

Freshwater Mollusk Survey, Jordan River, UT

Part 1: Unionid Mussels and Non-Pulmonate Snails



Final Report

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“Dedicated to Understanding Complex Ecological Interactions”

SUMMARY

North America supports the richest diversity of freshwater mollusks on the planet. These taxa serve vital ecosystem functions. However, many species in the western USA, particularly snails, are narrow endemics and their populations are in sharp decline. Freshwater snails have the dubious distinction of having the highest modern extinction rate yet observed, a distinction almost entirely bestowed upon by human activities. The greatest diversity of North America's freshwater mollusks occurs in the southeastern USA, although the Great Basin, Snake River Basin and Bonneville Basins, including the Great Salt Lake area, is a freshwater mollusk hotspot, particularly for freshwater non-pulmonate snails with at least seventy freshwater mollusk taxa reported from UT. Freshwater mollusk taxonomy, distribution, status, and ecologies are poorly known in UT and very few mollusk specific surveys have been conducted. Specialized training, survey methods, and taxonomic identification is required for successful freshwater mollusk surveys.

The focus of this report was on Superfamily Unionidea mussels in the families Margaritiferidae and Unionidae and on non-pulmonate snails in the families Hydrobiidae and Valvatidae, which were surveyed in the Jordan River drainage in 2014. An extensive review of historical records of Unionidea and non-pulmonate snails in UT was conducted. At least seven of these mollusk taxa have been reported from the Jordan River and Utah Lake area: two unionid mussels, *Margaritifera falcata* and *Anodonta californiensis*; three prosobranch snails, *Fluminicola coloradoensis* and at least two *Pyrgulopsis* species and; two heterobranch snails, *Valvata humeralis* and *Valvata utahensis*. Of these taxa, the only verified to exist in the Jordan River, as of 2004, were *F. coloradoensis* and *Pyrgulopsis* species.

As a result of the limited records and in response to EPA's recently revised ammonia criteria recommendations, a thorough mollusk survey was conducted at site-specific locations on the Jordan River and associated spring creeks in 2014. A combination of reconnaissance and qualitative mollusk surveys was conducted. Valid reconnaissance surveys depended on *a priori* knowledge of expected mollusk distribution and habitat requirements. There was no evidence of native unionid mussel presence during reconnaissance surveys; therefore qualitative surveys were conducted. Three to four mussel surveyors using aquascopes, kick nets, and shoreline examination surveyed approximately 7.5 miles of the Jordan River from April 1, 2014 to April 11, 2014 for a total of about 210 surveyor hours. Habitats examined included: riffles, runs, pools, and back eddies with substrate ranging from boulders/large cobbles to fine silt and clay. Shorelines were carefully examined for empty shells on sandbars, muskrat middens, and other areas of the shoreline.

No live native unionid mussels were found in 7.5 miles of the Jordan River in April 2014 or during the non-pulmonate snail survey in mid October 2014. However, live invasive Asiatic clam, *Corbicula fluminea* occurred in every site and often in very high abundance. Shells of native fingernail clams (Family Sphaeriidae) were observed at the majority of sites including tributaries and live native clams were often observed. One

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small shell fragment (about 2 cm long x 0.5 cm wide) of *Anodonta* sp. was found in Jordan River at Site 2 and many fragments and two whole *Anodonta* sp. shells in Spring Creek downstream of Mill Pond, Utah County but none that were alive or appeared to be recently dead (i.e. no muscle tissue present). The only complete matching pairs (both left and right halves) of *Anodonta* sp. shells found were in Spring Creek buried under sand and a thick layer of *Corbicula* shells.

No live non-pulmonate snails were found in the main stem Jordan River, except for the invasive New Zealand mudsnail. Empty shells of *Fluminicola coloradoensis*, *Pyrgulopsis* sp., *Valvata humeralis*, and *V. utahensis* were found in the main stem but their age and origin are unknown. It is likely that empty non-pulmonate shells found in the Jordan River samples were either deposited from tributaries where extant populations exist or from relatively recently extirpated (≥ 10 -20 ybp) main stem Jordan River populations.

Live *Fluminicola coloradoensis* and *Pyrgulopsis* spp. were found in the spring fed tributaries of the Jordan River and on occasion were relatively abundant. Bingham Creek flows through the Jordan Valley Water Conservation District and had the highest abundances of *F. coloradoensis* found in the survey. Upstream and downstream of JVVCD property, Bingham Creek is heavily impaired by construction and urbanization and downstream it becomes mixed with degraded canal return water before it enters the Jordan River. Very few live *F. coloradoensis* and no *Pyrgulopsis* spp. were found in the lower section of Bingham Creek.

Although not the focus of this report, several pulmonate snail taxa were found in the springs and the Jordan River including, two Physids, two Lymnaeids, and several Planorbidae taxa. Taxonomic identification of pulmonate snails continues. These taxa were collected within shoreline vegetation or slow backwater channels, their preferred habitat.

Highly invasive New Zealand mudsnails and Asiatic clams, *Corbicula*, occurred in almost all kick samples and at all sites and almost always dominated the benthic assemblages in abundances and likely, biomass. NZMS were extremely abundant at the JVVCD Bingham Creek site and were estimated to be at densities far greater than 100,000/m².

Based on historical records and this survey, it appears that native Unionidea mussels and non-pulmonate snails no longer occur in the Jordan River and Utah Lake, or they occur at such extremely low densities and in isolated locations so as to be almost non-detectable. Isolated populations may occur in sections of the Jordan River in very limited areas where spring creeks enter the Jordan River or spring upwelling occurs for a few short meters downstream in the river. The absence of live Unionidea mussels and non-pulmonate snails is consistent with the designation of the Jordan River downstream of the "Narrows" as a warm water fishery (many of the focal taxa surveyed prefer cold water) and it is unlikely that these taxa can survive under present conditions.

Spring seeps and creeks that enter the Jordan River are now critical habitat for remaining non-pulmonate snail taxa; *Fluminicola coloradoensis*, *Pyrgulopsis* spp., and *Valvata* spp.

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They may also be the last best available habitat for any future reintroduction programs. Spring seeps and creeks in the Jordan River system are in dire need of special protection and management. Ammonia criteria should be developed specifically for these habitats.

Reasons for the absence of native Unionidea mussels and non-prosobranch snails in the Jordan River likely include a combination of the following:

- High sediment loads, particularly clay/silt.
- Intensive and extensive urbanization, industrialization, and agriculture impacts, including dewatering and channelization of Jordan River.
- Water quality impairment.
- High densities of the invasive *Corbicula* clam limit available native bivalve habitat
- Absence of native fish hosts for native larval mussel glochidia. Very low fish abundances of any species other than carp in Jordan River.
- Recent high flows (e.g. 2011) in the highly channelized Jordan River may have covered any remaining mussel habitat and may have removed mussels.
- Rapidly recolonizing *Corbicula* can quickly become established in remaining suitable habitats after recent high flows and can preclude any reestablishment by any remaining native mussels.
- Historically there was a trout pond on Mill Pond, Utah County and native mussels may have been associated with these activities. Spring Creek, which flows into and out of Mill Pond, also could have had thriving populations of introduced native mussels when its flows were stable and water quality and habitat were less impaired.
- Two of the most highly invasive mollusk taxa now dominate the benthic assemblage in the Jordan River and probably Utah Lake: NZMS and *Corbicula*. These taxa are likely altering the nitrogen cycle in this system, including ammonia and most certainly compete with the natives.

The following recommendations can help support the conclusion that native mussels and non-pulmonate snails no longer exist in the Jordan River and Utah Lake:

- Expand the mollusk survey area and revisit Jordan River sites that the BLM/USU BugLab reported as having live *Fluminicola* and *Pyrgulopsis* in 2004. Snail population abundances can fluctuate yearly and may naturally have greater abundances in the future and therefore may be more detectable.
- Increase mollusk sampling efforts in Utah Lake.
- Develop and add eDNA sampling methods to the program.

In addition, ammonia criteria need to be recalculated to take the absence of native target mollusks into account and finally, spring seeps and spring creek tributaries of the Jordan River and Utah Lake need special protection, regulations, and management to maintain healthy populations of native mollusks in Utah that are rapidly being lost.

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INTRODUCTION

North America supports the richest diversity of freshwater mollusks (clams, mussels, and snails) on the planet with over 700 species of snails and 300 species of freshwater mussels described so far. Freshwater mollusks serve vital functions in freshwater ecosystems, are excellent indicators of water quality, and are increasingly recognized as important ecosystem providers (Mock et al 2004). Clams and mussels are water filterers whereas; snails are the principal grazers in many aquatic habitats (Huryn et al. 1995). Mollusks significantly influence algal primary productivity (e.g., Brown and Lydeard 2010) and play a pivotal role in aquatic food webs and nutrient cycling (Covich et al. 1999). Mollusks can easily dominate benthic stream communities in numbers (Hawkins and Furnish 1987; Johnson and Brown 1997) and often exceed 50% of invertebrate biomass (Brown et al. 2008; Brown and Lydeard 2010). Because mussels are filter feeders, they contribute greatly to water quality by removing suspended particles of sediment and detritus. According to Allen (1914), an average-sized mussel can filter over eight gallons of water during a 4-hour period. In high-density mussel beds, the filtering effect of thousands of mussels can be ecologically significant. However, many species in the western USA, particularly snails, are narrow endemics associated with lotic habitats, often isolated in a single spring, river reach, or geographically restricted river basin and throughout the region their populations are in sharp decline.

Freshwater mollusks are one of the most disproportionately imperiled species groups on earth. The Nature Conservancy recognized 55% of North American mussels as extinct or imperiled compared with 7% of bird and mammal species (Master 1990); future extinction rates for North American freshwater fauna are projected to be five times higher than those for terrestrial fauna (Riciardi and Rasmussen 1999). Of the 297 freshwater North American mussel taxa, 213 (72%) are considered endangered, threatened or are species of concern. Similarly 74% of the 703 freshwater snail taxa in N.A. are imperiled (Johnson et al., 2013). Freshwater snails thus have the dubious distinction of having the highest modern extinction rate yet observed, at > 9000 times background rates (Johnson et al. 2013). This alarming decline is almost entirely due to human activities (Williams et al. 1992).

The greatest diversity of North America's freshwater mollusks, particularly mussels, occurs in the southeast, whereas in the western half of N.A. the molluskan fauna is relatively depauperate. However, the area consisting of Great Basin, Snake River Basin and Bonneville Basins, including the Great Salt Lake area, is a freshwater mollusk hotspot, particularly for freshwater non-pulmonate snails.

FRESHWATER MOLLUSKS IN UTAH

There are at least seventy freshwater mollusk taxa reported from UT (mostly snails) (Oliver and Bosworth 2009), however their taxonomy, distribution, status, and ecologies are poorly known. Very few mollusk specific surveys have been conducted in UT. Most aquatic invertebrate surveys in Utah are related to water quality assessments (e.g. riffle habitat kick net, Surber, or Hess samplers with fixed subsample counts) and aren't specifically designed to collect mollusks or they identify mollusks at a taxonomic resolution greater than genus level, often only to family level. Hovingh (2004) conducted the most recent comprehensive mollusk survey in UT and suggested that the rareness of mussels in the Bonneville Basin area requires a thorough survey of rivers, which he did not attempt. In addition, specialized training, survey methods, and identification of freshwater mollusks are required. The focus of this report is on Superfamily Unionidea mussels in the families Margaritiferidae and Unionidae and on non-pulmonate snails in the families Hydrobiidae and Valvatidae surveyed in the Jordan River drainage in 2014.

Unionid Mussels

Two Superfamily Unionidea mussel families have been reported in UT, Margaritiferidae and Unionidae. The single taxon in the family Margaritiferidae, *Margaritifera falcata* (Western Pearlshell mussel) and a Unionidae taxon, *Anodonta californiensis* (California floater) are considered critically imperiled and imperiled, respectively in UT (Table 1). Historical records of *Margaritifera falcata* have been reported from: Box Elder, Davis, Morgan, Rich, Salt Lake, and Summit counties. *Anodonta californiensis* has been reported historically in: Box Elder, Cache, Juab, Millard, Piute, Rich, Salt Lake, Tooele, and Utah counties. Three other Unionidae mussel taxa may possibly occur in UT (Table 1) but adequate surveys in UT have not been conducted and the taxonomic status of two is under revision.

Table 1. Unionidea mussel taxa that occur or may have occurred in UT (from NatureServe websites, Oliver and Bosworth UT DNR, Pacific Northwest Mussel Guide and Hoving 2004).

Species	UT Status		NatureServe Global Status	
<i>Margaritifera falcata</i> (Gould, 1850)	S1	Critically Imperiled	G4	Apparently Secure
<i>Anodonta californiensis</i> Lea, 1852	S2	Imperiled	G3	Vulnerable
<i>Anodonta nuttalliana</i> Lea, 1838	Unknown ¹	Unknown	G4	Apparently Secure
<i>Anodonta oregonensis</i> Lea 1838	Unknown ²	Unknown	G5	Secure
<i>Gonidea angulata</i> (Lea, 1838)	Unknown ³	Unknown	G3	Vulnerable

¹From NatureServe: Preliminary analysis (K. Mock, Utah State University, pers. comm.) indicates Utah *Anodonta* are distinct from *Anodonta oregonensis* of the Pacific northwest and should tentatively be assigned to *Anodonta californiensis* pending future taxonomic work. From Pacific Northwest Mussel Guide: There were several historical records for Utah. Unfortunately, historical data are difficult to assess because people often included this species under other species names

²From NatureServe: Early reports of this species occurring eastward to Great Salt Lake and Weber and Jordan basins, Utah (see Oliver and Bosworth, 1999), are likely in error as this is likely a different species (K. Mock, pers. comm., 2006). Mock et al. (2004; 2005) found a lack of resolution (very little nuclear diversity) in

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phylogenetic reconstructions of *Anodonta* (*A. californiensis*, *A. oregonensis*, *A. wahlamatisensis*) populations in the Bonneville Basin, Utah, but there was a tendency for the Bonneville Basin *Anodonta* (tentatively *A. californiensis*) to cluster with *A. oregonensis* from the adjacent Lahontan Basin in Nevada.

³From NatureServe: Despite early reports by Henderson (1924; 1929; 1936) for Utah and Montana, more recent surveys (Chamberlin and Jones, 1929; Jones, 1940; Oliver and Bosworth, 1999; Gangloff and Gustafson, 2000; Lippincott and Davis, 2000) of these states have failed to find any individuals

Non-pulmonate Snails

Two families of non-pulmonate snail taxa in UT are the prosobranch snails in the family Hydrobiidae with two main genera, *Fluminicola* sp. (pebblesnails) and *Pyrgulopsis* sp. (springsnails) and the heterobranch family, Valvatidae which includes one genus, *Valvata* spp. (valve snails). The distribution and status of these taxa are also poorly known, however these are known to occur or have occurred in tributaries of the Great Salt Lake, including the Jordan River drainage.

Historical Records of unionid and non-pulmonate mollusks in the Jordan River drainage

Several unionid and non-pulmonate mollusk genera have been reported in the Jordan River. These include *Anodonta* (Family Unionidae), *Margaritifera* (Family Margaritiferidae), *Fluminicola* (Family Hydrobiidae), *Pyrgulopsis* (Family Hydrobiidae), and *Valvata* (Family Valvatidae). The unionid *Gonidea angulata* is also included in this report because it has the remote potential to exist in the area. A brief description of these taxa and their reported distribution in UT and the Jordan River drainage area follows.

