in Nevada (Marlette Lake). Additionally, Spooner Lake, Rye Patch Reservoir, Lahotan Reservoir, were analyzed for calcium analysis but not were surveyed for invasive species. These lakes were chosen because of the high frequency of recreational use.

Adult invasive invertebrate and plant surveys

A protocol was developed to survey lake shoreline area for adult invasive species and invasive plants. Shoreline area sight surveys were conducted via boat or on foot, depending on feasibility, along the entire lake shoreline. When boating was required, a 14 ft rowboat was driven at a slow and constant speed around the shore. Fifteen transects were chosen in each lake for a detailed evaluation. Transect locations were chosen based on areas where invasive mussel and clam species were likely to be found (i.e., boat launches, public docks, and other hard substrates). Because lake habitat is heterogeneous, our secondary consideration was to choose transects that would be representative of habitat variability in each system. GPS coordinates were recorded for each transect when possible and the location described.

At each transect, a 5 m^2 section was closely examined for the presence of invasive species and evaluated for substrate composition. Within each section, rocks were uprooted and examined for mollusk species and sand was dug up by hand and examined for New Zealand mud snails. Unknown plants and invertebrates were collected and taken back to the laboratory for identification. At each transect, the location, substrate composition, and percent of area where invasive species were present (when applicable) was recorded. Wentworth's substrate guide (1922) was modified and used to define general substrate types present at each transect such that rock substrate includes gravel (6.4 mm) to boulder (≥ 610.0 mm), woody structure includes material with a diameter of < 20.5 mm to ≥ 50.9 mm, and fine substrates include anything smaller than gravel (sand, silt, and organic matter). Because some of the lakes were completely frozen (Marlette Lake, and Martis Creek Lake) or partially frozen (Boca Reservoir, Prosser Reservoir, Independence Lake) surveys were done on the open water shorelines, and unable to be completed on those lakes completely frozen.

Quagga and zebra mussel veliger detection

Plankton tows were used to detect the presence of zebra and quagga mussel veligers in December of 2011 following a standard protocol developed by California Fish and Game (CFG 2008). In general samples, were sent to the California Fish and Game (CFG) laboratory for analysis within the time allotted in the CFG protocol. A 64 micron, 30 cm diameter plankton tow net was used to sample for dreissenid veligers at various locations within each lake. At lakes frozen over, an ice auger was used to drill a 50 cm hole, and then sampled beneath the ice. Combinations of vertical and horizontal tows were used depending on water depth and sampling location. Each sample was composed of 2-3 tows from the same location and stored in a 25% by volume 95% reagent grade (non-denatured) ethanol (ETOH) solution. To prevent possible contamination between lakes, all sampling equipment was soaked in vinegar, rinsed, and dried between samplings (California Fish and Game, 2008).

Concentrations of calcium

To determine the concentration of calcium in the water of each lake, 1 L water samples were taken from the surface, placed on ice and transported back to the Aquatic Ecosystems

Analysis Laboratory at the University of Nevada, Reno. Three 125 mL replicates were taken out of each 1 L sample, and filtered through a 0.45 µm magna-nylon filter. Samples were frozen and shipped overnight to the University of California–Davis plasma mass spectrometry center for analysis.

To determine the concentration of calcium in sediment pore-water, we collected samples from the "clam patch" described by the California Fish and Game and at various points around Donner Lake. Donner Lake was chosen because it has recently become invaded by Asian clams and previous data suggests variability in calcium concentration in the sediment pore-water (Rammer and Chandra 2010). To collect sediment pore-water a sediment sample was taken using a petit-ponar grab, and water was removed from the interstitial space using a modified-syringe apparatus (Rammer and Chandra 2010). Samples were placed on ice and transported back to the University of Nevada. Each sample was filtered through a 0.7µm Glass Fiber Filter (GFF), then through a 0.45 µm magna-nylon filter. Samples were frozen and shipped overnight to the University of California–Davis plasma mass spectrometry center for analysis.

RESULTS

Adult invasive invertebrate and plant surveys

Invasive species were detected in 2 of the 5 lakes which were surveyed (Table 2). In previous years non-native signal crayfish (*Pacifastacus leniusculus*) were detected in all but Spooner Lake and Martis Creek Lake (Rammer and Chandra 2010), however we did not sample for crayfish in 2011. Eurasian water milfoil was noticed through the ice at high densities in Martis Creek Lake (Table 2). Asian clams were detected in several parts of Donner Lake and may have spread since 2010 (Rammer and Chandra 2010). Dense patches of clams were detected along the state park beach, and near the outlet at the east end of the lake. Zebra mussels

(*Dreissena polymorpha*), quagga mussels (*Dreissena rostriformis*), New Zealand mudsnail snails (*Potamopyrgus antipodarum*) and hydrilla (*Hydrilla verticillata*) were not detected in any of the study lakes (Table 3). Shoreline invasive species survey data can be found in Appendix A. The relative lake substrate composition for each lake, derived from the examined transects is presented (Figure 2).

Quagga and zebra mussel veliger detection

Veliger DNA was not detected in any of the lakes sampled (Donner, Stampede, Boca, Prosser, Marlette, Martis Creek L., Independence) during 2011 (Table 3). This is consistent with a similar sampling done by Rammer and Chandra (2010).

