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# Unionoida Mussel and Non-Pulmonate Snail Survey and Status in the Jordan River, UT, 2014

## Final Report

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## SUMMARY

North America supports the richest diversity of freshwater mollusks on the planet. Although the western USA is relatively mollusk depauperate, the one exception is the rich molluskan fauna of the Bonneville Basin area, including drainages that enter terminal Great Salt Lake (e.g. Utah Lake, Jordan River, Bear River, etc.). There are at least seventy freshwater mollusk taxa reported from UT, many of which are endemics to the Bonneville Basin and their evolution and distribution are strongly linked with the geological and geomorphic history of pluvial Lake Bonneville. These mollusk taxa serve vital ecosystem functions and are truly a Utah natural heritage. Unfortunately, freshwater mollusks are also the most imperiled animal groups in the world; including those found in UT. Despite this unique and irreplaceable natural heritage, the taxonomy, distribution, status, and ecologies of Utah's freshwater mollusks are poorly known. Very few mollusk specific surveys have been conducted in UT. In addition, specialized training, survey methods, and identification of freshwater mollusks are required.

EPA recently recommended changes in freshwater ammonia criteria based primarily on sensitive freshwater mollusks, including non-pulmonate snails and unionid taxa found in the eastern USA. Because these taxa may not occur in a region or potentially impacted areas, EPA also developed a recalculation procedure to develop site- specific water quality criteria 'to better reflect the organisms that occur at a specific site", based on the presence or absence of Unionoida and non-pulmonates. 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 alternative criteria values or on their own criteria values resulting from application of the recalculation procedure. It therefore is imperative to determine the presence/absence of mollusk taxa and in particular, Unionoida mussels and non-pulmonate snails in the main stem and tributaries of the Jordan River, to determine if recalculation of EPA's ammonia criteria is warranted. These surveys are particularly important in areas potentially affected by water treatment facilities whose discharge empties into the Jordan River and the very high costs associated with ammonia reduction.

The objectives of this survey were to determine presence/absence and estimate the probability of occurrence/absence of Unionoida mussels and non-prosobranch snails in the Jordan River and nearby tributaries and examine reasons for their distribution and status. Results of this mollusk survey can be used to initiate site-specific recalculations of ammonia criteria based on those sensitive taxa that are present or assumed absent following EPA's guidelines.

A combination of reconnaissance and qualitative mollusk surveys was conducted. Reconnaissance surveys were cursory visual searches in the most promising habitats and provided a preliminary understanding of mollusk presence or absence in the Jordan River drainage and helped determine if additional more comprehensive qualitative surveys were warranted. Approximately 7.5 miles of the Jordan River, UT were surveyed for the presence/absence of mollusk taxa focusing on sections of the river directly upstream and downstream of wastewater treatment facilities, in May and October 2014. Surveyors were trained for one full day by the author prior to conducting the formal surveys. Three to

four mussel surveyors using aquascopes, shoreline sampling, and kick nets surveyed for a total of about 270 surveyor hours in May and about the same number of hours in October but without the use of aquascopes. Habitats examined included: riffles, runs, pools, and back eddies with substrate ranging from boulders/large cobbles to fine silt and clay. An estimated 70% of the Jordan River substrate was viewed in the survey for an estimated total of 58,000 to 76,000 $m^2$ surveyed in May.

We did not find any live Unionoida or native non-prosobranchs in any sections of the Jordan River, although we found native non-prosobranchs in tributaries of the Jordan River. At least one Unionoida taxon is known to still exist in the Jordan River drainage upstream of the river and outside of our study area. We did however find two highly invasive mollusks in the Jordan River, the New Zealand mudsnail, *Potamopyrgus antipodarum* and the Asian clam, *Corbicula fluminea*, both of which dominated the benthic macroinvertebrate assemblage. We also found several taxa of live native clams and prosobranch snails. Reasonable probability estimations for Unionoida in the Jordan River would be < 1 individual for 270 hours of visual examination or about < 1 individual/ 50,000 $m^2$.