UNIONID MUSSELS

Anodonta californiensis Lea 1852

Common Name: California floater

The range of Western *Anodonta* spp. extends from Alaska south to Mexico and as far east as Utah (Taylor 1966, 1981, 1985, Burch 1975, Clarke 1981, Warren and Harington 2000, Hovingh 2004). Pleistocene records of *Anodonta* spp. are reported from the Bonneville Basin (Eardley and Gvosdetsky 1960, Currey et al. 1983, Oviatt et al. 1999) and Hovingh (2004) found live specimens and shells of *A. californiensis* in UT. Henderson (1931), citing Tanner's dredging efforts, noted that *A. californiensis* was the only living mollusk in Utah Lake, although Call (1884) found many living mollusk taxa in Utah Lake fifty years earlier. Utah Lake was greatly reduced by drought in 1933, and by 1977 most fish in the lake were introduced species (Hovingh 2004). Unionid mussels require fish hosts to complete their life cycle and many are host specific. The BLM/USU BugLab database has no records of *Anodonta* spp. from the Salt Lake or Utah Counties area however they reported two *Anodonta* spp. locations in UT, the Bear River and East Fork Sevier River (Figure 1 and Figure 2) although several researchers reported possible *Anodonta* spp. shells from the Utah Lake shoreline and Mill Pond in Utah County.



Figure 1. *Anodonta californiensis* (California floater)

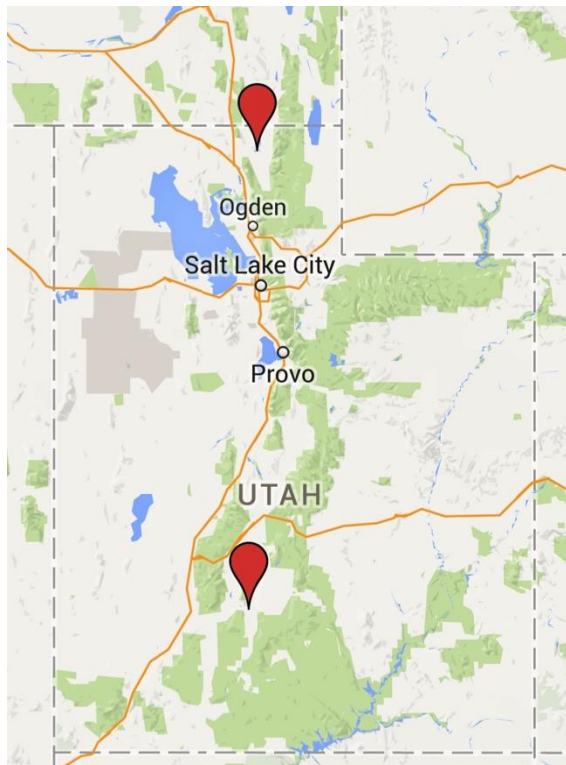


Figure 2. Reported locations of *Anodonta* spp. in UT from BLM/USU BugLab database (<http://www.cnr.usu.edu/wmc/html/data>).

***Gonidea angulata* (Lea 1838)**

Common Name: western ridged mussel

The mobile *G. angulata* (Figure 3) is well adapted to survive in streams with high sediment deposits and can reach high densities on gravel and stabilized sandbars (Vannote and Minshall 1982). *Gonidea angulata* has not been reported in the Jordan River drainage; however, there is a slight possibility of its presence in the system because it can occur in the types of substrate habitat found in the Jordan River. The BLM/USU BugLab database has no records of *G. angulata* from UT.



Figure 3. *Gonidea angulata* (Western Ridged Mussel)

***Margaritifera falcata* Gould 1850**

Common Name: western pearl shell mussel

M. falcata (Figure 4) have historically been found in the Jordan, Weber, and Bear River drainages. Specimens collected between 1880 and 1890 near Salt Lake City are considered to be native (Hovingh 2004) and were once common in this area (Call 1884); however, Hovingh (2004) did not find specimens at 155 sites in Utah, Nevada, and eastern California. According to Hovingh (2004):

“In Utah’s Jordan River drainage, populations could have been extirpated in 1948 by the destruction of Hot Springs Lake, a 3.5-km² lake that may once have contained populations of cutthroat trout that bred in the streams around Salt Lake City. Cutthroat trout native to Utah Lake were extirpated by 1936 (Radant and Sakaguchi 1980) by overfishing and spawning habitat destruction, which terminated spawning migrations up the Provo River (Heckmann et al. 1981)”.

Other factors are likely contributing to the decline of *M. falcata* including; dredging, channelization, water diversion and flood control, dams, the use of river corridors as highway corridors, declining water quality, reservoirs, urbanization, and agricultural practices (e.g. cattle grazing, irrigation return flows)(Hovingh 2004). The BLM/USU BugLab database has no records of *M. falcata* from UT.



Figure 4. *Margaritifera falcata* (Western Pearlshell mussel)

NON-PULMONATE SNAILS

Fluminicola, pebble snails

Fluminicola coloradoensis Morrison, 1940

Common Name: Green River pebblesnail

There are currently 24 recognized species of *Fluminicola* in northwestern North America. *Fluminicola* spp. are small 1.2–12.0 mm shell height, gill-breathing gastropods, commonly known as pebblesnails (Hershler and Frest 1996). They are often an abundant member of benthic communities but have recently become a focus of conservation activities (e.g., USDA Forest Service and USDI Bureau of Land Management 2001, Lydeard et al., 2004). Despite their large range, *Fluminicola* spp. have received little taxonomic or ecological study (Hershler and Frest 1996).

Fluminicola spp. occur in portions of the northern Great Basin, Snake- Columbia River system, Sacramento River system, and Pacific coastal drainages (British Columbia, California, Idaho, Nevada, Oregon, Utah, Washington, Wyoming) (Hershler and Frest 1996). They are usually found in clear, cold waters with high dissolved oxygen content. Larger sized species are typically found in streams, whereas smaller sized species are commonly found in either spring or stream environments (Hershler and Frest 1996). Many taxa are lithophiles ('rock loving' e.g. stable substrates) and graze on periphyton. *Fluminicola* spp. can be community dominants and can comprise most of the invertebrate biomass. They are fairly intolerant of impounded waters and soft substrates, as well as of nutrient enhanced or lacustrine habitats (Hsiu-Ping et al. 2013). *Fluminicola* spp. apparently have now been extirpated from large areas of their historic range (Hsiu-Ping et al. 2013).

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The only species of *Fluminicola* found in UT is *Fluminicola coloradoensis* Morrison (Hershler and Frest 1996; Hsiu-Ping et al. 2013)(Figure 5). This species is currently ranked as imperiled or vulnerable (G2/G3) by Nature- Serve (2011). Hsiu-Ping et al. 2013 suggested that *F. coloradoensis* is much more widely distributed than previously thought and may not merit these rankings, at least on a range wide basis. They suggested that conservation measures should perhaps be focused on geographic subunits that may be at risk (Hsiu-Ping et al. 2013).

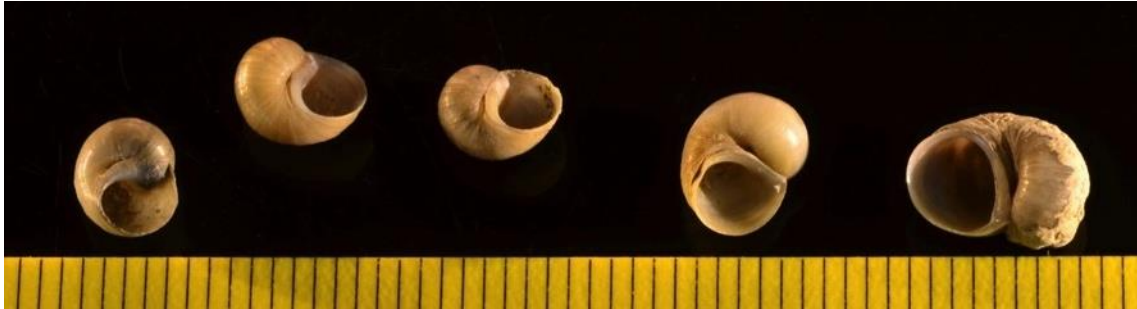


Figure 5. Empty shells of the prosobranch snail, *Fluminicola coloradoensis* found in several sections of the Jordan River and spring tributaries during the October 2014 survey. Scale lines are 1 mm.

A total of 21 individual *F. coloradoensis* were documented in the BLM/USU BugLab database from four sampling events in Jordan River/Salt Lake county (N = 20) and Utah county (N = 1) records in 2004, excluding the Jordan River Bluffdale Road Crossing misidentified lat/long site (Figure 6)(<http://www.cnr.usu.edu/wmc/html/data>). There were 85 individuals collected in two sampling events at the misidentified Jordan River site, which true location needs to be verified. This large number of individuals could represent a valid population in the Jordan River if it was truly collected there and if it is still viable. BLM/USU BugLab samples were collected in 2004 and unprecedented urbanization has taken place since then at their reported locations (Figure 7 and Figure 8). Consequently, this population may no longer exist.

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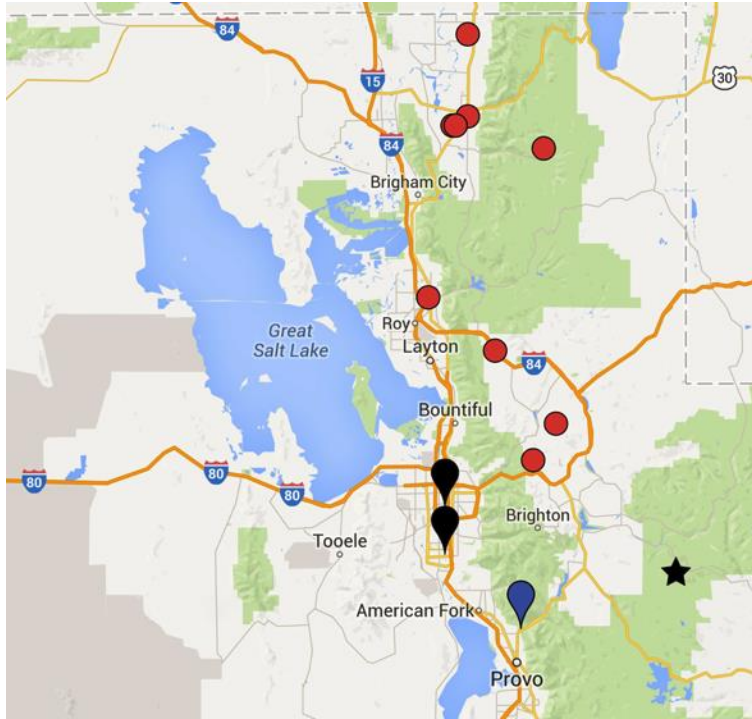


Figure 6 *Fluminicola coloradoensis* in NW UT. Locations from WCMAFE BLM/USU Aquatic Monitoring Center, BugLab website (<http://www.cnr.usu.edu/wmc/htm/data>). *F. coloradoensis* symbol locations: Black teardrop = Jordan River/ Salt Lake County; blue teardrop = Utah county; black star = BugLab description was Jordan River at Bluffdale Road Crossing but lat/long coordinates located this site shown on the map; red circles = drainages other than Jordan River/Salt Lake and Utah counties. An additional location was from the Green River near the CO border but is not shown.

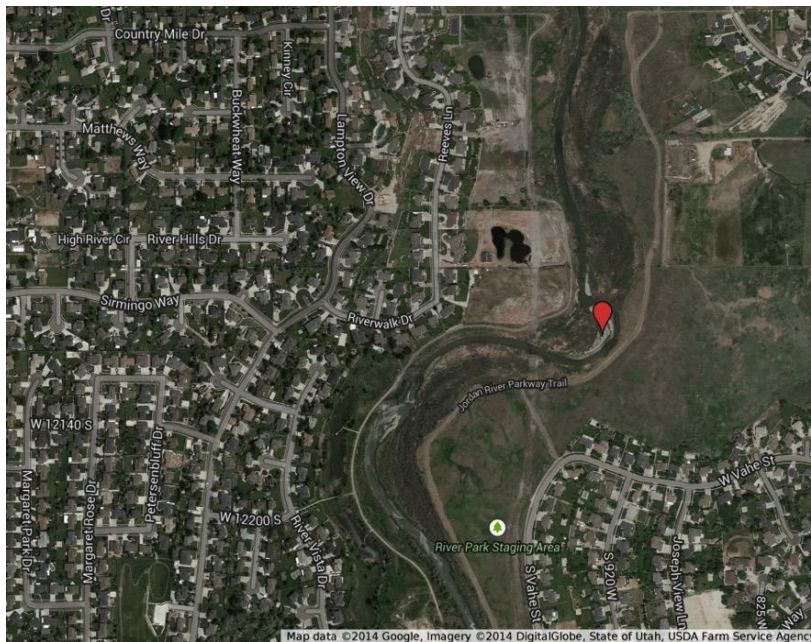


Figure 7. Location of *Fluminicola coloradoensis* BLM/USU BugLab collection site in 2004. A total of nine individual were collected from combined qualitative and quantitative data. (<http://www.cnr.usu.edu/wmc/htm/data>). Unprecedented urbanization has occurred in this area since 2004 and may have caused their demise.

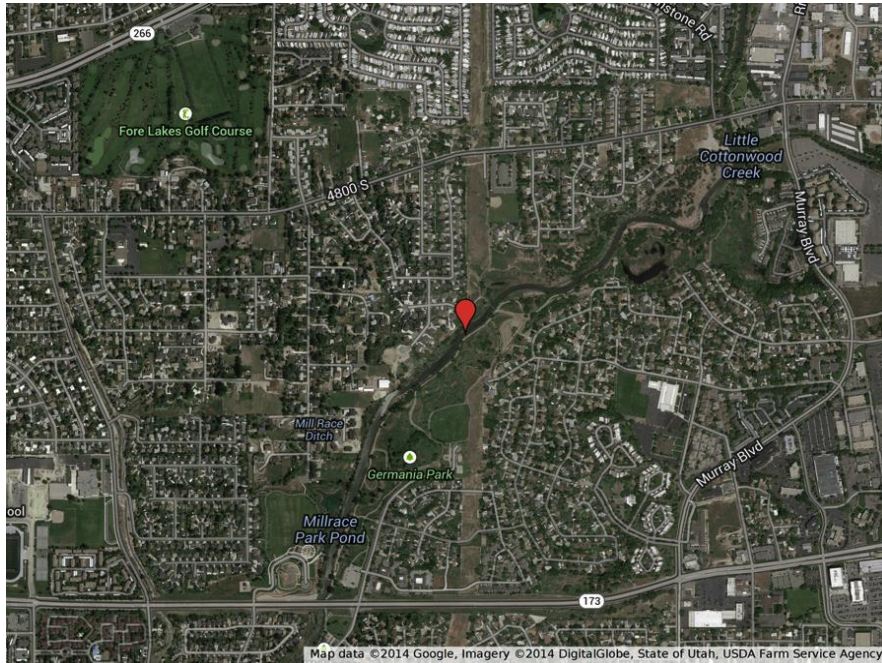


Figure 8. Location of *Fluminicola coloradoensis* BLM/USU BugLab collection site in 2004. A total of 11 individual shells were collected from qualitative data (<http://www.cnr.usu.edu/wmc/htm/data>). Unprecedented urbanization has occurred in this area since 2004 and may have caused their demise.