Calcium levels and dreissenid mussel invasion potential

Epilmentic calcium concentrations were low (< 15ppm) in the majority of lakes. The concentration of calcium in Spooner lake was relatively high (25.16 ± 0.26 ppm) compared to the other lakes (Table 4, Figure 3). At sites where calcium concentrations were collected in the summer and fall (Boca Reservoir, Prosser Reservoir, Stampede Reservoir, Independence Lake, Marlette Lake, Martis Creek Lake, Donner Lake) concentrations were consistent over time, thus means were calculated from all sampling dates (Table 4, Figure 3). Rammer and Chandra (2010) documented a general decrease over time in the concentration of calcium, our data did not show this pattern and may be caused by the high water year in 2011. However, the concentration of calcium in the epilimentic waters of these lakes was similar between 2010 and 2011 (Rammer and Chandra 2010).

The concentration of calcium in sediment pore-water in Donner Lake ranged from 3.86 – 7.98 ppm (Table 5). The clam patch, identified by CFG, had a concentration of 6.37 ± 0.42 ppm (Table 5). The concentrations from the clam patch were similar to those taken from other parts of the lake (T-test, $p < 0.05$), thus we averaged the whole lake together to compare our 2011 data to that of Rammer and Chandra (2010). The lake wide average from 2011 (6.19 ± 0.76 ppm) was significantly lower (T-test, $p < 0.05$) than the concentration (13.92 ± 5.71 ppm) presented by Rammer and Chandra (2010), however this difference is likely driven by the one outlier (25.36 ppm) which forced the high error associated with the 2010 sampling.

DISCUSSION

Status of invasive species

The results of the invasive species shoreline surveys suggest show that no new invasive species have arrived since 2010. Additionally, veliger DNA has yet to be detected in any of the lakes indicating that dreissenid mussles have yet to be introduced. This project provides baseline data on the status of invasive species in the lakes of the Truckee River Watershed, and is important to continue this monitoring to document any new invasions. Knowledge of the time of invasions can give researchers and managers the opportunity to document changes in lake processes caused by the invasion of exotic species.

Calcium levels and dreissenid mussel invasion potential

Invasive dreissenids, zebra (*Dreissena polymorpha*) and quagga (*Dreissena rostriformis bugensis*) mussels, in particular have altered the ecology of lakes and rivers by coupling pelagic and benthic trophic pathways, increasing offshore clarity, stimulating benthic production and altering biodiversity (Makarewicz et al. 1999, Bially and MacIssac 2000, Ricciardi et al. 1998). In recent years there has been a western range expansion in North America of mussels and it first appeared in western U.S. in Lake Mead, AZ-NV in early 2007 (Stokstad et al. 2007) and has subsequently been found in other major western impoundments including Lakes Powell and

Mohave. The costs of the invasion are already apparent, as the Southern Nevada Water Authority has spent approximately $32 million (US dollars until 2009) to manage quagga biomass impacts on the water intake infrastructure of Lake Mead, a recently invaded reservoir in the Western U.S. (Peggy Roefer, Southern Nevada Water Authority, pers. communication). These recent invasions have spurred efforts to determine invasion risk posed by zebra and quagga mussels in western waters.

There are a large number of dreissenid mussel establishment risk assessment approaches that have been based on European and Eastern North American invasions that may or may not be appropriate for evaluations of western water ways. Risk assessment for the western U.S. should be based on these approaches, but with careful consideration of western water body characteristics such as differences in water temperature, calcium and other nutrient concentrations as well as food availability and substrate size that may determine different parameters for western waterways. Water column calcium concentration is often used as an index for determining the potential for mollusk establishment, growth, and reproduction with variable requirements depending on the species (Ramcharan et al. 1992, Sousa et al. 2008, Whittier et al. 2008). Food availability is also an important variable for mollusk establishment, and is often the cause for massive dreissenid mussel population crashes after initial population explosions (Strayer et al. 1996). Since the recent establishments in Lakes Mead, Powell and Mohave, numerous studies are underway to determine zebra and quagga mussel invasion risk to Western waterways. Based on empirical information gathered from water quality databases and modeled systems, Whittier et al. (2008) created a watershed-scale risk model for dreissenid species. This model is based on calcium requirements, primarily derived from zebra mussel due to limited experimental data on quagga mussel survival. Managers have used this model to determine the risk-potential of quagga mussel establishment from invaded water bodies such as Lake Mead. However, because quagga mussels appear to have different environmental tolerances than zebra mussels, (Jones and Riccardi 2005, Baldwin et al. 2002, Stoeckmann 2003, Roe and MacIssac 1997, Zhulidov 2004), and possibly in other parts of their range (Domm et al. 1993, Antonov and Shkorbatov 1990), the potential risk of invasion to western water bodies may be underestimated by using zebra mussel-based risk assessments.