Based on historical records and this survey, it appears that native Unionoida mussels and possibly non-pulmonate snails no longer occur in the main stem of the Jordan River and possibly Utah Lake, or they occur at such extremely low densities and in isolated locations so as to be almost non-detectable. Isolated populations of non-pulmonate snails 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. Unionoida taxa likely no longer survive even as metapopulations but as small isolated populations in a highly fragmented landscape upstream of Jordan River within the drainage. Because of this, Unionoida extinction probabilities are much greater than if they would have remained as large continuous populations or as metapopulations. In addition to the extinction risk of native Unionoida caused by isolation and fragmentation, a multitude of other factors that negatively effect the physical, chemical, and biological integrity of the Jordan River drainage increases their extinction risk with little likelihood of natural recolonization of the Jordan River including:

- Dewatering
- Non natural flow regime
- Channelization
- Sedimentation
- Unprecedented urbanization
- Dredging
- Flood event scouring
- Loss of floodplain connection (e.g. flood dynamics are not the same as when Jordan River was allowed to inundate flood plain. Floodplains also dissipate flood scour energy/intensity).
- Global climate change. Expected increased temperatures, decreased precipitation, and increased and unpredictable/ extreme storm events that likely will have deleterious but unquantifiable effects on physical, chemical, and biological integrity

- Lowered dissolved oxygen, particularly under winter ice
- Point and non-point sources of pollutants
- Increased salinity (evaporative loss in Utah Lake exceeding input)
- Nutrients
- High summer temperatures
- The chemical integrity of Utah Lake
- Invasive species
- Loss of biodiversity
- Loss of species interactions (the extinction or loss of ecological interactions often accompanies or even precedes loss of biodiversity)
- Loss of population interactions (e.g. metapopulation dynamics, isolated populations)
- Loss or change in genetic diversity
- Unknown changes in species interactions resulting from loss of biodiversity and species interactions
- Effects of demographic and environmental stochasticity on small, isolated populations

All of these factors likely have pushed native Unionoida in the Jordan River drainage to enter what is known as the 'extinction vortex' and it is likely they are now ecologically irrelevant to the ecosystem. If conditions do not improve or additional populations don't exist they can be considered as part of the 'extinction debt' and may not persist into the foreseeable future. Native non-pulmonate snails are also becoming scarce in the Jordan River drainage and spring -stream tributary habitats may be the last refugia for these species in the Jordan River if they are able to coexist with the already present invasive New Zealand mudsnails and Asian clams. Additional surveys are urgently needed and comprehensive metapopulation viability analyses should be conducted for all of these taxa and particularly for *A. californiensis/nuttalliana*. The multitude of physical, chemical, and biological impairments discussed in this report and by others combine to prevent re- establishment of Unionoida taxa into the Jordan River. Proposed monetarily expensive efforts to further reduce ammonia concentrations in the Jordan River will likely have no net -benefit until these other more deleterious factors are remedied. Monies could be better spent to help reduce the negative effects of those factors.

The following are recommended to determine the distribution and status of Unionoida and non-pulmonate snails in the Jordan River drainage and help reduce extinction risk:

- Expand the mollusk survey area and revisit Jordan River sites at least every 3 years.
- Survey the location 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 or lesser abundances in the future and therefore detectability rates may change.
- Increase mollusk survey efforts in Utah Lake and tributaries.
- Develop and add eDNA sampling methods to the program.