Pyrgulopsis, spring snails

Pyrgulopsis spp. (Figure 9) are known as ‘spring snails’ because they typically inhabit spring creeks, although some *Pyrgulopsis* spp. can also be found in rivers (ex. *P. robusta* and other unnamed *Pyrgulopsis* spp. in the Snake River, ID) and one species inhabits thermal springs (*P. bruneauensis* only found in the Bruneau River, ID). *Pyrgulopsis* spp. are one of the most diverse members of the endemic western North American aquatic biota and the largest number of species (at least 73) occur in the Great Basin (Figure 10) (Hershler et al., 2014). The Great Salt Lake drainage basin, particularly the Utah Lake drainage is one of the hotspots of *Pyrgulopsis* spp. distribution (Figure 10). However, their status is poorly known and many species are considered rare or extinct in UT (Bosworth and Oliver 2009). *Pyrgulopsis* spp. are rapidly becoming one of the most important indicators of groundwater and freshwater spring health because of their endemism and their conservation status (Hershler et al., 2014). These tiny gastropods are imperiled by threats ranging from groundwater pumping to livestock grazing (Hershler et al., 2014). BLM/USU identified *Pyrgulopsis* spp. and *P. pilsbryana* J. L. Baily and R. I. Baily, 1952 (common name: Bear Lake springsnail) in Salt Lake and Utah counties (Figure 11) and two individual *Pyrgulopsis* spp. collected from the Jordan River, in a 2002 qualitative sample (Figure 12). The pyrgs in the BLM/USU BugLab database could be more than one or two species due to difficulty in taxonomy.

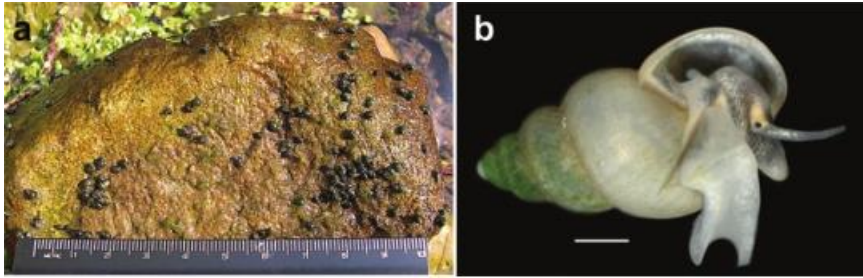


Figure 9. (a) *Pyrgulopsis* sp. on rock (East Fork Rock Creek, Idaho). Photograph: Daniel Gustafson. (b) *Pyrgulopsis robusta* (Snake River, Idaho). The scale bar represents 1 millimeter. Photograph: Robert Hershler. Both photos from Hershler et al., 2014.

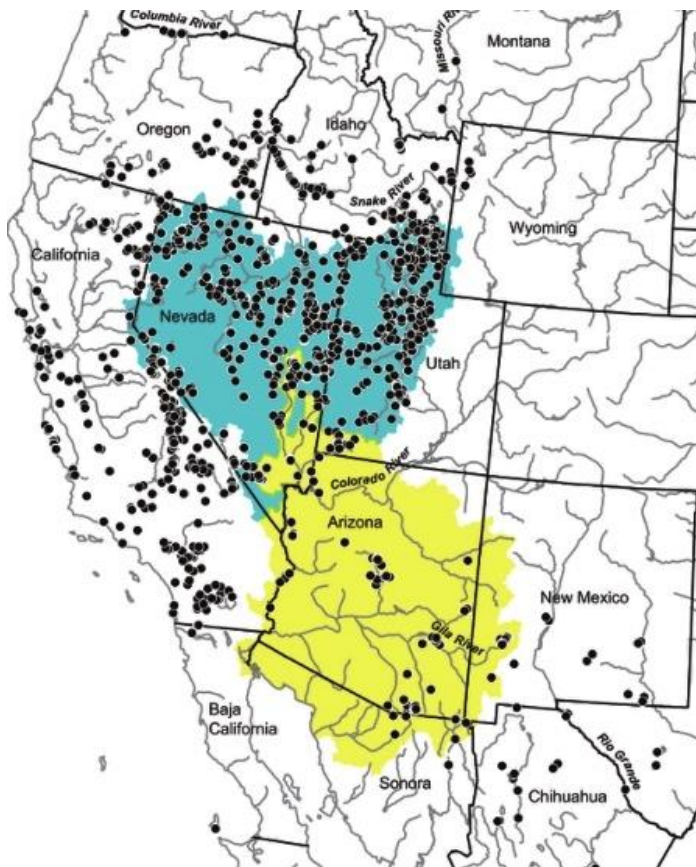


Figure 10. The distribution of *Pyrgulopsis*, based on records in the Smithsonian National Museum of Natural History and several other repositories. The Great Basin and lower Colorado River Basin are shaded in cyan and yellow, respectively. (Figure from Hershler et al. 2014)

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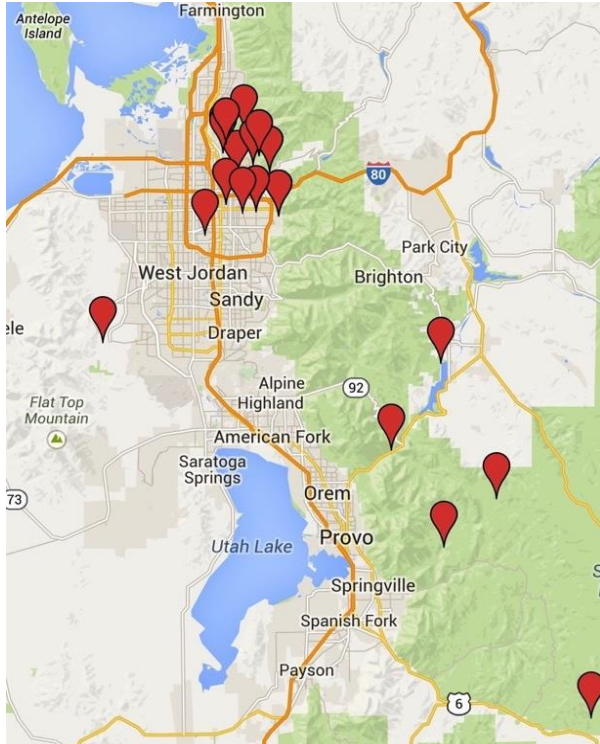


Figure 11. Reported locations of *Pyrgulopsis* spp. in Salt Lake and Utah counties from BLM/USU BugLab database (<http://www.cnr.usu.edu/wmc/html/data>).

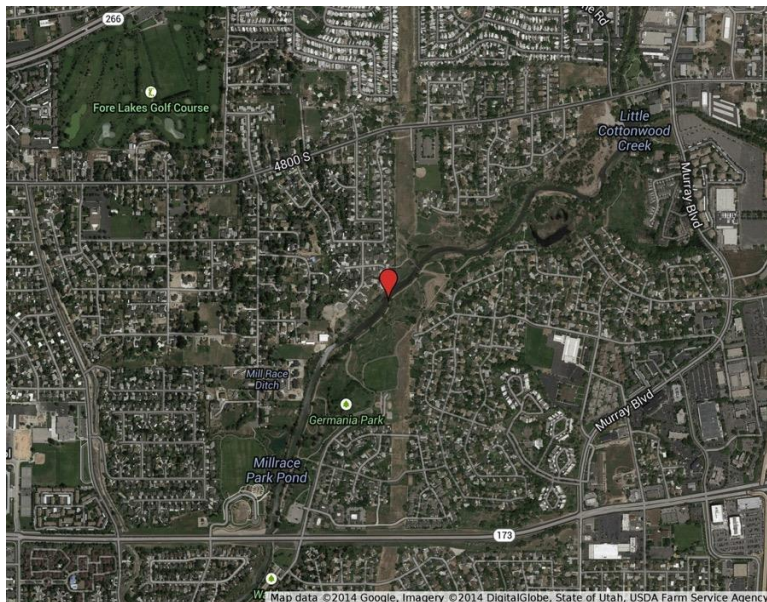


Figure 12. Location of two individual *Pyrgulopsis* spp. reported by BLM/USU BugLab in Jordan River, in a 2002 qualitative sample. (<http://www.cnr.usu.edu/wmc/html/data>). Unprecedented urbanization has occurred in this area since 2002 and may have caused their demise.

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Other prosobranchs

Two additional uncommon prosobranch snails also occur in UT, *Tryonia porrecta* (Mighels, 1845)(Common Name: Desert tryonia) and *Colligyrus greggi* (Pilsbry, 1935)(Common Name: Rocky Mountain dusky snail) but were not reported in the Jordan River drainage in the WCMAFE BLM/USU Aquatic Monitoring Center, BugLab database

(<http://www.cnr.usu.edu/wmc/html/data>)(Figure 13).

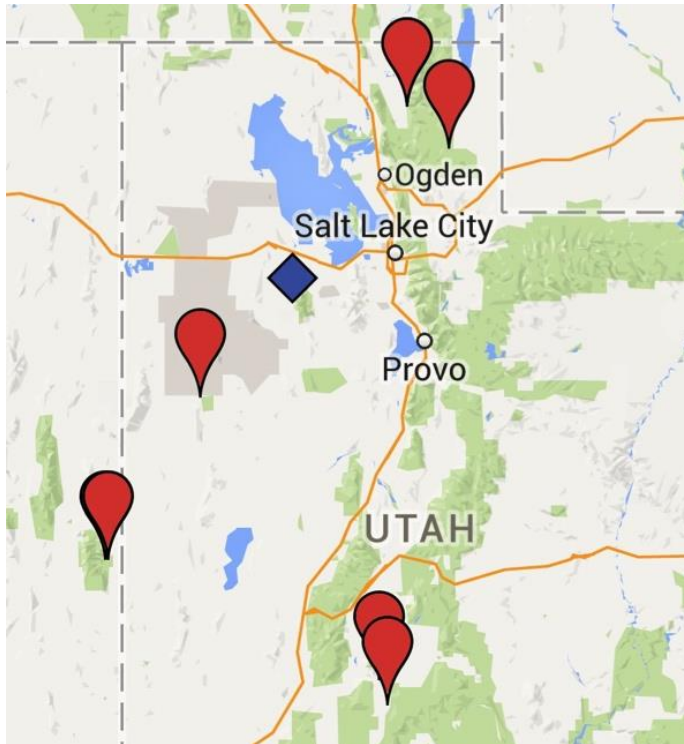


Figure 13. *Colligyrus greggi*. (red balloons) and *Tryonia* sp. (blue diamond) locations reported from WCMAFE BLM/USU Aquatic Monitoring Center, BugLab website (<http://www.cnr.usu.edu/wmc/html/data>).

Valvata, valve snails

Valvata is a genus of very small freshwater snails with an operculum, in the family Valvatidae, the valve snails. They are non-pulmonates and are heterobranchs meaning “different gilled snails” (as opposed to prosobranchs which means “gills in front of heart”). There are likely two taxa that can or have occurred in the Jordan River drainage, *V. humeralis* and *V. utahensis*. Hovingh (2004) considers *V. humeralis* in UT to be *V. californica* based on shell morphology, however this taxon will be identified as *V. humeralis* in this report.

Valvata humeralis Say 1829

Common Name: Glossy *Valvata*

Valvata humeralis is widely distributed in Western North America (but see Hovingh 2004) including the Colorado River, the upper Rio Grande, the Columbia-Snake River, the California Pacific Coast drainages, and the Great Basin. Its habitats range from large lakes to small ponds, marshes, streams, and springs (Hovingh 2004). This species historically occurred in: Box Elder, Cache, Juab, Kane, Rich, Sevier, Summit, Tooele, Utah, and Wasatch watersheds in UT,

Jordan River Mollusk Survey 2014 Part 1: Unionidea and Non-Pulmonate Snails

NatureServe suggests that *V. humeralis* may possibly have been extirpated in all of these counties (<http://explorer.natureserve.org>), however Hovingh (2004) and BLM/USU BugLab reported live populations in UT (Figure 14) but none from Salt Lake or Utah counties. This discrepancy highlights the difficulty in assessing populations of tiny hard to find and identify snails.

Valvata utahensis Call 1884

Common Name: Utah round mouth snail, desert snail

Valvata utahensis was federally delisted because it has been found in a wider range of habitats and locations in the Snake River, ID. It is distinguished from *V. humeralis* based on the much taller shell spire and prominent carinae (as opposed to a flatter, noncarinate shell in *V. humeralis*) (Miller et al., 2006)(see Figure 33). *Valvata utahensis* historically occurred in a wide variety of habitats including: creeks, high gradient medium sized rivers, moderate gradient, springs and spring brooks. It also can occur in shallow and deep lakes (NatureServe Explorer, Hovingh 2004). It can occur in a wide range of benthic habitats including submergent aquatic plants on fine silt substrate, pebbles, and cobbles (USFWS, 1992; Lysne and Koetsier 2006). *Valvata utahensis* was extirpated from Utah Lake and Call (1884) was apparently the only person to collect shells of this species with opercula (i.e. live specimens)(Chamberlin and Jones 1929, Hovingh 2004). NatureServe reported *V. utahensis* historically in the Bear Lake and Utah Lake HUC8 watersheds. (<http://explorer.natureserve.org>) but consider this species to be extinct in UT (Figure 14). Live *V. utahensis* are known only to occur in the Snake River, ID (Hovingh 2004).

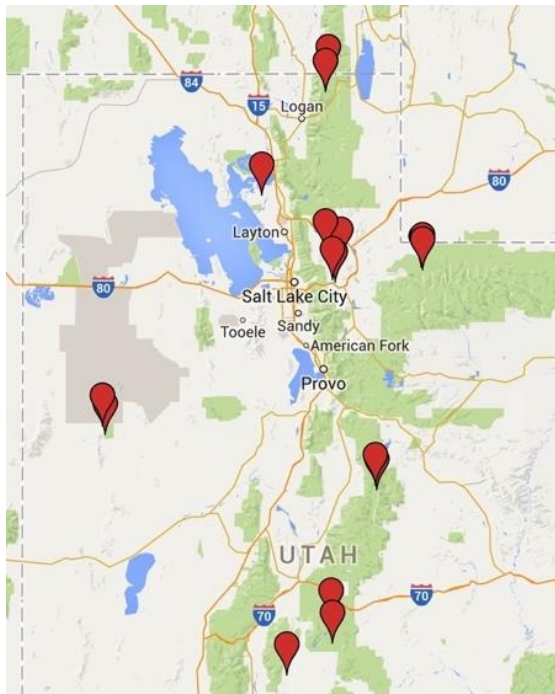


Figure 14 | *Valvata* spp. in UT locations reported from WCMAFE BLM/USU Aquatic Monitoring Center, BugLab website (<http://www.cnr.usu.edu/wmc/htm/data>). No *Valvata* spp. were reported in the BLM/USU BugLab database for Salt Lake and Utah counties and *Valvata* spp. and *Valvata humeralis* were the only two *Valvata* taxa reported.

Jordan River Mollusk Survey 2014 Part 1: Unionidea and Non-Pulmonate Snails

Table 2. Status of native Unionid mussels and non-pulmonate snails that could occur in Jordan River and which were the focus of this survey.

Taxon	NatureServe Status ¹			UT- DNR ²	IUCN ³	AFS ⁴
	Global	National	Utah			
Unionid mussels						
<i>Gonidea angulata</i>	3	3	NA	NA	NE	Und.
<i>Anodonta californiensis</i>	3Q	3Q	1Q	NA	LC	Und.
<i>Margaritifera falcata</i>	4, 5	4, 5	1, H	NA	NE	Und.
Non-pulmonate snails						
<i>Colligyrus greggi</i>	4	4	1	R, I, RE	LC	CS
<i>Fluminicola coloradoensis</i>	2, 3	2, 3	2, 3	R, I, RE	NE	T
<i>Pyrgulopsis pilsbryana</i>	2	2	1	R, I, RE	NT	T
<i>Pyrgulopsis spp.</i>	NA	NA	NA	NA	NA	NA
<i>Tryonia porrecta</i>	3	2	2	R, I, RE	LC	CS
<i>Valvata humeralis</i>	5Q	5	H	R, I, RE	LC	CS
<i>Valvata utahensis</i>	1, 2	1, 2	X	R, I, RE	VU	E

¹Nature Serve Status Codes:

1. Critically imperiled - At very high risk of extinction or elimination due to extreme rarity, very steep declines, or other factors.
- 2: Imperiled-At high risk of extinction due to very restricted range, very few populations (often 20 or fewer), steep declines, or other factors.
- 3: Vulnerable-At moderate risk of extinction due to a restricted range, relatively few populations (often 80 or fewer), recent and widespread declines, or other factors.
4. Apparently Secure-Uncommon but not rare; some cause for long-term concern due to declines or other factors.
5. Secure-Common; widespread and abundant.
- Q. Questionable taxonomy-Taxonomic distinctiveness at the current level is questionable; resolution of this uncertainty may result in change from a species to a subspecies or hybrid, or the inclusion of this taxon in another taxon
- X. Presumed Extinct -Not located despite intensive searches and virtually no likelihood of rediscovery.
- H. Possibly Extinct -Missing; known from only historical occurrences but still some hope of rediscovery.
- NA. Not reported to occur in UT.