We measured calcium levels and used existing literature to determine the invasion risk of each ecosystem based on these levels using Whittier's (2008) model to suggest the risk of invasion and comparing to an adult survival study using Lake Tahoe water by Chandra et al. (2009). Whittier et al. (2008) used literature-based calcium thresholds in create a broad scale, landscape-level approach to determine survival probability for dreissenid mussels in Western watersheds. Thresholds were established based on calcium limitations of zebra mussel, since little calcium-based survival information existed for quagga mussel. Thus, these authors assumed that zebra and quagga mussel requirements were similar because of the genetic proximity of these two closely related taxa. Their findings are still useful however for a 1st order estimate of the invasion potential by dreissenids. They defined risk based on calcium concentrations as: very low (< 12 mg L^{-1}), low (12–20 mg L^{-1}), moderate (20–28 mg L^{-1}), and high (> 28 mg L^{-1}). According to their risk categories, the water bodies with "very low" risk include Stampede, Boca, Prosser, Independence, Marlette, Donner and Martis. Although in 2010 Stampede was marginal in concentration and could be placed in the low category (Rammer and Chandra 2010), this was not the case in 2011. Systems with "low" risk were Rye Patch and Lahotan reservoirs, while Spooner Lake was classified in "moderate to high" risk.

In contrast to the Whittier and colleagues risk assessment however, we also utilized another study assessing adult survivability based on Lake Tahoe waters which contain approximately 13 ppm calcium. Chandra et al. (2009) suggests that after a 51 day exposure, quagga adults survive, exhibit positive growth, and may have the potential to release gametes. This study did not have the funding to follow the reproductive cycle of the mussels to determine if they could produce mature veligers. They suggest that the occurrence of veligers in the low calcium waters of Colorado Lake which are similar to the Truckee River Region suggest the potential for some viable production. Using this study as a benchmark and analyzing risk from another viewpoint, only Spooner Lake is at risk.

Rammer and Chandra (2010) analyzed the concentration of calcium in sediment pore-water and found variability within each lake. In this study, we chose to examine the variability of concentration in sediment pore-water in Donner Lake because of the presence of Asian clams in the lake. Our results suggest homogeneity of calcium in the sediment pore-water in Donner Lake and no clear pattern was observed between location of clams and density of calcium. In contrast to Rammer and Chandra (2010), the calcium concentration in the water column and in the sediment was similar in Donner Lake (T-test, $p<.05$), however this could be an artifact of a high water year in 2011 and should be interpreted with caution.

According to Whittier's (2008) risk assessment based on the concentration of calcium in the water column, the majority of systems surveyed in Truckee River Watershed were at relatively low risk for the invasion of dreissenids during 2011. Because this assessment was developed using a biased amount of data for the zebra mussel, it is likely that quagga mussels have different requirements (Jones and Riccardi 2005, Chandra et al. 2009). It is unclear, if adult quagga mussels can reproduce in calcium limited systems, making it difficult to accurately assess their potential to establish in the Truckee River Watershed Lakes. To develop more accurate assumptions research should be devoted to dreissenid reproduction in low calcium waters, and include parameters other than calcium (pH, substrate size, nutrient limitation, food quality, etc.), to lead to better preventative measures, and a decreased chance of dreissenid establishment.

Table 1. Basic morphological characteristics of the 2011 Truckee River region study lakes.

Lakes	**Max Depth (m)**	**Surface Area (ha)**	**Shoreline (km)**
Donner	70.0	390.0	12.07
Stampede	52.0	1351.7	40.2
Boca	24.0	396.6	24.14
Prosser	24.0	303.5	17.7
Martis Creek L.	6.0	23.4	Na
Independence	44.0	252.9	9.3
Spooner	4.0	31.6	Na
Marlette	11.0	na	Na

Table 2. Invasive plants and adult invertebrates present in Truckee River region lakes in 2011 as determined from UNR shoreline surveys and CFG visual surveys. Species presence is denoted by "X." A blank space indicates no species were found during the surveys.

	Adult Invertebrates				**Plants**	
Lakes	**Quagga**	**Zebra**	**NZMS**	**Asian Clam**	**EWM**	**Hydrilla**
Marlette[2]						
Donner				X		
Stampede						
Boca[1]						
Prosser[1]						
Martis Creek L.					X*	
Independence						

*Martis Creek L. was no officially surveyed for invasives in 2011 because of ice cover, however EWM presence was noted through the ice.

[1] A large portion of these lakes were ice covered, invasive surveys were conducted at all unfrozen shorelines.

[2] Marlette lake was frozen over and not surveyed

Table 3. Veliger results for invasive mussels collected and analyzed for quagga and zebra mussel DNA by California Fish and Game Bodega Marine Laboratory for each study lake in 2011.

Lake	Veliger Tow Date(s)	Result Pos/Neg
Donner	12-14-11	Negative
Stampede	12-14-11	Negative
Boca	12-14-11	Negative
Prosser	12-14-11	Negative
Marlette	12-13-11	Negative
Martis Creek L.	12-14-11	Negative
Independence	12-14-11	Negative

Table 4. Mean epilimentic calcium concentrations (ppm ± SE) for Truckee River Watershed Lakes in 2011. Samples were taken from summer 2011 to winter 2011 see Appendix A for details.

Lake	n	Mean Calcium Concentration
Boca	6	7.22 ± 0.29
Stampede	6	6.80 ± 0.29
Prosser	6	5.91 ± 0.64
Independence	4	5.37 ± 0.65
Marlette	4	4.47 ± 0.22
Martis	6	9.57 ± 0.83
Donner	6	6.11 ± 0.87
Rye Patch	2	12.12 ± 3.30
Spooner	3	25.16 ± 0.26
Lahotan	1	12.25

Table 5. Sediment pore-water calcium concentrations from Donner Lake in 2011 see Appendix B for GPS positions and concentrations from each clam patch sample.