- Resurvey known locations of *Anodonta* populations in the Jordan River drainage and conduct quantitative surveys to estimate abundances and size classes for each population.
- Conduct metapopulation viability analyses and quantitative risk assessments for Unionoida and non-pulmonate snails in Jordan River drainage.
- Conduct acute and chronic ammonia toxicity tests on mussels native to UT.
- Conduct detailed distribution, life history, and ecological studies of invasive New Zealand mudsnails and Asian clams in the Jordan River drainage.
- Immediate and increased protection of remaining Unionoida populations and their habitat in the Jordan River drainage. **This is critical**.
- Immediate and increased protection of spring tributaries of the Jordan River to help insure that native non-pulmonate snail populations do not follow down the path towards extinction in UT that *Anodonta* appears to be traveling on. **This is also critical**.
- Educate Utah citizens regarding their unique natural heritage of native mollusks, which is 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. It is well known that snails, particularly at high densities, have a strong effect on nutrient cycling (Hall et al. 2003). For example, when snails are present in streams there can be less C as DOC and more C as $CO_2$ in the water column (Morales and Ward 2000). Many mollusk species in the western USA, particularly non pulmonate 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 disproportionally 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), many of which are endemics to the Bonneville Basin. The evolution and distribution of the Bonneville Basin's and Utah's unique freshwater mollusks are strongly linked with the geological and geomorphic history of pluvial Lake Bonneville (Johnson and Jordan 2000, Hershler and Sada 2002, Johnson 2002, Polhemus and Polhemus 2002, Smith et al. 2002, Mock et al. 2004)(Figure 1).

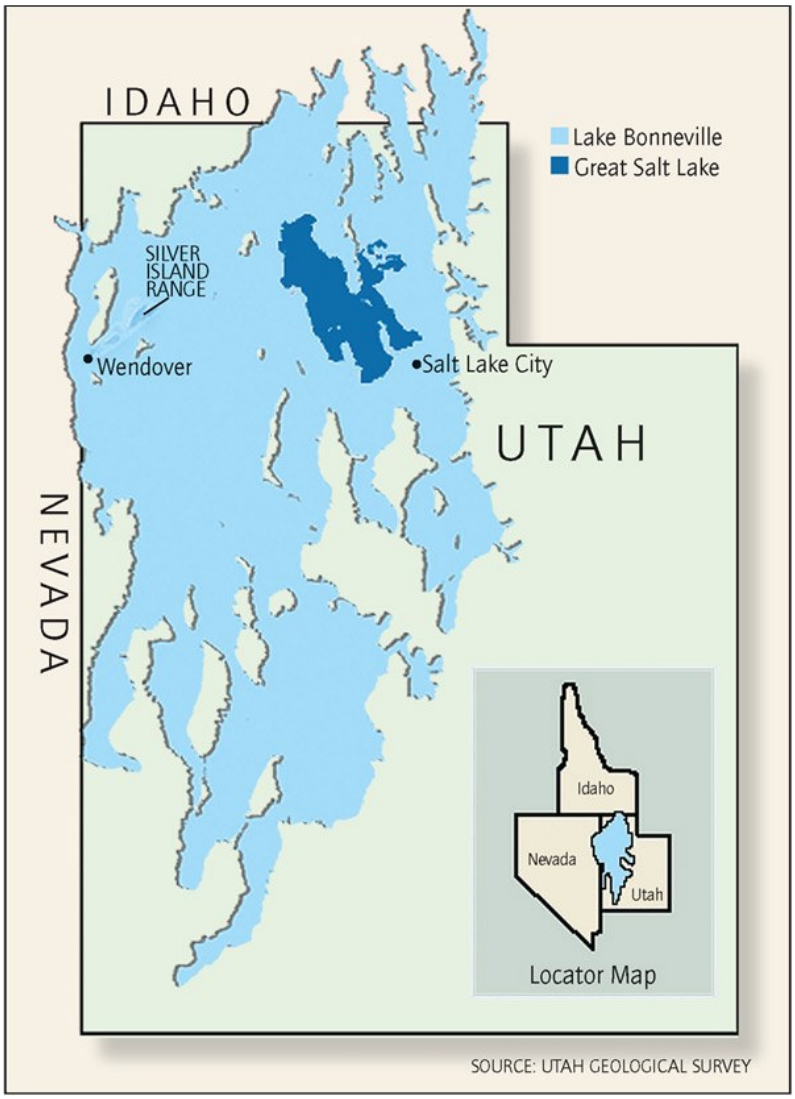


**Figure 1. Location of Ancient Lake Bonneville at its maximum area (about 17,000 years ago) and what remains, Great Salt Lake (Utah Lake not shown).sss**

Despite this unique and irreplaceable natural heritage, the taxonomy, distribution, status, and ecologies of Utah's freshwater mollusks 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 the order Unionoida mussels in the families Margaritiferidae and Unionidae and on non-pulmonate snails in the families Hydrobiidae and Valvatidae surveyed in the Jordan River (Figure 2) in 2014.