²UT DNR: Utah Department of Natural Resources, Oliver and Bosworth (1999) Utah Status Report Codes:

- R. Rare
- I. Imperiled
- RE. Recently extinct or extirpated

³IUCN: Red List Category Codes:

- LC. Least concern
- NT. Near threatened
- NE. Not evaluated

⁴AFS = American Fisheries Society Codes

- E. Endangered: A species that is in imminent danger of extinction.
- T. Threatened: A species that is imminently likely to become endangered throughout all or a significant portion of its range.
- V. Vulnerable: A species that is imminently likely to become threatened throughout all or a significant portion of its range; equivalent to “Special Concern” as designated by Deacon et al. (1979) and Williams et al. (1989).
- CS. Currently Stable: Species populations not currently at risk.
- Und. Undetermined.

Invasive mollusks

Non-native, invasive mollusks can be extremely abundant in the Jordan River, particularly the prosobranch New Zealand mudsnails (NZMS) (*Potamopyrgus antipodarum*) and the Asiatic clam, *Corbicula fluminea*. At high densities these two invasives can completely alter nutrient cycling (spiraling), particularly ammonia (Appendix 23).

JORDAN RIVER MOLLUSK SURVEY, 2014

JUSTIFICATION AND OBJECTIVES

In addition to augmenting the limited information on the status of Utah's freshwater mollusks, the U.S. Environmental Protection Agency (USEPA) recently recommended changes in ambient water quality criteria for ammonia in freshwaters (USEPA 2013). These recommendations were primarily based on toxicity test results conducted on freshwater mollusks (mussels, clams, and snails): specifically several Eastern USA freshwater mussel species in the family Unionidae and also non-pulmonate, gill bearing- snails, whose taxonomic relatives also occur in western USA freshwaters. Because these taxa may not occur in a region or potentially impacted area, EPA also developed a recalculation procedure to develop site specific water quality criteria 'to better reflect the organisms that occur at a specific site' (EPA 2013b: *Revised Deletion Process for the Site-Specific Recalculation Procedure for Aquatic Life Criteria*). "The Recalculation Procedure is intended to allow site-specific criteria that appropriately differ from national criteria recommendations (i.e., ammonia concentrations that are higher or lower than national recommendations) where there are demonstrated differences in sensitivity between the aquatic species that occur at the site and those that were used to derive the national criteria recommendations." (USEPA 2013). If Unionidae mussels and prosobranch snails are determined to be absent from a site then states and tribes may decide to adopt site-specific criteria based either on the alternative criteria values provided in Appendix N of the 2013 national ammonia criteria recommendations, or on their own criteria values resulting from application of the Recalculation Procedure.

It therefore becomes imperative to determine the presence/absence of mollusk taxa and in particular, Unionidae mussels and non-pulmonate snails in tributaries of the Jordan River, the main stem of the Jordan River, to determine if recalculation of EPA's ammonia criteria is warranted. Mollusk presence/absence surveys are particularly important in areas potentially affected by the water treatment facilities along the Jordan River. Mollusk taxa should be identified at the species level because each species will have unique tolerance values to ammonia and mean values based on genera or family level taxonomy may not represent values of local species. For example, EPA ammonia species mean acute values (SMAV) for mussel species in the family Unionidae ranged from 23.12 mg TAN/L to 109 mg TAN/L (Appendix 22). This represents a 471% difference in SMAV in just the eastern U.S. unionid species used to develop EPA criteria. Within the Unionidae genus *Lampsilis*, SMAV values ranged from 26.03 mg

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TAN/L to 69.97 mg TAN/L (Appendix 22), a 270% difference in values. Thus each species will have it's own unique ammonia tolerance value and species found in the western U.S. may have tolerance values far different than those used by EPA.

The objectives of this survey are to determine presence and estimate the probability of occurrence/absence of Unionidea mussels and non-prosobranch snails in the Jordan River and nearby tributaries. Results of this mollusk survey will be used to begin site-specific recalculation of ammonia criteria based on those sensitive taxa that are present or assumed absent. Recalculation of site-specific ammonia criteria will follow EPA's guidelines.

METHODS

First Tier Mollusk Surveys: Literature Review, and Reconnaissance and Qualitative Surveys

Literature Review

All relevant databases and literature concerning historic and recent mollusk distributions in watersheds of the Great Salt Lake focusing on the Jordan River drainage were searched. These included: UT Department of Natural Resources reports, the WCMAFE BLM/USU Aquatic Monitoring Center, BugLab website (<http://www.cnr.usu.edu/wmc/htm/data>), NatureServe Explorer (<http://explorer.natureserve.org>), The Xerces Society (xerces.org), American Malacological Society, Freshwater Mollusk Conservation Society (molluskconservation.org) and pertinent peer reviewed and gray literature.

Survey locations

Nine sites were surveyed for native mussels on the Jordan River, including sites upstream and downstream of water treatment facilities, for a total river length distance of about 7.5 miles (Table 3 and Figure 15-21) in April 2014. Mill Pond and Spring Creek, which empty into the NE corner of Utah Lake in Utah County were also surveyed based on reports of historic *Anodonta* sp. shells occurring there by Dr. Larry Gray and others.

Table 3. Mussel survey site latitude and longitude coordinates and river length surveyed.

Site 1	Latitude	Longitude	Distance (miles)
Upstream	40°27'37.85"N	111°55'56.28"W	
Downstream	40°28'23.15"N	111°55'57.25"W	0.9
Site 2			
Upstream	40°32'57.44"N	111°54'55.95"W	
Downstream	40°33'54.58"N	111°54'32.04"W	1.47
Site 3			
Upstream	40°34'34.65"N	111°55'7.42"W	
Downstream	40°34'59.87"N	111°55'2.67"W	0.6
Site 4			
Upstream	40°35'16.58"N	111°54'45.54"W	
Downstream	40°35'28.92"N	111°54'45.01"W	0.25

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Site 5			
Upstream	40°36'55.37"N	111°55'14.97"W	
Downstream	40°37'24.85"N	111°55'15.05"W	0.6
Site 6			
Upstream	40°41'9.73"N	111°55'15.27"W	
Downstream	40°41'57.37"N	111°55'27.51"W	1.3
Site 7			
Upstream	40°42'25.89"N	111°54'26.10"W	
Downstream	40°42'35.93"N	111°55'25.34"	0.9
Site 8			
Upstream	40°43'42.31"N	111°55'29.92"W	
Downstream	40°44'4.41"N	111°55'23.76"W	0.4
Site 9			
Upstream	40°50'5.48"N	111°56'39.88"W	
Downstream	40°50'54.21"N	111°57'13.63"W	1.1



Figure 15. Sample location in The “Narrows” section of Jordan River. Sampling occurred between the blue pins on the map.

Jordan River Mollusk Survey 2014 Part 1: Unionidea and Non-Pulmonate Snails



Figure 16. Site 2. Sampling occurred between the blue pins on the map.

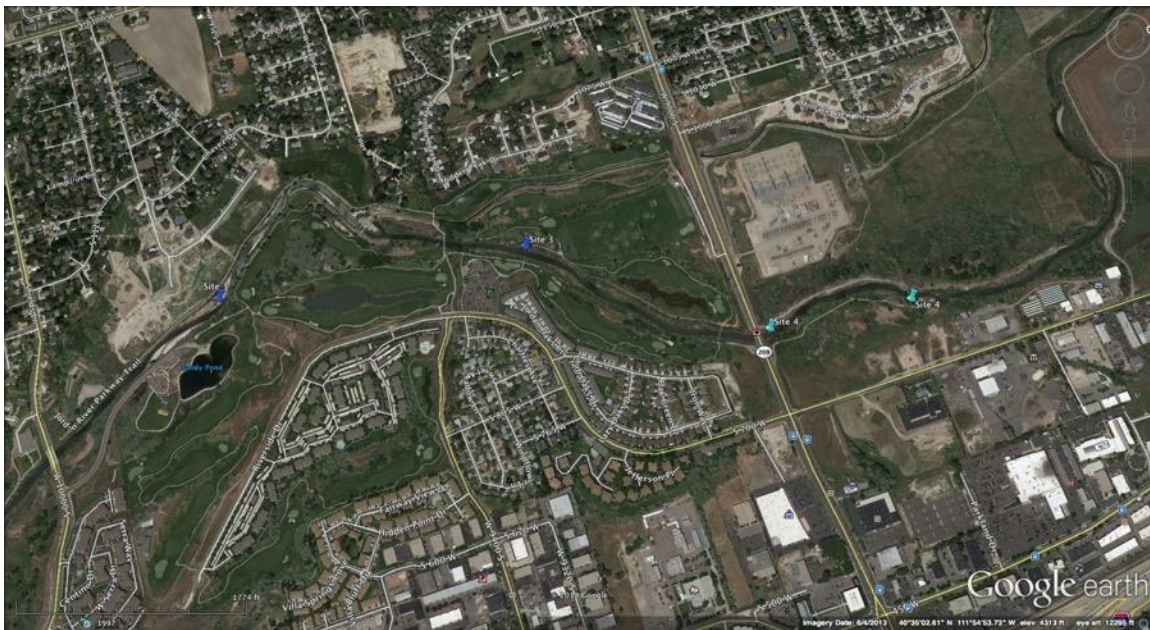


Figure 17. Mussel survey sites 3 and 4. Sampling occurred between the blue pins on the map.

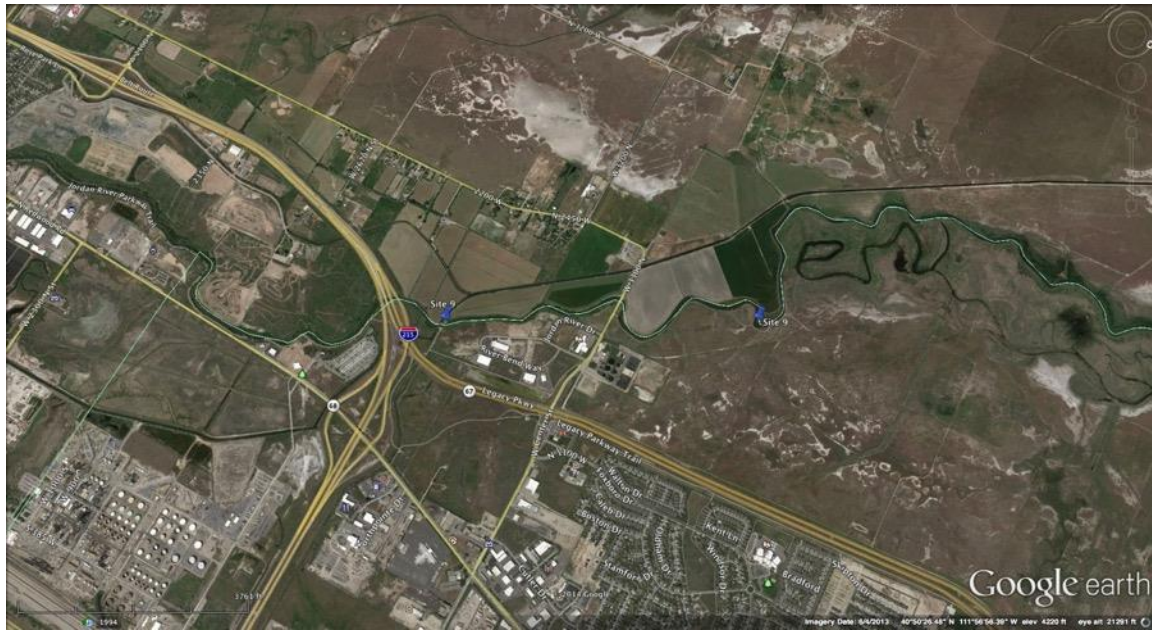


Figure 20. Mussel survey site 9. Legacy Nature Preserve. Sampling occurred between the blue pins on the map.

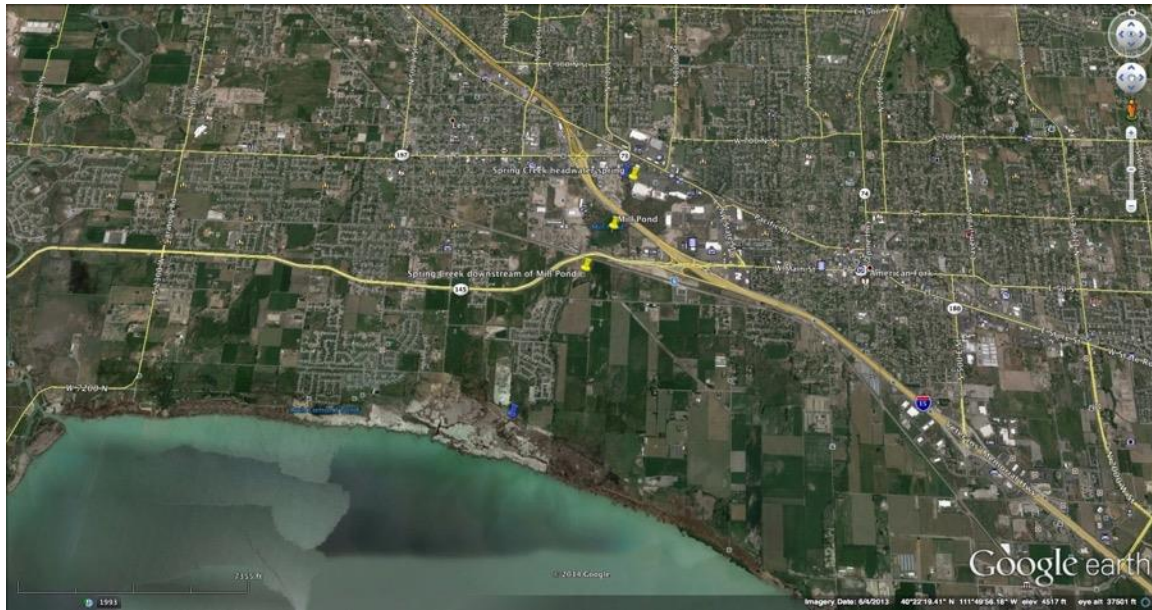


Figure 21. Mill Pond and Spring Creek, Utah County. Unionid mussel surveys were conducted between blue pins; yellow pin at headwater spring is in a Wal-Mart parking lot and under a dumpster; yellow pin at Spring Creek downstream of Mill Pond is where the most *Anodonta californiensis* shells were found in the 2014 survey.

Survey methods

Native unionid mussels

A combination of reconnaissance and qualitative mollusk surveys was conducted.