Location	Depth	Clams	% Fine Substrate	Calcium Concentration
Clam Patch*	0.8[1]	Y	100	6.37 ± 0.42
Lake Outlet	1.6	N	100	4.3735
NE Resident Docks	3.7	Y	100	4.8645
Rocky Beach	3.1	N	30	3.863
SW Resident Docks	3.1	Y	70	7.98
Boat Launch	2.4	N	70	7.585
West Beach	5.8	N	100	4.3975

* Mean and standard error from the CFG identified clam patch (n=24).

[1] Mean depth from samples (n=24).

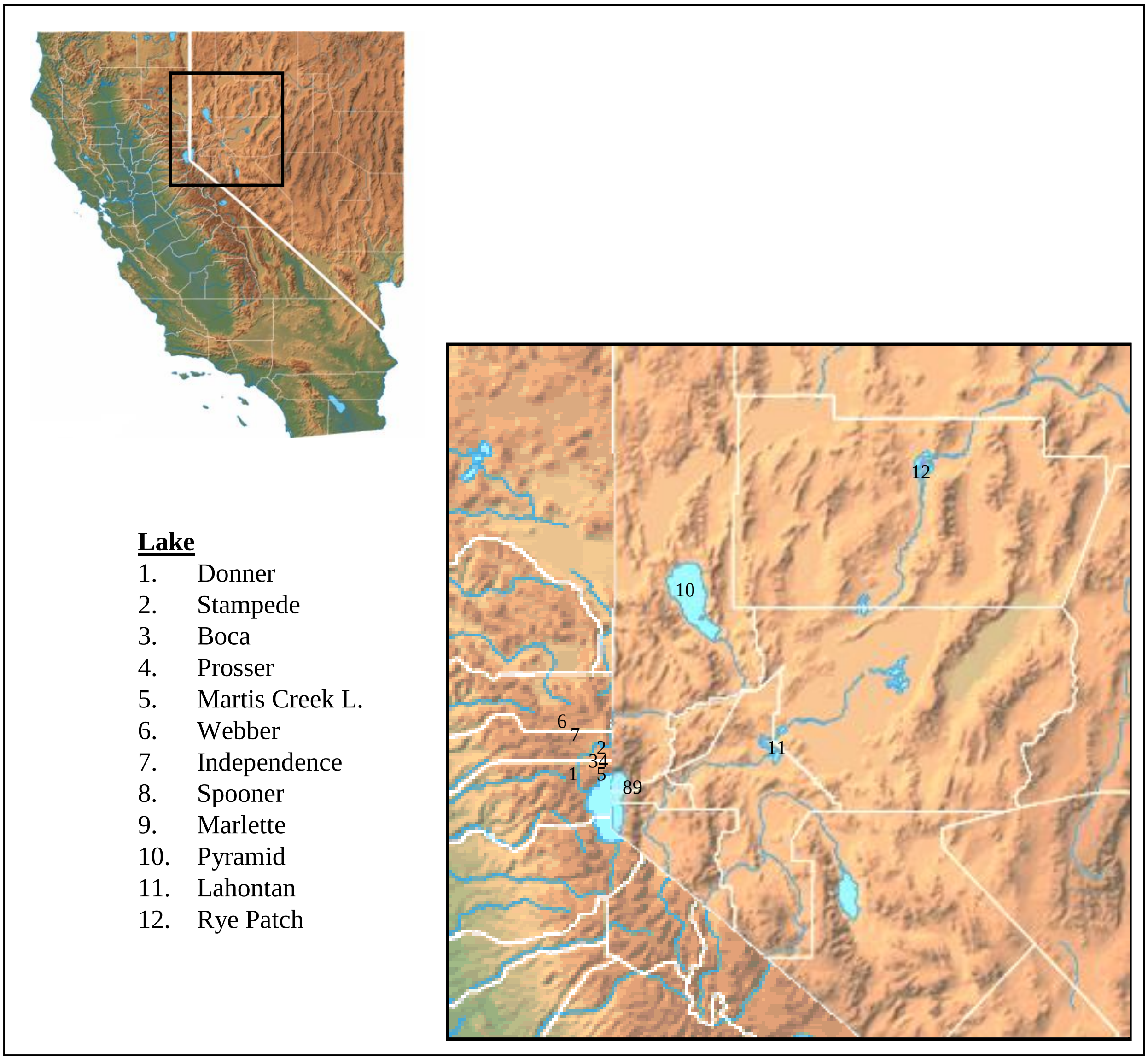

Figure 1. Truckee River Watershed and location of study lakes within the watershed.