**Figure 2. Jordan River flows north from the outlet of Utah Lake to its terminus at Great Salt Lake.**

**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/nuttalliana* (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 occured in UT (from NatureServe websites, Oliver and Bosworth UT DNR, Pacific Northwest Mussel Guide and Hoving 2004).**

| Species | UT Status | | NatureServe Global Status | |
|---|---|---|---|---|
| *Margaritifera falcata* (Gould, 1850) | S1 | Critically Imperiled | G4 | Apparently Secure |
| *Anodonta californiensis* Lea, 1852 | S2 | Imperiled | G3 | Vulnerable |
| *Anodonta nuttalliana* Lea, 1838 | Unknown[1] | Unknown | G4 | Apparently Secure |
| *Anodonta oregonensis* Lea 1838 | Unknown[2] | Unknown | G5 | Secure |
| *Gonidea angulata* (Lea, 1838) | Unknown[3] | Unknown | G3 | Vulnerable |

[1]From 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

[2] From 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 phylogenetic reconstructions of *Anodonta* (*A. californiensis*, *A. oregonensis*, *A. wahlamatensis*) 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.

[3]From 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* (pebblesnails) and *Pyrgulopsis* (springsnails) and two smaller genera, *Colligyrus* and *Tryonia*; and the heterobranch family, Valvatidae which includes one genus, *Valvata* (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 Unionoida and non-pulmonate mollusks in the Jordan River drainage**

Several Unionoida and non-pulmonate mollusk genera have been reported in the Jordan River area. These include *Anodonta* (Family Unionidae), *Margaritifera* (Family Margaritiferidae), *Fluminicola* (Family Hydrobiidae), *Pyrgulopsis* (Family Hydrobiidae), *Colligyrus* (Family Hydrobiidae), *Tryonia* (Family Hydrobiidae), and *Valvata* (Family Valvatidae). The unionid

species *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.

## UNIONOIDA 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). Tertiary and 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 considered host specific. Although the range of host species is speculative and unknown for *A. californiensis,* invasive carp do not appear to be a suitable host candidate (http://www.xerces.org/california-and-winged-floaters/, Lefevre and Curtis 1912). Further studies are urgently needed to determine which fish species in the Jordan River are suitable hosts. 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 3 and Figure 4). Additionally, several researchers reported possible *Anodonta* spp. shells along the shoreline of Utah Lake and Mill Pond in Utah County. More intensive and extensive native mussels surveys are clearly needed to document existing populations as well as continued compilation of recently reported locations. Recent genetic analyses have suggested that *A. californiensis* and *A. nuttalliana* are within the same clade (Mock et al. 2004) and for the purpose of this report will be identified as *Anodonta californiensis/nuttalliana*.

**Figure 3.** ***Anodonta californiensis/nuttalliana*** **(California floater/Winged Floater). Shell lengths up to 5 inches; reach sexual maturity 4 to 5 years, and maximum life span about 15 years (© Ethan Jay Nedeau, reproduced from the field guide** ***Freshwater Mussels of the Pacific Northwest*** **(Nedeau et al. 2009).**