Reconnaissance surveys were cursory visual searches in the most promising habitats and gave us

Jordan River Mollusk Survey 2014 Part 1: Unionidea and Non-Pulmonate Snails

a preliminary understanding of mollusk presence or absence in the Jordan River drainage. Reconnaissance surveys were conducted to help determine if additional more comprehensive qualitative surveys were warranted. Valid reconnaissance surveys depended on *a priori* knowledge of expected mussel distribution and habitat requirements. For example, *Margaritifera falcata* tend to be immediately upstream or downstream of riffles, while in the low gradient sections of the Jordan River, *M. falcata* and *Anodonta* sp. mussels would most likely be present in areas with higher flows. There was no evidence of native unionid mussel presence during reconnaissance surveys; therefore we conducted qualitative surveys. For the qualitative surveys, three to four mussel surveyors using aquascopes (Figure 22), kick nets (Figure 23), and shoreline examination (Figure 24) surveyed approximately 7.5 miles of the Jordan River from April 1, 2014 to April 11, 2014 for a total of about 210 surveyor hours. Visibility was typically between 2 to 3 feet. Surveyors using aquascopes could view depths to about 4 feet therefore, habitats with depths > 4 feet were not closely examined. Habitats with silt/clay sediments > 2 to 3 feet thick were also not examined. Surveyors using aquascopes traversed the river bottom from side to side and then moved several meters upstream in most of the sections looking for mussel shell fragments or whole live or dead mussels. Habitats examined included: riffles, runs, pools, and back eddies with substrate ranging from boulders/large cobbles to fine silt and clay. Empty invasive Asian clams, *Corbicula fluminea* shells and live *Corbicula* were clearly visible using aquascopes and most live *Corbicula* were seen to be actively filtering, therefore native mussels were also assumed to be detectable on the substrate surface using the aquascopes. However, as a precaution, kick net samples were also collected in promising habitat to help determine if mussels were buried under the sediment and not visible to aquascope surveys. Shorelines were carefully examined for empty shells on sandbars, muskrat middens, and other areas of the shoreline.



Figure 22. One of the commercial aquascope types used in the mussel survey.



Figure 23. Mollusk surveyor using kick net



Figure 24. Mollusk surveyor searching shoreline and gravel bar.

Non-pulmonate snails

Snails were surveyed using 0.5 mm mesh kick nets and by examining cobbles in October 2014 at the same locations as the unionid mussel surveys. Three spring tributaries of the Jordan River; an unnamed spring seep system on the west bank of Surplus/State/South Jordan canal at the “Narrows”, Midas/Butterfield Creeks confluence with Jordan River, and Bingham Creek at the Jordan Valley Water Conservation District and its confluence with the Jordan River were also

sampled (Figure 25 and



Figure 26). Nets were dragged upstream through the substrate to depths of about 2-5 cm while simultaneously vigorously kicking substrate upstream of the net, which allowed loosened material to flow into the net. Most samples contained numerous heavy live *Corbicula* clams, sand, gravel, or cobbles, which assured that the kick methods were able to efficiently collect live snails or empty shells. When nets were about ¼ full, sample contents were placed into large shallow trays ½ filled with water and allowed to stand for approximately 15 minutes to allow snails to become active and more visible and in many cases to attach to the sides and bottoms of the trays. Slightly stirred water was slowly poured out of trays to remove detritus (but not empty shells) up to several times depending on the amount of detritus. All live snails and empty snail shells were hand picked from contents at the site. Hand lens were often used to locate very small snails or determine that they were not tiny pebbles or sand particles. Empty shells were placed in small sample jars dry, live snails were placed in jars with river water sprinkled with menthol crystals and relaxed for 24 hrs in a refrigerator or on ice in a cooler. Relaxed snails were then stored in 70% EtOH final solution. The EtOH preserved samples may be used for future genetic taxonomic verification. All snail samples are kept as voucher specimens at OreoHelix Consulting, Moab, UT and are available for use and taxonomic verification. Any evidence of unionid mussels was also noted. However, no live or empty shells of mussels were observed during the snail survey in October 2014.

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Figure 25. Springs on west side of Jordan River at “Narrows” (40°27'56.19"N; 111°56'1.87"W)



Figure 26. Two Bingham Creek sample locations: JRWCD land (40°36'17.17"N; 111°55'14.68"W) and where Bingham Creek enters the Jordan River (40°36'4.84"N; 111°55'41.67")

RESULTS

Unionid mussels

No live native unionid mussels were found after the intensive ten-day survey of 7.5 miles of the Jordan River in April 2014 or during the non-pulmonate snail survey in October 2014. However,

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live invasive Asiatic clam, *Corbicula fluminea* occurred in every site and often in very high abundance. Shells of native fingernail clams (Family Sphaeriidae) were observed at the majority of sites including tributaries and live native clams were often observed.

One small shell fragment (about 2 cm long x 0.5 cm wide) of *Anodonta* sp. was found in Jordan River at Site 2 and many fragments and two whole *Anodonta* sp. shells in Spring Creek downstream of Mill Pond, Utah County but none that were alive or appeared to be recently dead (i.e. no muscle tissue present). The only complete matching pairs (both left and right halves) of *Anodonta* sp. shells that we found were in Spring Creek buried under sand and a thick layer of *Corbicula* shells. Two of the *Anodonta* sp. shells were from one large and one empty shell was from a smaller *Anodonta* sp. (Figure 27).

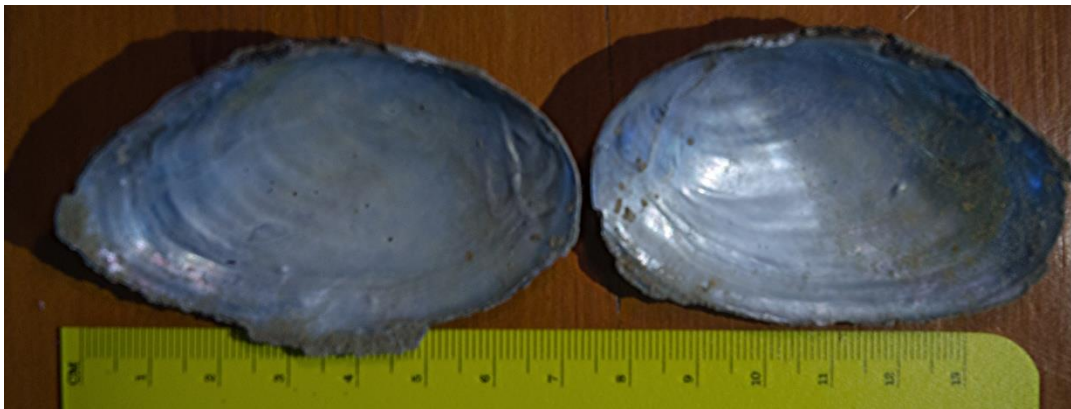


Figure 27. Complete *Anodonta* sp. shell from Mill Pond, Utah County, April 2014. No body tissue was present and the time since death is unknown.

Substrate throughout most of the Jordan River was mostly sand, silt, clay, and organic matter, with occasional gravel/cobble riffles. The narrows' section of the Jordan River included large boulders and appeared to be the most likely section for finding *M. falcata*. Mill Pond and Spring Creek, Utah County, also had mostly sand, silt, and clay substrate. Mill Creek upstream of Central Valley Treatment Facilities effluent had mostly hardpan, tightly embedded gravels with some sand/silt, clay. Mill Creek downstream of effluent was mostly sand/silt/clay/OM.

Corbicula fluminea occurred throughout the Jordan River at every site we sampled including Mill Pond but was not seen in the upstream Mill Creek site (7). It was often in extremely high abundance, if empty shells were included in the estimate. *Corbicula* sp. was extremely abundant in the canal that flowed along the west side the Jordan River near the "Narrows" (Site 1).

Because this was a presence/absence survey, mollusk densities were not estimated. *Corbicula* appeared to be most abundant in sand/gravel sediments between the anoxic layer that occurred a few centimeters deep and the surface of the substrate and often under a thin layer of filamentous algae (*Cladophora* sp.) where it was present. Sand/gravel substrates are preferred by *Corbicula* habitat (see Appendix 23). The largest *Corbicula* shell that the author ever encountered in his career was collected at Mill Pond and measured about 6 cm in max diameter (Figure 28).



Figure 28. Atypical large *Corbicula* shells for Jordan River, UT drainage.

Non-pulmonate snails

No live non-pulmonate snails were found in the main stem Jordan River, except for the invasive New Zealand mudsnail, *Potamopyrgus antipodarum*. Empty shells of *Fluminicola coloradoensis*, *Pyrgulopsis* sp., *Valvata humeralis*, and *V. utahensis* shells were found in the main stem but their age and origin are unknown (Figure 29– 33). Mollusk shells can remain intact for >100 years. It is likely that empty shells found in the Jordan River samples were either deposited from tributaries where extant populations exist or from relatively recently extirpated (\geq 10-20 years) main stem Jordan River populations. Live *F. coloradoensis* and *Pyrgulopsis* spp. were reported in the Jordan River and surrounding areas as recently as 2004 (BLM/USU BugLab data). If live *F. coloradoensis* and *Pyrgulopsis* spp. were found in the Jordan River in BLM/USU BugLab surveys then additional intensive surveys should be conducted as soon as possible in those locations to help verify their status in the Jordan River.

Live *Fluminicola coloradoensis* and *Pyrgulopsis* spp. were found in the spring fed tributaries of the Jordan River and on occasion were relatively abundant. These tributaries were: an unnamed series of springs along the west side of the Narrows and the South Jordan Canal (Figure 25), Bingham Creek, and others. The largest spring creek, Bingham Creek, flows through the Jordan Valley Water Conservation District (Figure 34) and had the highest abundances of *F. coloradoensis* in the survey. Upstream and downstream of JVVCD property, Bingham Creek is heavily impaired by construction and urbanization and downstream it becomes mixed with degraded canal return water before it enters the Jordan River (Figure 35 and Figure 36). It is surprising that native non-pulmonates survive in downstream sections of Bingham Creek.



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Figure 29. Empty shells of the prosobranch snail, *Fluminicola coloradoensis* from the Jordan River.



Figure 30. Empty shells of the prosobranch snail, *Fluminicola coloradoensis* from the Jordan River. Scale lines are 1 mm.



Figure 31. Empty shells of the prosobranch snails, *Pyrgulopsis* spp., and *Fluminicola coloradoensis* and heterobranch *Valvata* spp. from the Jordan River. Scale lines are 1 mm.



Figure 32. Two empty shells of the prosobranch snail, *Pyrgulopsis* spp., and the invasive New Zealand mudsnail, *Potamopyrgus antipodarum* from the Jordan River. Scale lines are 1 mm. Many snail taxa are somewhat difficult to distinguish using shell morphology and often require a malacological expert in the field.



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Figure 33. Empty shells of two species of the heterobranch snail, *Valvata humeralis* (smooth shell) and *V. utahensis* (ridged shell) found in the Jordan River and its spring tributaries. Scale lines are 1 mm.



Figure 34. Bingham Creek upstream of construction site on the Jordan Valley Water Conservation District property, October 2014. These are typical attainable, stable, conditions of relatively healthy spring creeks in the Jordan River drainage.



Figure 35. All too common construction impacting spring creek tributaries of the Jordan River, UT. This location at the Jordan Valley Water Conservation District property was photographed October 2014.



Figure 36. Bingham Creek downstream of several construction sites and after canal return flows as it enters the Jordan River, October 2014. These are typical conditions of the spring creeks during construction and after heavy rains in the Jordan River drainage.

Pulmonate Snails

Although not the focus of this report, several pulmonate snail taxa shells were found in the springs and the Jordan River including, two Physids, two Lymnaeids, and several Planorbidae taxa. Taxonomic identification of pulmonate snails continues. Two live pulmonate taxa were found in the springs and Jordan River; *Physa* sp. and a planorbid taxon. These two live taxa were collected within shoreline vegetation or slow backwater channels, their preferred habitat.

Invasive species

New Zealand mudsnails (NZMS)(Figure 37 and Figure 32) and Asiatic clams occurred in almost all kick samples and at all sites. *Corbicula* sp. was extremely abundant at the downstream site near 1700 South (Figure 38). NZMS were extremely abundant at the JWCD spring creek site and estimated to be at densities far greater than 100,000/m² (Figure 37).



Figure 37. Live invasive NZMS and native Physid snails from a quick dip net scoop in aquatic vegetation and estimated at $>> 100,000/m^2$ in Bingham Spring Creek as it flows through the Jordan Valley Water Conservation District property.



Figure 38. Clamming on the Jordan River at 1700 South. *Corbicula* sp. at extreme high densities. This is also the location of the muskrat midden shown in the appendices.

DISCUSSION AND CONCLUSION

The Great Basin including GSL tributaries such as the Jordan River and Utah Lake historically were western USA native freshwater mollusk diversity ‘hotspots’ and part of Utah’s unique biotic heritage. However, it now appears that native Unionidea mussels and non-pulmonate snails no longer occur in the Jordan River and Utah Lake, or they occur at such extremely low densities and in isolated locations so as to be almost non-detectable. Isolated populations may occur in sections of the Jordan River in very limited areas where spring creeks enter the Jordan River or spring upwelling occurs for a few short meters downstream in the river. As discussed throughout the report, conditions other than ammonia likely contribute to their absence.

The absence of live Unionidea mussels and non-pulmonate snails is consistent with the designation of the Jordan River downstream of the “Narrows” as a warm water fishery (many of the focal taxa surveyed prefer cold water) and it is unlikely that these taxa can survive under present conditions. Empty native mussel and non-pulmonate snail shells in the Jordan River are likely from tributary flushing and depositing in the benthos or from extinct populations. More pollution tolerant pulmonate snails (e.g. *Physa* sp.) occur throughout the Jordan River, typically in the slower, shoreline, vegetated sections.

Spring seeps and creeks that enter the Jordan River are now critical habitat for remaining non-pulmonate snail taxa; *Fluminicola coloradoensis*, *Pyrgulopsis* spp., and *Valvata* spp. They may also be the last best available habitat for any future reintroduction programs. Unfortunately, these spring creeks also now act as nurseries for the invasive NZMS and often *Corbicula*. Spring seeps and creeks in the Jordan River system are in dire need of special protection and management and ammonia criteria should be developed specifically for these habitats.

Mollusk presence can be defined in numerous ways (EPA 2013). Mollusk presence in this survey was defined as existence of live mollusks, recently dead mollusk shells, unweathered shells, and/or valid presence data from recent surveys. Defining mollusk absence however, was not as clear-cut. Observed mollusk absence could have been due to many factors including: mollusks were extremely rare or uncommon, not visually observing mollusks when using aquascopes or other sampling methods (i.e. sampling error), or mollusks were truly absent. The combination of reconnaissance and qualitative surveys using an experienced field malacologist encompassed enough area and duration to demonstrate a reasonable probability of target mollusk absence, particularly in the site-specific survey locations. Because concluding true absence of target mollusks is not possible without examining the entire substrate of the Jordan River (or Utah Lake), the development of eDNA sampling methods as an additional line of evidence will strongly improve a conclusion of target mollusk absence (see Appendix 24. DNA Barcoding).