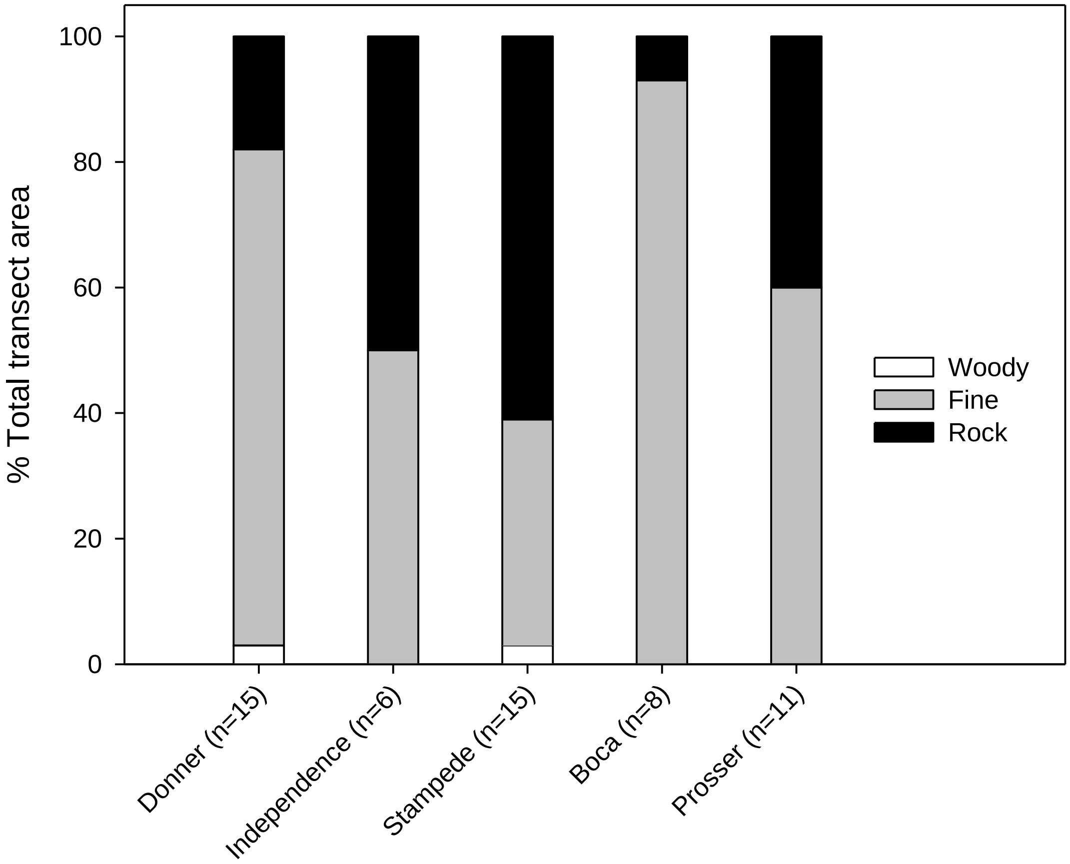

Figure 2. Lake substrate composition from all transects examined during the invasive surveys using modified categories from Wentworth's substrate guide (1922) where rock substrate includes gravel (6.4mm) to boulder (≥ 610.0mm), woody structure includes material with a diameter of < 20.5mm - ≥ 50.9mm, and fine substrates include anything smaller than gravel (sand, silt, and organic matter).

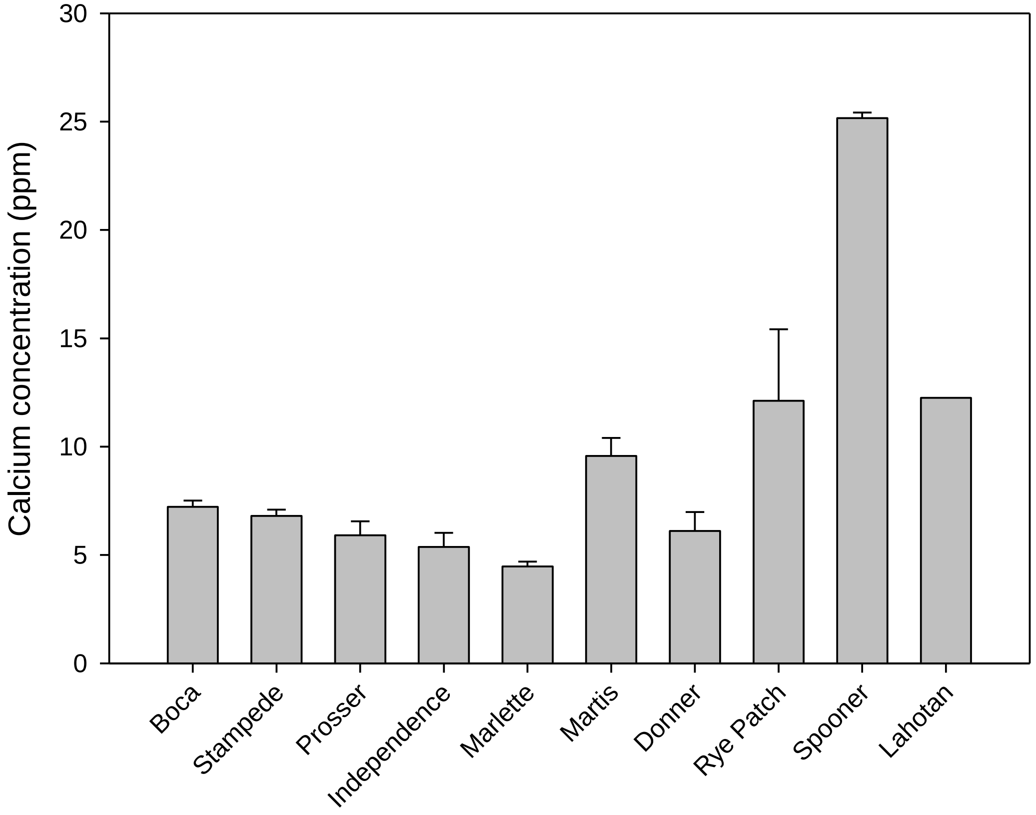

Figure 3. Mean concentration of calcium in the epilimentic waters of the Truckee River Watershed lakes.