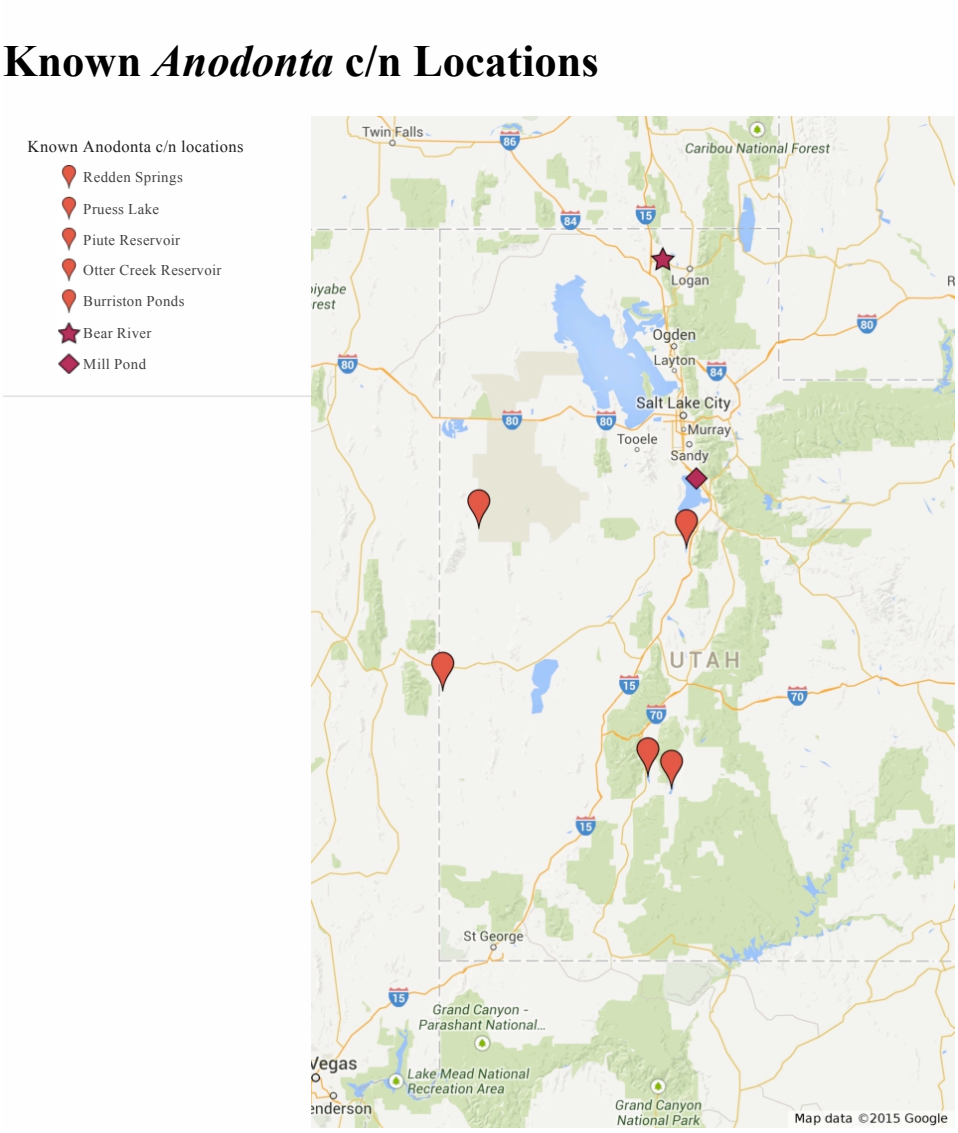


**Figure 4. Known locations of *Anodonta californiensis/nuttalliana* in UT from Xerces Society web site, literature, and this survey. Red teardrops are geo-referenced locations; red star is location only reported as Bear River, and red diamond is location where only shells were found, no live individuals.**

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

Common Name: western ridged mussel

The mobile *G. angulata* (Figure 5) 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.