Reasons for the absence of native Unionidea mussels and non-prosobranch snails in the Jordan River likely include a combination of the following:

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- High sediment loads, particularly clay/silt.
- Intensive and extensive urbanization, industrialization, and agriculture impacts, including dewatering and channelization of Jordan River.
- Water quality impairment.
- High densities of the invasive *Corbicula* clam limited available native bivalve habitat (for other impacts of *Corbicula* see Appendix 23).
- Absence of native fish hosts for native larval mussel glochidia. Very low fish abundances of any species other than carp in Jordan River.
- Recent high flows (e.g. 2011) in the highly channelized Jordan River may have covered any remaining mussel habitat and may have removed mussels.
- Rapidly recolonizing *Corbicula* can quickly become established in remaining suitable habitats after recent high flows and can preclude any reestablishment by any remaining native mussels.
- Historically there was a trout pond on Mill Pond, Utah County and native mussels may have been associated with these activities. Spring Creek, which flows into and out of Mill Pond, also could have had thriving populations of introduced native mussels when its flows were stable and water quality and habitat were less impaired.
- Two of the most highly invasive mollusk taxa now dominate the benthic assemblage in the Jordan River and probably Utah Lake: NZMS and *Corbicula*. These taxa are likely altering the nitrogen cycle in this system, including ammonia (see Appendix 23). For example, Hall et al. (2006) showed that NZMS production could far outweigh that of native taxa with production estimates among the highest ever reported in the literature for a single species of freshwater macroinvertebrate. NZMS can also dominate carbon and nitrogen cycling, where they can consume up to 75% of gross primary production and excrete two-thirds of total ecosystem ammonium demand (Hall et al. 2003). Welker and Walz (1998) and Vaughn et al. (unpublished data) have found that the volume of water filtered by freshwater bivalves (e.g. *Corbicula*) within dense beds can equal or exceed daily stream discharge. In fact, Strayer et al. (1999) and Dame (1996) have suggested that **any** assemblage of bivalves may significantly influence phytoplankton concentrations when filtration rates are large relative to food supply.

RECOMMENDATIONS

The following recommendations can help support the conclusion that native mussels and non-pulmonate snails no longer exist in the Jordan River and Utah Lake:

- Expand the mollusk survey area and revisit Jordan River sites that the BLM/USU BugLab reported as having live *Fluminicola* and *Pyrgulopsis* in 2004. Snail population abundances can fluctuate yearly and may naturally have greater abundances in the future and therefore may be more detectable.
- Increase mollusk sampling efforts in Utah Lake.

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- Develop and add eDNA sampling methods to the program.

In addition, ammonia criteria need to be recalculated to take the absence of native target mollusks into account and finally, spring seeps and spring creek tributaries of the Jordan River and Utah Lake need special protection, regulations, and management to maintain healthy populations of native mollusks in Utah that are rapidly being lost.

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APPENDICES

Appendix 1. Photos of Mollusk Survey Sites.



Appendix 1. Jordan River “Narrows” section. Furthest upstream site surveyed on Jordan River.



Appendix 2. Side channels of Jordan River were also surveyed.



Appendix 3. Spring creek tributary of Jordan River. No native unionid mussels were found in these tributaries but live non-pulmonate snails, primarily *Fluminicola coloradoensis* and *Pyrgulopsis* sp., were common and empty shells were abundant.



Appendix 4. Typical channelization of Jordan River. Channelization and associated dredging is not conducive to native unionid mussel population viability.



Appendix 5. Mill Creek upstream of CVWTF and Jordan River.



Appendix 6. Many downstream sections of the Jordan River have substrates of mostly silt, sand, clay, and organic matter.



Appendix 7. Muskrat midden of invasive clam, *Corbicula fluminea*. No native unionids were found in this midden.



Appendix 8. Jordan River bank stabilization rip rap.



Appendix 9. Mollusk surveyor examining Jordan River substrate.



Appendix 10. Typical upstream section of Jordan River. Mostly gravel and sand substrate. Very good *Corbicula* habitat.



Appendix 11. Mollusk surveyor positioning aquascope for visualizing substrate and mollusks.



Appendix 12. Common Jordan River habitat. Side bars were visually examined for mollusk shells.



Appendix 13. Large Jordan River sidebar that was extensively examined for mollusk shells (mostly *Corbicula* shells were found).



Appendix 14. Mollusk surveyor preparing to use aquascope along channelized section of Jordan River.



Appendix 15. Shoreline of Mill Pond, Utah County. Several *Anodonta* shells were collected about 50 meters from this site. Thousands of *Corbicula* shells were observed along shores of Mill Pond.



Appendix 16. Mill Pond, Utah County.



Appendix 17. Outlet of Mill Pond, Utah County.



Appendix 18. Spring Creek, upstream of Mill Pond, Utah County.



Appendix 19. Spring Creek downstream of Mill Pond where *Anodonta* shells were collected amidst the hundreds of *Corbicula*.



Appendix 20. Complete *Anodonta* shell found in Spring Creek, Utah County. No other complete *Anodonta* shells were collected and this may be the last of the population. Further surveys at this site are strongly recommended.

Appendix 21. List of freshwater mollusks known to occur or have been extirpated in Utah and their current status. Status and rank descriptions are below table (taxa list from Oliver and Bosworth 1999).

	Family	Species	AFS common name	AFS status ¹	G-rank ²	UT Status ³
Bivalves (mussels and clams)						
	Margaritiferidae	<i>Margaritifera falcata</i>	western pearlshell	?	G4	S1
	Unionidae	<i>Anodonta californiensis</i>	California floater	?	G3	S2
	Unionidae	<i>Anodonta nuttalliana</i>	winged floater	?	G4	?
	Unionidae	<i>Anodonta oregonensis</i>	Oregon floater	?	G5	?
	Unionidae	<i>Gonidea angulata</i>	Western ridged mussel	?	G3	?
	Sphaeriidae	To be completed at a later time	fingernail clams	?	?	?
Gastropods (snails)						
<i>Non-pulmonates (gilled)</i>	Hydrobiidae	<i>Amnicola limosus</i> (Say, 1817)	Mud Amnicola	CS	G5	R, I, RE
	Hydrobiidae	<i>Colligyrus greggi</i> (Pilsbry, 1935)	Rocky Mountain Dusky Snail	CS	G4	R, I, RE
	Hydrobiidae	<i>Tryonia porrecta</i> (Mighels, 1845)	Desert Tryonia	V	G3	R, I, RE
	Hydrobiidae	<i>Pyrgulopsis anguina</i> Hershler, 1998	Longitudinal Gland Pyrg	E	G1	R, I, RE
	Hydrobiidae	<i>Pyrgulopsis chamberlini</i> Hershler, 1998	Smooth Glenwood Pyrg	E	G1	R, I, RE
	Hydrobiidae	<i>Pyrgulopsis deserta</i> (Pilsbry, 1916)	Desert Springsnail	T	G2	R, I, RE
	Hydrobiidae	<i>Pyrgulopsis fusca</i> Hershler, 1998	Otter Creek Pyrg	E	G1	R, I, RE
	Hydrobiidae	<i>Pyrgulopsis hamlinensis</i> Hershler, 1998	Hamlin Valley Pyrg	E	G1	R, I, RE
	Hydrobiidae	<i>Pyrgulopsis inopinata</i> Hershler, 1998	Carinate Glenwood Pyrg	E	G1	R, I, RE
	Hydrobiidae	<i>Pyrgulopsis kolobensis</i> (Taylor, 1987)	Toquerville Springsnail	CS	G5	?
	Hydrobiidae	<i>Pyrgulopsis nonaria</i> Hershler, 1998	Ninemile Pyrg	E	G1	R, I, RE
	Hydrobiidae	<i>Pyrgulopsis peculiaris</i> Hershler, 1998	Bifid Duct Pyrg	T	G2	?
	Hydrobiidae	<i>Pyrgulopsis pilsbryana</i> (Bailey and Bailey, 1952)	Bear Lake Springsnail	T	G2	R, I, RE
	Hydrobiidae	<i>Pyrgulopsis plicata</i> Hershler, 1998	Black Canyon Pyrg	E	G1	R, I, RE

	Hydrobiidae	<i>Pyrgulopsis saxatilis</i> Hershler, 1998	Sub-globose Snake Pyrg	E	G1	R, I, RE
	Hydrobiidae	<i>Pyrgulopsis variegata</i> Hershler, 1998	Northwest Bonneville Pyrg	T	G2	R, I, RE
	Hydrobiidae	<i>Pyrgulopsis transversa</i>	southern Bonneville springsnail	?	?	R, I, RE
	Hydrobiidae	<i>Fluminicola coloradoensis</i> Morrison, 1940	Green River pebblesnail	T	G2G3	R, I, RE
	Valvatidae	<i>Valvata humeralis</i> Say, 1829	Glossy <i>Valvata</i>	CS	G5Q	R, I, RE
	Valvatidae	<i>Valvata tricarinata</i> (Say, 1817)	<i>Threeridge Valvata</i>	CS	G5	?
	Valvatidae	<i>Valvata utahensis</i> Call, 1884	Desert <i>Valvata</i>	E	G1	R, I, RE
<i>Pulmonates</i> (lunged)	Ancylidae	<i>Ferrissia rivularis</i>	creeping ancylid	?	?	R, I, RE
	Lymnaeidae	<i>Fisherola nuttalli</i> (Haldeman, 1841)	Shortface Lanx	T	G2	?
	Lymnaeidae	<i>Galba bulimoides</i> (Lea, 1841)	Prairie Fossaria	CS	G5	R, I, RE
	Lymnaeidae	<i>Galba dalli</i> (Baker, 1907)	Dusky Fossaria	CS	G5	?
	Lymnaeidae	<i>Galba modicella</i> (Say, 1825)	Rock Fossaria	CS	G5	?
	Lymnaeidae	<i>Galba obrussa</i> (Say, 1825)	Golden Fossaria	CS	G5	?
	Lymnaeidae	<i>Galba parva</i> (Lea, 1841)	Pygmy Fossaria	CS	G5	R, I, RE
	Lymnaeidae	<i>Galba rustica</i> (Lea, 1841)	Rusty Fossaria	CS	G5Q	?
	Lymnaeidae	<i>Galba techella</i> Haldeman, 1867	[uncertain classification]	V	G3G4Q	R, I, RE
	Lymnaeidae	<i>Stagnicola apicina</i> (Lea, 1838)	Abbreviate Pondsnaill	CS	G5	?
	Lymnaeidae	<i>Stagnicola bonnevillensis</i> (Call, 1884)	Fat-Whorled Pondsnaill	E	G1	R, I, RE
	Lymnaeidae	<i>Stagnicola caperata</i> (Say, 1829)	Wrinkled Marshsnaill	CS	G5	?
	Lymnaeidae	<i>Stagnicola elodes</i> (Say, 1821)	Marsh Pondsnaill	CS	G5	?
	Lymnaeidae	<i>Stagnicola montanensis</i> (Baker, 1913)	Mountain Marshsnaill	V	G3	R, I, RE
	Lymnaeidae	<i>Stagnicola pilsbryi</i> (Hemphill, 1890)	Fish Springs Marshsnaill	X	GX	R, I, RE
	Lymnaeidae	<i>Stagnicola traski</i> (Tryon, 1863)	Widelip Pondsnaill	V	G3	R, I, RE
	Lymnaeidae	<i>Stagnicola utahensis</i> (Call, 1884)	Thickshell Pondsnaill	X	GX	R, I, RE
	Physidae	<i>Aplexa elongata</i>	lance aplexa	CS	G5	R, I, RE
	Physidae	<i>Physa megalochlamys</i> Taylor, 1988	Cloaked <i>Physa</i>	V	G3	R, I, RE
	Physidae	<i>Physa skinneri</i> Taylor, 1954	Glass <i>Physa</i>	CS	G5	R, I, RE

	Physidae	<i>Physella cooperi</i> (Tryon, 1865)	Olive Physa	V	G3	?
	Physidae	<i>Physella gyrina</i> (Say, 1821)	Tadpole Physa	CS	G5	?
	Physidae	<i>Physella lordi</i> (Baird, 1863)	Twisted Physa	CS	G5Q	?
	Physidae	<i>Physella microstriata</i> (Chamberlain and Berry, 1930)	Fish Lake Physa	X	GX	R, I, RE
	Physidae	<i>Physella propinqua</i> (Tryon, 1865)	Rocky Mountain Physa	CS	G5Q	?
	Physidae	<i>Physella utahensis</i> (Clench, 1925)	Utah Physa	T	G2Q	R, I, RE
	Physidae	<i>Physella virgata</i> (Gould, 1855)	Protean Physa	CS	G5Q	R, I, RE
	Physidae	<i>Physella zionis</i> (Pilsbry, 1926)	Wet-rock Physa	E	G1	R, I, RE
	Planorbidae	<i>Ferrissia rivularis</i> (Say, 1817)	Creeping Ancyloid	CS	G5	?
	Planorbidae	<i>Gyraulus circumstriatus</i> (Tryon, 1866)	Disc Gyro	CS	G5	?
	Planorbidae	<i>Gyraulus parvus</i> (Say, 1817)	Ash Gyro	CS	G5	?
	Planorbidae	<i>Helisoma newberryi</i> (Lea, 1858)	Great Basin Ramshorn	E	G1Q	R, I, RE
	Planorbidae	<i>Menetus opercularis</i> (Gould, 1847)	Button Sprite	CS	G5	?
	Planorbidae	<i>Planorbella binneyi</i> (Tryon, 1867)	Coarse Ramshorn	CS	G4G5Q	R, I, RE
	Planorbidae	<i>Planorbella oregonensis</i> (Tryon, 1865)	Lamb Ramshorn	E	G1	R, I, RE
	Planorbidae	<i>Planorbella subcrenata</i> (Carpenter, 1857)	Rough Ramshorn	CS	G5	?
	Planorbidae	<i>Planorbella tenuis</i> (Dunker, 1850)	Mexican Ramshorn	CS	G5	?
	Planorbidae	<i>Planorbella trivolvis</i> (Say, 1817)	Marsh Ramshorn	CS	G5	?
	Planorbidae	<i>Promenetus exacuous</i> (Say, 1821)	Sharp Sprite	CS	G5	R, I, RE
	Planorbidae	<i>Promenetus umbilicatellus</i> (Cockerell, 1887)	Umbilicate Sprite	CS	G4	?
Invasive Species						
Bivalves	Corbiculidae	<i>Corbicula fluminea</i>	Asiatic clam			
Gastropod	Hydrobiidae	<i>Potamopyrgus antipodarum</i>	New Zealand Mudsnailed			

¹The following listing criteria were adopted from previous AFS lists (Taylor et al. 2007; Jelks et al. 2008). Status categories were developed by the AFS Endangered Species Committee.

Endangered (E): A species that is in imminent danger of extinction.

Threatened (T): A species that is imminently likely to become endangered throughout all or a significant portion of its range.

Vulnerable (V): A species that is imminently likely to become threatened throughout all or a significant portion of its range; equivalent to “Special Concern” as designated by Deacon et al. (1979) and Williams et al. (1989).

Currently Stable (CS): Species populations not currently at risk.

Extinct (X): A taxon for which no living individual has been documented in nature for 50 or more years despite repeated efforts to do so.

Possibly Extinct (Xp): A taxon that is suspected to be extinct as indicated by more than 20 but less than 50 years since last observed in nature.

Unknown (U): A taxon in which the conservation or taxonomic status is unknown.

²To facilitate direct comparisons with state natural heritage programs and Canadian conservation data centers, G-ranks, as developed by The Nature Conservancy and NatureServe (Master et al. 2009), were also included. This system ranks taxa on a scale from 1 to 5 based on estimated number of population occurrences, as follows:

G1 = critically imperiled (at very high risk of extinction or elimination due to extreme rarity, very steep declines, or other factors)

G2 = imperiled (at high risk of extinction or elimination due to very restricted range, very few populations or occurrences, steep declines, or other factors)

G3 = vulnerable (at moderate risk of extinction or elimination due to a restricted range, relatively few populations or occurrences, recent and widespread declines, or other factors)

G4 = apparently secure (uncommon but not rare; some cause for long-term concern due to declines or other factors)

G5 = secure (common; widespread and abundant)

GX = presumed extinct (not located despite intensive searches and virtually no likelihood of rediscovery)

GH = possibly extinct (known from historical occurrences but still some hope of rediscovery)

GU = Unable to assign rank due to taxonomic uncertainty or incomplete distributional information (Master et al. 2009)

Both the AFS and G-rank criteria are based on occurrence data and status evaluation is independent of geopolitical boundaries. However, this review does not utilize the same formal criteria required to list a species under the U.S. Endangered Species Act of 1973. A species may be rare because of a naturally restricted range but may not qualify for protection under the Endangered Species Act if specific threats to its continued existence are not imminent.