Appendix A. Invasive species shoreline survey data during the 2011 field season. Lakes without 15 transects were partially ice covered, all open shoreline was surveyed.

a. Donner Lake

		GPS		% Sub			Invasives				
Date	T	N	W	W	F	R	EWM	Hydrilla	Zebra	Quagga	Clams
12/9/2011	1	39 19.587	120 15.918	10	40	50	0	0	0	0	0
	2	39 19.479	120 17.010	0	80	20	0	0	0	0	0
	3	39 19.1577	120 17.2539	0	100	0	0	0	0	0	0
	4	39 19.0894	120 15.1660	0	100	0	0	0	0	0	1
	5	39 19.2173	120 15.1660	5	90	5	0	0	0	0	1
	6	39 19.4325	120 14.5866	0	100	0	0	0	0	0	1
	7	39 19 4395	120 14.4288	0	100	0	0	0	0	0	1
	8	39 19.5240	120 14.3977	30	70	0	0	0	0	0	1
	9	39 19.6410	120 14.8572	0	98	2	0	0	0	0	1
	10	39 19.7061	120 15.3925	5	95	0	0	0	0	0	1
	11	39 19.1644	120 15.5588	0	60	40	0	0	0	0	0
	12	39 19.0923	120 16.2859	0	60	40	0	0	0	0	1
	13	39 19.0562	120 16.7091	0	10	90	0	0	0	0	0
	14	39 19.4801	120 16.3608	0	90	10	0	0	0	0	0
	15	39 19.4440	120 16.7233	0	90	10	0	0	0	0	0

b. Independence Lake

		GPS		% Sub			Invasives				
Date	T	N	W	W	F	R	EWM	Hydrilla	Zebra	Quagga	Clams
12/14/2011	1	39 26.9751	120 17.3782	0	0	100	0	0	0	0	0
	2	39 27 4.56	120 17 32.31	0	50	50	0	0	0	0	0
	3	39 26 8460	120 17.4448	0	60	40	0	0	0	0	0
	4	39 26.8088	120 17.5069	0	70	30	0	0	0	0	0
	5	39 26.7427	120 17.6037	0	70	30	0	0	0	0	0
	6	39 26.6653	120 17.7087	0	50	50	0	0	0	0	0

c. Stampede Reservoir

		GPS		% Sub			Invasives				
Date	T	N	W	W	F	R	EWM	Hydrilla	Zebra	Quagga	Clams
1/10/2012	1	39 29.8432	120 5.5745	0	50	50	0	0	0	0	0
	2	39 29 .7197	120 5.8008	20	50	30	0	0	0	0	0
	3	39 29.6072	120 5.9484	20	40	40	0	0	0	0	0
	4	39 29.3598	120 6.0100	0	80	20	0	0	0	0	0
	5	39 29.3302	120 6.2779	0	50	50	0	0	0	0	0
	6	39 29.0369	120 6.5455	0	10	90	0	0	0	0	0
	7	39 29.3352	120 6.6245	0	0	100	0	0	0	0	0
	8	39 29.5371	120 7.1053	0	30	70	0	0	0	0	0
	9	39 30.0592	120 7.9351	0	100	0	0	0	0	0	0
	10	39 28.6801	120 9.3135	0	50	50	0	0	0	0	0
	11	39 28.5461	120 9.9979	0	0	100	0	0	0	0	0
	12	39 28.3890	120 6.3729	0	0	100	0	0	0	0	0
	13	39 28.1531	120 7.8794	0	30	70	0	0	0	0	0
	14	39 28.2548	120 8.0308	10	0	90	0	0	0	0	0
	15	39 27.9574	120 8.0983	0	50	50	0	0	0	0	0

d. Boca Reservoir

		GPS		% Sub			Invasives				
Date	T	N	W	W	F	R	EWM	Hydrilla	Zebra	Quagga	Clams
1/10/2012	1	39 24.186	120 6.1333	0	100	0	0	0	0	0	0
	2	39 24.1825	120 6.0985	0	80	20	0	0	0	0	0
	3	39 24.1141	120 6.1385	0	100	0	0	0	0	0	0
	4	39 24.0509	120 6.1522	0	100	0	0	0	0	0	0
	5	39 24.0037	120 6.1646	0	100	0	0	0	0	0	0
	6	39 23.9429	120 6.2310	0	80	20	0	0	0	0	0
	7	39 23.9388	120 6.1502	0	90	10	0	0	0	0	0

e. Prosser Reservoir

		GPS		% Sub			Invasives				
Date	T	N	W	W	F	R	EWM	Hydrilla	Zebra	Quagga	Clams
1/10/2010	1	39 23.1017	120 8.6878	0	90	10	0	0	0	0	0
	2	39 23.0329	120 8.5801	0	0	100	0	0	0	0	0
	3	39 22.9986	120 8.5023	0	30	70	0	0	0	0	0
	4	39 23.1300	120 9.4862	0	0	90	0	0	0	0	0
	5	39 23.0730	120 9.4572	0	50	50	0	0	0	0	0
	6	39 23.0198	120 9.4586	0	70	30	0	0	0	0	0
	7	39 23.0415	120 8.7081	0	100	0	0	0	0	0	0
	8	39 22.9882	120 8.6535	0	100	0	0	0	0	0	0
	9	39 22.6504	120 8.6755	0	90	10	0	0	0	0	0
	10	39 22.6454	120 8.7404	0	50	50	0	0	0	0	0
	11	39 22.6776	120 8.8292	0	80	20	0	0	0	0	0