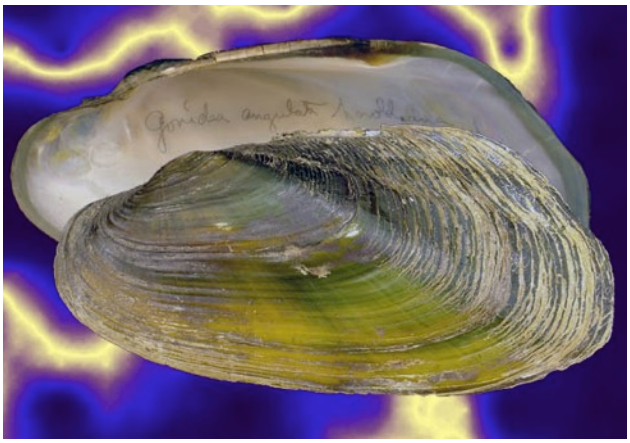

**Figure 5. *Gonidea angulata* (Western Ridged Mussel) (http://mussel-project.uwsp.edu/motm/2008/08-01.html)**

***Margaritifera falcata Gould 1850***
Common Name: western pearl shell mussel

*M. falcata* (Figure 7) 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-$km^2$ 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. More recent surveys have documented populations of *M. falcata* in the Weber River and Bear River drainage (http://www.xerces.org/western-pearlshell/, and others). It is likely that additional small isolated colonies may be found using mussel specific surveys and more intensive and extensive native mussels surveys are clearly needed to document existing populations.