Oliver and Bosworth 1999 Utah Status

R=rare

I=imperiled

RE=recently extinct or extirpated

Appendix 22 Variability in Species Mean Acute Value (SMAV) in the Family Unionidae (pearly mussels). Derived from Table 3 (USEPA 2013). Mussels within the genus *Lampsilis* are highlighted in blue.

FAMILY	Common Name	Species	Rank	GMAV (mg TAN/L)	SMAV (mg TAN/L)
Unionidae	Ellipse,	<i>Venustaconcha ellipsiformis</i>	1	23.12	23.12
Unionidae	Green floater,	<i>Lasmigona subviridis</i>	2	23.41	23.41
Unionidae	Pink mucket,	<i>Lampsilis abrupta</i> (LS)	5	46.63	26.03
Unionidae	Oyster mussel,	<i>Epioblasma capsaeformis</i> (LS)	3	31.14	31.14
Unionidae	Rainbow mussel,	<i>Villosa iris</i>	4	34.23	34.23
Unionidae	Higgin's eye,	<i>Lampsilis higginsii</i> (LS)	5	46.63	41.9
Unionidae	Pondshell mussel,	<i>Utterbackia imbecillis</i>	6	46.93	46.93
Unionidae	Atlantic pigtoe,	<i>Fusconaia masoni</i>	7	47.4	47.4
Unionidae	Wavy-rayed lampmussel,	<i>Lampsilis fasciola</i>	5	46.63	48.11
Unionidae	Plain pocketbook,	<i>Lampsilis cardium</i>	5	46.63	50.51
Unionidae	Fatmucket,	<i>Lampsilis siliquoidea</i>	5	46.63	55.42
Unionide	Mucket,	<i>Actinonaias ligamentina</i>	15	71.25	63.89
Unionidae	Neosho mucket,	<i>Lampsilis rafinesqueana</i> (LS)	5	46.63	69.97
Unionidae	Giant floater mussel,	<i>Pyganodon grandis</i>	14	70.73	70.73
Unionide	Pheasantshell,	<i>Actinonaias pectorosa</i>	15	71.25	79.46
Unionide		<i>Alasmidonta heterodon</i> (LS)	29	109	109

Appendix 23. LITERATURE REVIEW: NATIVE BIVALVES AND INVASIVE CLAM, *CORBICULA* SP.

The following literature review was conducted in response to the high densities of the invasive Asian clam, *Corbicula* sp. that we found throughout the survey and its likely negative impacts on native mussels in the Jordan River. This review describes *Corbicula* sp. and native bivalve, biology, life history, ecology, and known and assumed impacts of *Corbicula* sp. on the natives.

Bivalve mollusks (clams and mussels) are dominant filter feeders that often make up most of the biomass and exert control over ecosystem structure and function of many streams (Dame, 1996; Strayer et al., 1999). Production by bivalves (range from 1 to 20 g

dry mass m^2 / year) can equal that of all other macrobenthos in many stream systems (Strayer et al., 1994) and can rival other highly productive systems such as tropical rainforests and kelp beds (Leigh et al., 1987). Aggregations (beds) of bivalves can also alter light, temperature, sediment loading and deposition, and water circulation patterns (Dame, 1996; Seed, 1996; Wildish & Kristmanson, 1997).

Bivalves remove particles from the water column, excrete nutrients, and biodeposit feces into the sediment layer. Filtration by bivalves has been shown to lead to a large decrease in phytoplankton and other particles in the water column (Kasprzak, 1986; Kryger and Riisgaard, 1988; Welker and Walz, 1998; Strayer et al., 1999) and has the greatest effects on ecological processes when their biomass is large (Strayer 1999). This is likely the case with *Corbicula* sp. in the Jordan River because their biomass can be quite large in sections of the river.

Welker and Walz (1998) and Vaughn et al. (unpublished data) have found that **the volume of water filtered by unionid mussels within dense beds can equal or exceed daily stream discharge**. Welker and Walz (1998) reported that filtration by unionids in the River Spree, Germany, caused 'biological oligotrophication' by decreasing phytoplankton biomass and total phosphorus, thus increasing water clarity. *Corbicula* sp. also has the ability to influence phytoplankton abundances and water clarity (Cohen et al., 1984; Phelps, 1994). In fact, Strayer et al. (1999) and Dame (1996) have suggested that any assemblage of bivalves may significantly influence phytoplankton concentrations when filtration rates are large relative to food supply.

Bivalves can filter and consume interstitial bacteria (Mitropolskij, 1966; Lopez & Holopainen, 1987, Say, 1829). Some species of native clams have elongated inhalant siphons to vacuum detrital particles from the streambed surface (Way 1989). Pedal feeding is another form of deposit feeding and has been observed for juvenile unionids. For example, during the first 18 months or so, juvenile *Margaritifera Margaritifera* (Unionidae) pedal feed by using cilia on their foot to move small particles into their mantle cavity. Most adult unionids do not pedal feed. Pedal feeding unionid juveniles have been shown to grow faster when able to feed in sediment as compared with filter feeding alone (Hudson and Isom, 1984; Yeager et al. 1994; Gatenby et al. 1996). *Corbicula* can both pedal and filter feed as adults (Reid et al., 1992) and can decrease sediment organic matter concentrations when very little planktonic food is available (Cleland, 1988; Hakenkamp and Palmer, 1999). Even though bivalves can filter the daily discharge of a stream, deposit feeding may provide a significant proportion of total food energy. For example, Raikow and Hamilton (2000) showed that unionids consumed 80% deposited and 20% suspended material.

Unionids in Lake St Clair (Nalepa et al., 1991) and a Polish lake (Lewandowski & Stanczykowska, 1975) filtered large quantities of seston much of which was which in turn biodeposited to the sediments. *Corbicula* is associated with significant increases in nearby sediment organic matter concentrations (Hakenkamp and Palmer, 1999) and has been shown to increase sediment concentrations by as much as 25 to 30% (Prokopovich, 1969). It is unknown how much sediment concentrations the *Corbicula* sp. population deposits in the Jordan River but it is likely to be significant.

Bivalves link surface water and benthic processes by filtering suspended particles from the water column and injecting the undigested material (feces) into the sediments (Newell 2004). Biodeposition can be an extremely important regulator of water column processes when bivalves occur at high densities and are actively feeding (Newell 2004). Thus, bivalves act as 'top-down' controls on phytoplankton and can reduce turbidity caused by phytoplankton (Newell 2004). Excreted nitrogen and phosphorus and regenerated from biodeposits can then be recycled back to the water column and support phytoplankton production (Newell 2004). Some of the original N and P that were excreted can become buried in the accumulating sediments. Coupled nitrification-denitrification can permanently remove N from the sediments as N₂ gas from the aerobic sediment layers that overlay deeper anaerobic sediments via microbial activity (Newell 2004). Bivalves can also reduce phytoplankton production by curbing anthropogenic N and P in eutrophied aquatic systems. However, biodeposition at very high bivalve densities may be so intense that resulting microbial respiration can reduce the oxygen content of the surrounding sediments and can inhibit coupled nitrification-denitrification (Newell 2004). This can cause P to become unbound and released to the water column, and result in a toxic buildup of H₂S (Newell 2004). This may occur in the Jordan River due to high densities of *Corbicula* sp.

Corbicula is usually assumed to be a non-selective feeder (Lauritsen, 1986; Way et al., 1990) and can physiologically adjust its filter-feeding rate in response to food availability and a wide range of particle concentrations (Way et al., 1990). Contrarily, many unionids are more selective in terms of the size of particles consumed (Newell 2004). Therefore, *Corbicula* would be less impacted than other bivalves when any one type of resource becomes limiting (Newell 2004). Not all bivalve species have similar feeding mechanisms and behavior and may use different food sources in different habitats (Newell 2004).

Freshwater bivalves produce hypo-osmotic urine, primarily NH₃ (Burton 1983). Williams and McMahon (1989) showed a 20 to 40-fold increase in NH₃ excretions during *Corbicula* spawning activity. Extremely high densities of *Corbicula* sp. in sections of the Jordan River may thus be a significant ammonia source, particularly when they are most

active, especially during spawning periods. *Corbicula* excretory products are also likely important and readily useable resources for phytoplankton by other organisms (James, 1987; Lauritsen and Mozley, 1989). In addition, Fisher & Matis (1985) found that bivalve burrowing activities can indirectly influence nutrient cycling by enhancing the rate of nitrate release in sediments. Phosphorus recycling by bivalves may be sufficient to shift the phytoplankton community structure towards nitrogen-limited cyanobacteria (Strayer 1999, Newell 2004).

Bivalves may serve as a nutrient source when their biomass is declining and when populations release more nutrients than they absorb (Strayer 1999, Newell 2004). Bivalves may serve as a nutrient sink while a population is growing (i.e. accumulating biomass) or if biomass is being lost from the ecosystem (Strayer 1999, Newell 2004).

***Corbicula* Life History**

Corbicula sp. burrow in the substratum and filter and deposit feed, however, they differ from unionids in many important ways (Vaughn and Hakenkamp 2001). *Corbicula* are less sedentary, shorter-lived (1 to 5 year), grow rapidly, mature earlier, reproduce two to three times per year, and disperse both actively and passively throughout their life cycle (Prezant and Chalermwat, 1984; McMahon, 1991). Like unionids, *Corbicula* often occurs in dense aggregations that can consist solely of *Corbicula* or be intermixed with native assemblages (Vaughn and Hakenkamp 2001). *Corbicula* biomass can far exceed that of all other benthic invertebrates in sandy streams (e.g. Jordan River)(Poff et al., 1993). *Corbicula* are typically smaller than unionid bivalves but have markedly greater mass-specific filtration rates (Kraemer, 1979; Mattice, 1979; McMahon, 1983) and typically higher abundances (Kraemer, 1979; McMahon, 1991). This results in community filtration rates that often exceed those of native bivalve assemblages (Strayer et al., 1999; Vaughn and Hakenkamp 2001).

Arguably, *Corbicula* sp. are the most invasive of all freshwater bivalves (McMahon 1999). As stated earlier, *Corbicula* are adapted for rapid population growth, including traits such as rapid individual growth, early maturity, short life spans, a limited number of reproductive periods, high fecundities, small egg-offspring size, and extensive dispersal capacity (McMahon 2002). Such traits are generally characteristic of r-selected species that are adapted to unstable habitats and where intraspecific competition is low or unlikely due to frequent population density reductions or extirpations associated with unpredictable, catastrophic, natural environmental events (Sibly and Calow 1986, McMahon 2002).

Corbicula sp. grows rapidly, in part because it has higher filtration and assimilation rates than other freshwater bivalve species (McMahon 2002). Only a relatively small proportion of its assimilation (29%) is devoted to respiration, the majority (71%) being

allocated to growth and reproduction. This species allocates a high proportion (85–95%) of non-respired assimilation to growth, allowing individuals to reach 15–30 mm in shell length in the first year of life and 35–50 mm in the terminal third to fourth year (McMahon 1999). Thus, *Corbicula* sp. has the highest net production efficiencies recorded for any freshwater bivalve, reflected by short turnover times of 73–91 days (McMahon 2002). Newly released juveniles of *Corbicula* sp. are small (shell length \approx 250 μ m) but completely formed, with a well developed bivalved shell, adductor muscles, foot, statocysts, gills, and digestive system (McMahon 2002).. They anchor to sediments or hard surfaces with a mucilaginous byssal thread but can be re-suspended in turbulent flows to be dispersed long distances downstream (McMahon 1999). A relatively low percentage of non-respired assimilation in *Corbicula* sp. is allocated to reproduction (5–15%, equivalent to that expended by unionoideans); however, its elevated assimilation rates allow higher absolute energy allocation to reproduction than in other freshwater bivalves (McMahon 2002). Fecundity is high, estimated at almost 70,000 juveniles on average per adult per year (Aldridge and McMahon 1978). Juvenile survivorship, while higher than that of unionoideans, is still low, and unlike unionoideans, mortality rates remain high throughout adult life (74–98% in the first year, 59–69% in the second year, and 93–97% in the third year of life) (McMahon 2002). Low adult survivorship leads to populations dominated by juveniles and immature individuals (McMahon 1999). Most North American *Corbicula* sp. populations have two annual reproductive periods (i.e., spring through early summer and late summer through early fall; McMahon 1999). *Corbicula fluminea* is hermaphroditic and self-fertilizing (Kraemer et al. 1986), allowing single individuals to found new populations. Maturation occurs within 3 to 6 months at a shell length of 6–10 mm, thus spring-born juveniles can participate in autumn reproduction (McMahon 2002). Maximum life span is highly variable, ranging from 1 to 4 years, within which early maturity and bivoltine reproduction allows individuals to participate in one to seven reproductive efforts (McMahon 2002).

Native Unionid Life History

The principle bivalve fauna of North American rivers and lakes are freshwater mussels of the order Unionoida (Families Unionidae and Margaritiferidae in the western USA) (McMahon 2002). In contrast to *Corbicula*, native unionid mussels are more K- selected. They tend to inhabit only infrequently disturbed aquatic habitats and achieve densities approaching the carrying capacity of the environment (McMahon 2002). This can result in extensive intra- and inter-specific competition for limited resources (McMahon 2002). Native unionid life-history traits associated with stable habitats include: slow individual growth rates, delayed maturity (6 to 12 years), grow rapidly to maturity and, thereafter, grow slowly, have extremely low juvenile survivorship but high adult survivorship, long life spans (6 to >100 years), low fecundity, extensive iteroparity (multiple reproductive cycles over lifetime), large egg–offspring size (glochidia), and limited capacity for

dispersal (Sibly and Calow 1986, McMahon 2002). Native unionids typically have one reproductive period per year, and tend to allocate high proportions of non-respired assimilated energy (85.2–97.5%) to growth and low proportions to reproduction (2.8–14.8%) (McMahon and Bogan 2001). Low juvenile survival and low adult growth rates lead to low population productivity, reflected in extended turnover times (i.e., time in days for population production to produce the equivalent of mean population standing crop biomass) of 1790–2849 days (McMahon 2002). High adult survival, long life spans, and low juvenile survival result in domination of unionoidean populations by adults relative to juveniles (Sibly and Calow 1986). Their slow population growth prevents rapid population recovery after extirpation or reduction by catastrophic environmental disturbance and there is likely strong selection pressure for unionid development of extensive resistance to environmental extremes (McMahon 2002).

Unionoideans deviate from the life-history traits expected of species adapted to stable habitats in that females produce every large numbers (200,000 – 17,000,000) of small young (size = 50–450 μ m) (McMahon 2002).. Females retain eggs in marsupial chambers within the exhalant water channels of their outer gills where they are fertilized by sperm carried to the inhalant currents (McMahon 2002).. After fertilization, eggs develop into a small, externally released, bivalved larva called a glochidium (plural = glochidia)(McMahon and Bogan 2001). The glochidium is parasitic on specific fish hosts, encysting in their fins or gills for periods of less than 200 days to more than 1000 days depending on species, allowing dispersal and growth to a more competitive size before excystment as a free-living juvenile (Bauer1994). Thus, elevated fecundity and small offspring size in unionoideans are adaptations that ensure a sufficiently high probability of glochidial contact with appropriate fish hosts to maintain adequate juvenile recruitment (McMahon and Bogan 2001). Low success of glochidial host-fish contact, high levels of host-fish immune rejection of encysted glochidia, and host-fish mortality before excystment of the transformed juvenile allow only a tiny fraction of released glochidia to transform into relatively large well-developed juveniles (McMahon 2002). Thus, the effective fecundity of unionoidean species is quite low and leads to production of a few, large, well-developed offspring (i.e., excysted juveniles), a characteristic of K - selected species from stable habitats (Sibly and Calow 1986).