Appendix B. The concentration of calcium in the sediment pore-water in Donner Lake. Sites 1-24 were taken from the clam patch discovered by CFG, remaining samples are from various locations around the lake.

	GPS			
Site	N	W	Depth (m)	Calcium Concentration
1	39 19.430	120 14.513	1.10	5.43
2	39 19.425	120 14.519	0.98	5.18
3	39 19.419	120 14.523	0.76	6.22
4	39 19.414	120 14.523	0.52	10.64
5	39 19.410	120 14.521	0.27	5.09
6	39 19.427	120 14.530	1.25	4.54
7	39 19.423	120 14.535	1.07	5.35
8	39 19.418	120 14.539	0.55	6.30
9	39 19.414	120 14.540	0.40	4.86
10	39 19.410	120 14.536	0.34	4.66
11	39 19.433	120 14.550	1.55	4.37
12	39 19.425	120 14.545	1.04	5.90
13	39 19.418	120 14.555	0.64	6.35
14	39 19.414	120 14.553	0.37	4.51
15	39 19.410	120 14.551	0.30	4.13
16	39 19.432	120 14.561	1.52	7.28
17	39 19.427	120 14.562	1.25	9.98
18	39 19.421	120 14.560	0.64	8.71
19	39 19.417	120 14.564	0.61	6.28
20	39 19.412	120 14.566	0.30	6.61
21	39 19.430	120 14.584	1.55	4.98
22	39 19.421	120 14.587	0.61	7.91
23	39 19.429	120 14.598	1.34	11.61
24	39 19.421	120 14.596	0.94	5.96
25	39 19.445	120 14.462	1.65	4.37
26	39 19.672	120 14.991	3.75	4.86
27	39 19.380	120 15.114	3.08	3.86
28	39 19.091	120 16.040	3.20	7.98
29	39 19.314	120 17.344	2.44	7.59
30	39 19.474	120 16.945	5.82	4.40

ACKNOWLEDGMENTS

We would like to thank all cooperating agencies and personnel for contributing to the successful completion of this project: Jim Gaither, David Mandrella, and Gina Rammer at the The Nature Conservancy provided access and field support at the Independence Lake preserve. The California Fish and Game for analysis of veliger DNA. Sami Evanson was a wonderful technician and was of great help as was the entire staff at the University of Nevada's Aquatic Ecosystem and Analysis Laboratory. Special thanks to Kim Boyd and Dave Roberts at the Tahoe Resource Conservation District (TRCD) for submitting an application for funding and guiding the overall project. This project was funded by the Truckee River Fund to TRCD to S. Chandra at the University of Nevada- Reno.

REFERENCES

Antonov, P.I. and G.L. Shkorbatov. 1990. The ecological-physiological characteristics of *Dreissena* of lower reaches of the Dnepr River. – *In*: The Species in Its Range: Biology, Ecology and Productivity of Aquatic Invertebrates. Minks, Navuka I tehnika, publ., pp 135-141.

Baldwin, B. S., M.S. Mayer, J. Dayton, N. Pau, J. Mendilla, M. Sullivan, A. Moore, A. Ma and E.L. Mills, 2002: Comparative growth and feeding in zebra and quagga mussels (*Dreissena polymorpha* and *Dreissena bugensis*): implications for North American lakes. Canadian Journal of Fisheries and Aquatic Sciences. 59: 1159-1174.

Bially, A., H.J. MacIsaac. 2000. Fouling mussels (Dreissena spp.) colonize soft sediments in Lake Erie and facilitate benthic invertebrates. Freshwater Biology 43: 85-97.

Bossenbroek, J., Kraft, C.E., Nekola, J.C., 2001. Prediction of long-distance dispersal using gravity models: zebra mussel invasion on inland lakes. Ecological Applications 11(6): 1778-1788.

California Fish and Game and California Department of Water Resources. Zebra and quagga mussel veliger sampling protocol, vertical tow. Unpublished: 2008. https://nrmsecure.dfg.ca.gov/FileHandler.ashx?DocumentID=4954

Chandra, S, M Wittmann, A Caires, A Kolosovich, JE Reuter, G Schladow, and T Thayer. 2009. An experiment test of quagga mussel survival and reproductive status using Lake Tahoe water. Tahoe Regional Planning Agency and the Lake Tahoe Aquatic Invasive Species Working Group

Domm, S.R. W. McCauley and E. Kott. 1993. Physiological and taxonomic separation of two Dreissenid mussels in the Laurentian Great Lakes. Canadian Journal of Fisheries and Aquatic Sciences. 50: 2294-2297.

Drake, J.M., Bossenbroek, J., 2004. The potential distribution of zebra mussels in the United States. BioScience. 54(10): 931-941.

Jones, L.A., Riccardi, A., 2005. Influence of physiochemical factors on the distribution and biomass of invasive mussles (Dreissena polymorpha and Dreissena bugensis) in the St. Lawrence River. Candian Journal of Fisheries and Aquatic Sciences. 62(9): 1953-1962.

Kamerath, M., Chandra, S., Allen, B.C., 2008 Distribution and impacts of warm water invasive fish in Lake Tahoe, USA. Aquatic Invasions. 3(1): 35-41.

Ludyansky, M.L., McDonald, D., MacNeill, D., 1993. Impact of the zebra mussel, a bivalve invader. BioScience. 43 (8): 533-544.

Leung, B., Lodge, D.M., Finnoff, D., Shogren, J.F., Lewis, M.A., Lamberti, G., 2002. An ounce of prevention or a pound of cure: bioeconomic risk analysis of invasive species. Poceedings of the Royal Society of London. Series B: Biological Sciences. 269 (1508): 2407-2413.

Makarewicz, J.C.; T.W. Lewis, and P. Bertram. 1999. Phytoplankton composition and biomass in the offshore waters of Lake Erie: Pre- and post-Dreissena introduction (1983-1993). Journal of Great Lakes Research 25: 135-148.

Mills, E. L., Leach, J.H., Carlton, J.T., Secor, C.L., 1994. Exotic species and the integrity of the Great Lakes. BioScience. 44 (10): 666-676.

O’Dowd, D.J.,Green, P.T., Lake, P.S., 2003. Invasional ‘meltdown’ on an oceanic island.

Ecology Letters. 6: 812-817.

Pimetel, D., Lach, L., Zuniga, R., Morrison, D., 2000. Environmental and economic costs of nonindigenous species in the United States. BioScience. 50(1): 54-65.

Ramcharan C.W., Padilla D.K., Dodson, S.I. 1992. Models to predict potential occurrence and density of the zebra mussel Dreissena-polymorpha. Canadian Journal of Fisheries and Aquatic Sciences. 49: 2611-2620.

Rammer, G., Chandra, S., 2010. Inventory of aquatic invasive species and water quality in lakes in the Lower Truckee River Region: 2010.

Riccardi, A., MacIsaac, H.J., 2000. Recent mass invasion of the North American Great Lakes by Ponto-Caspian species. Trends in Ecology and Evolution. 15 (2): 62-65.

Ricciardi, A; Neves, RJ; Rasmussen, JB. 1998. Impending extinctions of North American freshwater mussels (Unionoida) following the zebra mussel (Dreissena polymorpha) invasion. Journal of Animal Ecology 67: 613-61).

Roe, S.L. and H.J. MacIsaac. 1997. Deepwater population structure and reproductive state of quagga mussels (*Dreissena bugensis*) in Lake Erie. Canadian Journal of Fisheries and Aquatic Sciences. 54: 2428–2433.

Sousa, R., Antunes, C., and L. Guilhermino. 2008. Ecology of the invasive Asian clam *Corbicula fluminea* (Muller, 1774) in aquatic ecosystems: an overview. Annales de Limnologie-International Journal of Limnology 44: 85-94.

Stoeckmann, A. 2003. Physiological energetics of Lake Erie Dreissenid mussels: a basis for the displacement of *Dreissena polymorpha* by *Dreissena bugensis*. Canadian Journal of Fisheries and Aquatic Sciences. 60: 126-134.

Stokstad, E. 2007. Feared Quagga mussel turns up in Western United States. Science 315:453.

Strayer, D.L., Powell, J., Ambrose, P. Smith, L.C. Pace, M.L. Fischer, D.T. 1996. Arrival, spread, and early dynamics of a zebra mussel (Dreissena polymorpha) population in the Hudson River estuary. Canadian Journal of Fisheries and Aquatic Sciences. 1144-1153.

Umek, J., Chandra, S., and Brownstein, J. 2009. Limnology and food web structure of a large terminal ecosystem, Walker Lake (NV, USA). Natural Resources and Environmental Issues: Vol 15:15.

Vander Zanden, M.J., Chandra, S., Allen, B.C., Reuter, J.E., Goldman, C.R., 2003. Historical food web structure and restoration of native aquatic communities in the Lake Tahoe (California-Nevada) Basin. Ecosystems. 6(3): 274-288.

Whittier, T.R., Ringold, P.L., Herlihy, A.T., and Pierson, S.M. 2008. A calcium-based invasion risk assessment for zebra and quagga mussels (*Dreissena* spp). Front Ecol Environ 6(4): 180-184

Whittmann, M., J. Reuter, G. Schladow, S. Hackley, B Allen, S Chandra, A. Caires.Unpublished: January 2008. Asian Clam (*Corbicula fluminea)* of Lake Tahoe: Preliminary scientific findings in support of a management plan.

Zhulidov, A.V., D.F. Pavlov, T.F. Nalepa, G.H. Scherbina, D.A. Zhulidov, T. Yu. Gurtovaya. 2004. Relative Distributions of *Dreissena bugensis* and *Dreissena polymorpha* in the Lower Don River System, Russia. International Review of Hydrobiology. 89(3): 326-333.