Unionoid species' specific glochidial host-fish species are often closely associated with their preferred adult habitat (McMahon and Bogan 2001), increasing chances for excystment of juveniles into habitats favorable for survival to maturity. However, utilization of fish hosts associated with habitat of the adult reduces chances for long-distance juvenile dispersal. Limited dispersal capacity is hypothesized to have resulted in high levels of diversity and endemism within the North American unionid fauna (McMahon and Bogan 2001).

Extended life spans, delayed maturity, low effective fecundities, reduced powers of dispersal, high habitat selectivity, poor juvenile survival, and long turnover times make unionoidean populations highly susceptible to human perturbations (Strayer et al. 1999; McMahon and Bogan 2001, McMahon 2002). These unionoidean life-history traits (particularly long life spans and low effective fecundities) slow population recovery from human- or naturally mediated habitat disturbances (Strayer et al. 1999; McMahon and Bogan 2001, McMahon 2002).

Effects of *Corbicula* on Native Bivalves

The invasive *Corbicula* are assumed to have negatively impacted native bivalve abundance and diversity throughout North America (Gardner et al., 1976; Taylor and Hughart, 1981; Clarke, 1988) and has the potential to affect native unionids in several ways (Vaughn and Hakenkamp 2001). *Corbicula* has been accused of greater impacts on the native bivalves of North America than any invader other than the zebra mussel (Strayer 1999). At very high density the burrowing activity of *Corbicula* may uproot unionids in sandy sediments (Fuller & Richardson, 1977). *Corbicula* may also suspension and deposit feed on juvenile unionids, which may negatively impact juvenile unionid recruitment (Yeager et al., 1994; Vaughn and Hakenkamp 2001). Strayer (1999) suggested that *Corbicula* may compete for benthic food resources with sphaeriids (native fingernail clams) and juvenile unionids, and that bioturbation by *Corbicula* could reduce available habitat. *Corbicula* also have much greater filtration rates (on a per biomass basis) than sphaeriids or unionids (McMahon, 1991) and thus have the potential to limit availability of planktonic food to native bivalves (Vaughn and Hakenkamp 2001). *Corbicula* allocate a higher percentage of non-respired energy to somatic growth than unionids (McMahon, 1991) and with their ability to deposit feed have broader diet breadths than is known for unionids (Vaughn and Hakenkamp 2001) particularly when there is little food available in the water column or when flow conditions make suspension feeding difficult (e.g. during floods) than is known for unionids (Vaughn and Hakenkamp 2001). Deposit feeding by *Corbicula* is likely to have contributed to their invasion success, especially in streams with smaller sediment sizes (e.g. sandy streams) that would allow easy burrowing and feeding (Vaughn and Hakenkamp 2001).

In North America, *Corbicula* sp. is a self-fertilizing simultaneous hermaphrodite. Eggs are fertilized internally, and developing larvae are held in the parent's gills through early development and then released as tiny (0.25-mm long) benthic juveniles. Juveniles are produced in large numbers (103-105 adult⁻¹ y⁻¹). Animals may reach maturity in as little as 3 to 6 mo, and may live for 1 to 4 y, spawning once or twice a year. This life history contributes to *Corbicula*'s success as an invader, and is well suited to the disturbed habitats often frequent-ed by *Corbicula*. Populations of *Corbicula* may grow very

rapidly, and are prone to rapid die-offs following reproduction (e.g., Aldridge and McMahon 1978, McMahon and Williams 1986), sudden changes in water temperature, or low dissolved oxygen (McMahon and Williams 1986, Sickel 1986). *Corbicula* may filter feed on suspended particles or pedal feed on particles of food in the sediments thereby starving native bivalves. Modest to dramatic declines in phytoplankton or seston have been seen in heavily infested habitats (Cohen et al. 1984, Lauritsen 1986, Leff et al. 1990, Phelps 1994). Because *Corbicula* pedal feeds on edible particles in the sediments, it may also deplete this food resource, affecting some sphaeriids and juvenile unionids that use benthic organic matter as food (Neves 1993). Dense populations of *Corbicula* may ingest large numbers of unionid sperm, glochidia, and newly metamorphosed juveniles. *Corbicula* actively disturbs sediments, so dense populations may reduce habitable space for native bivalves, especially sphaeriids and juvenile unionids. In addition, periodic die-offs of *Corbicula* populations may produce enough ammonia and consume enough oxygen to kill native bivalves.

Stronger evidence of negative effects of *Corbicula* on native mussels is provided by temporal changes in native bivalve populations that coincide with the arrival of *Corbicula*. Gardner et al. (1976) found precipitous declines in populations of native bivalves that coincided exactly with the explosive growth of a *Corbicula* population in the Altamaha River, Georgia. On the other hand, dense populations of *Corbicula* and unionids often coexist at many sites (Clarke 1988, Miller and Payne 1994), suggesting that *Corbicula* does not necessarily extirpate native bivalves. Nevertheless, because unionids have long life cycles, declines in recruitment or growth may not be apparent for years or even decades. It is impossible to rule out the possibility of strong interactions, even in cases of co-existence, without at least detailed information on the density and recruitment of native bivalve populations before and after the *Corbicula* invasion.

If bivalves perform similar ecological processes at similar rates (i.e. they are 'functionally redundant' sensu Walker, 1992), these mass extinctions may make little difference in an ecosystem context, as long as the overall bivalve biomass is maintained. If species play distinct roles, however, this loss of biodiversity may permanently alter ecosystem functioning. In many rivers *Corbicula* biomass may replace, or compensate for, lost unionid biomass. If *Corbicula* functions in a manner similar to unionids, then the decline in bivalve biodiversity may have little impact on the functional roles of mollusks in these systems. However it is more likely that these taxa have distinct role and functions. Therefore, multispecies assemblages should be maintained to protect ecosystem health and functioning. While unionids and *Corbicula* share many functional roles, differences in the range of processes and the rates at which these processes are performed may be leading to a dramatic shift in the current functional role of burrowing bivalves in some freshwater ecosystems (Vaughn and Hakenkamp 2001). In the case of the highly

perturbed Jordan River, *Corbicula* appears to be the competitive dominant and conditions may not be suitable for native unionids to exist at this time.

Appendix 24. DNA Barcoding

Suggested Method

There is an increased emphasis on using genetic bar coding (species-specific DNA fingerprints), including using environmental sampling (i.e. eDNA) in taxonomic surveys. Barcoding is particularly useful for taxa that are rare and uncommon, cryptic, or spatially clustered. Indeed, genetic bar coding is one of the most promising developments in species sampling methods this century and is rapidly becoming the method of choice, when appropriate. Genetic bar coding analyses can result in a presence/absence detection signal or relative DNA composition of a given sample. Current leading laboratory instrumentation allows for concentrations of a dynamic number of bar codes (from 24 up to 96 species) to be simultaneously tested for within samples. Additionally, if standard dose curves have been developed for target species, the proportion of total DNA represented by each species at time of collection can be quantified.

One of the most important contributions of genetic bar coding in ecological assessment programs is the cost of processing samples. Once a genetic bar code database has been established from relevant species type specimens, **sample processing costs can be reduced by as much as twenty times** using molecular methods. This improvement in data generation efficiency will allow managers to collect greater than twenty times more samples (e.g., temporal or geographic expansion) for the same budget, vastly increasing the power of their studies. Alternatively, projects could be completed using standard metrics at a fraction of typical times and budgets.

The first step is to generate a taxonomic and distribution list of all known mollusks in UT by compiling available literature and data sets (e.g., NatureServe©), consultation with mollusk experts and researchers, and examination of museum specimens. A complete search of the Barcode of Life data base (BOLD) and the National Center for Biological Information (NCBI) nucleotide data base for the mitochondrial genes COI (the “universal barcode gene”) and Cytochrome B (CytB) should be conducted to retrieve published and publically available DNA sequences for all species on the list. The database search will reveal: 1) which species have been barcoded and 2) which target species need to be DNA barcoded.

- 1) For the species that have publically available DNA sequences for the mitochondrial genes COI (the “universal barcode gene”) and Cytochrome B (CytB) the sequences should be downloaded and saved for future comparison to all target species.

- 2) DNA barcodes will be determined for target species for which there are no publically available DNA sequence data.

For each of these species a minimum of 5- 10 vouchered individuals from across the broadest portion of their range and within the area of proposed monitoring should be collected and used for barcoding. Sequence data for the mitochondrial genes COI and CYTB will be generated for each of the 5-10 individuals for all species. The DNA sequences generated will be used for future comparison to all target species. COI and CytB sequence data will be compiled and cross-referenced to identify short (~100-400bp) nucleotides unique to each species. Additionally the species specific nucleotides will be compared to all published nucleotide sequences using NCBI GENBANK nucleotide Basic Local Alignment Software Tool (BLAST) or what is more commonly referred to as a nucleotide BLAST. The BLAST will ensure that all nucleotides for both COI and CytB are specific not only when compared to those species that are closely related and co-existing on the taxonomic list but unique when compared to all published nucleotide sequences for all species.

Assay Design and Validation

The COI and CytB nucleotide sequences identified as unique to each species will be used to generate species specific Quantitative Polymerase Chain Reaction (qPCR) assays using commercially available software and algorithms. QPCR is a commonly used technique in molecular biology that enables both detection and quantification for one or more specific DNA sequences in a sample. The qPCR assay is both extremely specific and sensitive. All assays will be validated for specificity and sensitivity to ensure that each assay does not cross- react with other closely related co-existing species. Only after each assay has been validated will it be used to identify the DNA from control and field samples. While individual qPCR assays are ideal for species-specific detection, our goal is to produce a high throughput qPCR method for the simultaneous identification of all our target species. To accomplish this we will use the Fluidigm® BioMark™ microfluidic chip platform. Using qPCR assays on the BioMark chip will allow us to simultaneously detect the presence of DNA from as few as 24 up to 96 unique species within as many as 124 samples within hours. The BioMark microfluidic chip platform is dynamic and can be adapted to meet sampling requirements as needed. In other words, depending on which species are being targeted, species-specific assays can be alternated on the BioMark. The dynamic nature of the BioMark platform will give us the capability to create chips that are regionally and even project specific.

Field and Laboratory Taxonomic Work for Mollusks not already DNA Barcoded

In the field collect mollusks using the most appropriate sampling method (e.g., kick nets, Hess or Surber samplers, snorkeling, aquascopes, etc.). Mollusks will be hand picked from samples and several specimens of each species will immediately be placed into chilled mentholated water for 24 hours and allowed to empty their gut contents and to relax before preservation. Relaxed individuals of some species are often needed for

proper taxonomic identification. Relaxed mollusks will be then placed in 70% EtOH as voucher specimens. Several (N= 5- 10) individuals will be placed in chilled water without menthol for 24 hours to allow emptying of gut contents, which could foul DNA analyses, and then placed into properly labeled vials for genetic analysis.

In the laboratory, sort the specimens to the best taxonomic resolution possible. Specimens will be stored in a 70% ethanol solution made with distilled water in glass vials. They will be kept at room temperature in a taxonomic library collection with only external labels to prevent contamination from the laboratory environment. It may take several field visits to accumulate sufficient specimens for genetic analyses. When a sufficient amount of material from a sufficient number of species has been accumulated, specimens will be available for further analysis by the genetic laboratory.

In situations where taxonomic identification is questionable (e.g., hard to identify rare and uncommon springsnails), specimens will be sent to mollusk experts. Experts include malacologists from the Smithsonian Institute, Orma J. Smith Museum, Caldwell, ID, and Desert Research Institute, Reno, NV.

Diagnostic assays developed above for target freshwater mollusks will be tested using environmental material (water) collected using standard protocols from controlled aquariums, with water sampled using 0.45 µm Sterivex columns (Millipore) that isolates organic material. The purpose of this step is to assess assay performance free from ambiguity regarding target species presence. Following collection, DNA will be extracted from environmental samples following manufacturer (MO-BIO) protocols. All genotyping will be conducted following standard procedures.

Probability of Mollusk Detection using eDNA

Although eDNA sampling is often vastly superior to traditional survey methods, the probability of detecting mollusk species using eDNA is rarely 100%. This is because detection is dependent on the amount of eDNA from a species collected. This amount of eDNA is dependent on:

- The amount of DNA released by each species, which can vary. For example, carp shed massive amounts of DNA daily, whereas tiny springsnails may shed very little DNA. Taxa may also shed more DNA when active or spawning. For example, native mussels can release millions of glochidia (larvae) into the water column during spawning.
- The amount of DNA present is correlated with biomass. The density (biomass) of mollusks will influence detection, in that the more individuals there are in the survey site, the more eDNA will be present.
- The volume of water sampled. The greater the amount of water sampled, the greater the probability of collecting eDNA.

As an example, researchers developed molecular methods to detect the presence of New Zealand mudsnails in rivers in MT (Goldberg et al. 2013). Their methods were able to

detect between 11 to 144 snails/m² in a eutrophic 5th order river, which is quite good. Yet, our proposed method uses improved field filtration, laboratory chemistry, and occupancy modeling, which should enhance the sensitivity at detecting DNA.

Quantify detection probability of target species DNA from environmental sampling of water (eDNA) under field conditions

Collection of environmental material will occur at field locations where target species are known to be present and density information is available from previous surveys (i.e., ideal field). The collection spatial scale will be consistent with current methods if applicable (e.g., time step, habitat, session). Detection rate may vary seasonally, so collections will occur during a sampling frame when species are most likely to be detected (e.g., August; low flow). Proposed sampling rates can provide a 97% chance of detection (Bernoulli trials probability) even if actual probability of detection is as low as 10% in the field. Laboratory analysis will then be performed on material collected using the same protocols and procedures described above. Our approach will allow us to evaluate the following questions:

1. What is the probability of detection for target species under typical field conditions?
2. Does the probability of detection differ between habitats?
3. Does the probability of detection differ between sampling sessions?
4. Does the probability of detection differ between locations?

Determine feasibility of eDNA methodology for monitoring distribution and occupancy of target Mollusks

As non-detection of a species does not necessarily mean that species is absent, the information derived from objectives above can be used to optimize sampling scenarios. Using Mackenzie et al. (2002) equation 1, a maximize likelihood estimate for species presence at a site (ψ) can be calculated:

$$L(\psi, \mathbf{p}) = \left| \psi^n \cdot \prod_{\tau=1}^r p_{\tau}^{n_{\tau}} (1 - p_{\tau})^{n - n_{\tau}} \right| x \left| \psi \prod_{\tau=1}^r (1 - p_{\tau}) + (1 - \psi) \right|^{N - n}$$

Nomenclature shown follows publication and is primarily based on the number of sites surveyed with positive detects. As shown by Mackenzie et al. (2002), a logistic model can also be used to incorporate site characteristics (covariates) that may influence probability of occurrence (ψ). Further, sampling rates can be optimized to achieve a specified estimated precision level of ψ (e.g., Std. Err. = 0.05) (Mackenzie and Royle 2005). We envision that following an evaluation of feasibility and development of sampling scenarios, that management agencies and other interested parties will be empowered and able to apply a new genetics-based monitoring tool with confidence. We have chosen to focus on the initial stages of enhancing monitoring procedures and the proposal reflects this approach. While genetic methods offer a means to explore many

important aspects of population dynamics, our experience with eDNA has shown us that a solid understanding of basic sampling parameters is critical to the successful application of the method and credible interpretation of results.