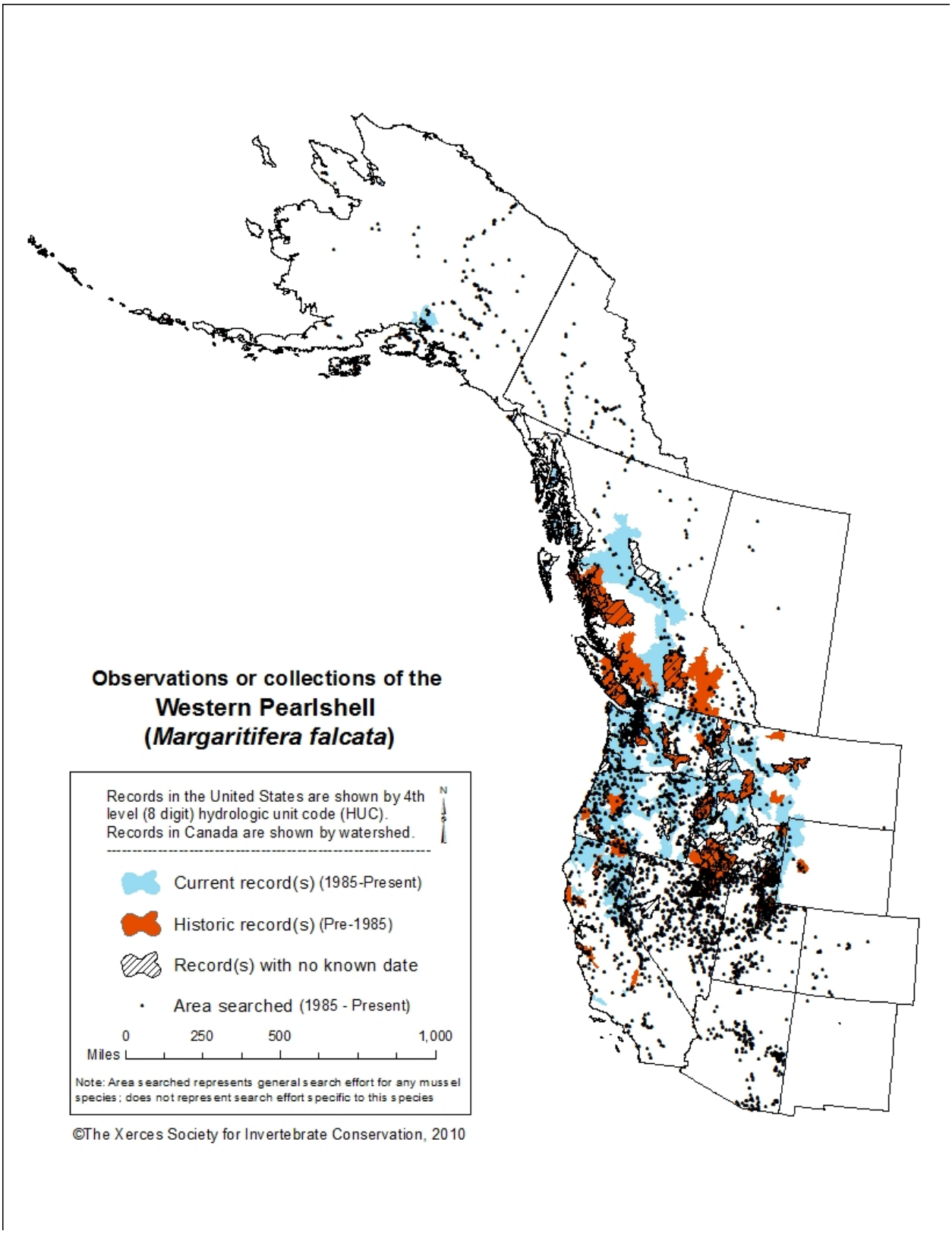


**Figure 6. Map of *M. falcata* observations and collections in western USA (http://www.xerces.org/western-pearlshell/).**

**Figure 7. *Margaritifera falcata* (Western Pearlshell mussel)( http://www.fws.gov/refuge/willapa/wildlife_and_habitat/western_pearlshell_mussel.html)**

**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 American. *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).

The only species of *Fluminicola* found in UT is *Fluminicola coloradoensis* Morrison (Hershler and Frest 1996; Hsiu-Ping et al. 2013)(Figure 8). 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 8. 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 9)(http://www.cnr.usu.edu/wmc/htm/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 10 and Figure 11). Consequently, this population may no longer exist.

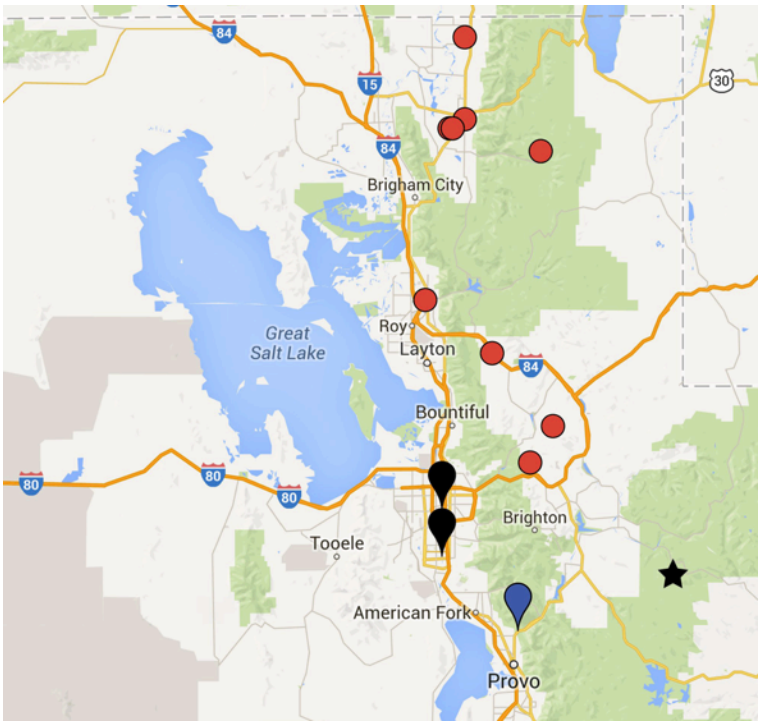


**Figure 9 *Fluminicola coloradoensis* in NW UT. Locations from WCMAFE BLM/USU Aquatic Monitoring Center, BugLab website (http://www.cnr.usu.edu/wmc/htm/data). *F. coloradoensis* symbol locations: Black teardrop = Jordan River/ Salt Lake County; blue teardrop = Utah county; black star = BugLab description 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.**

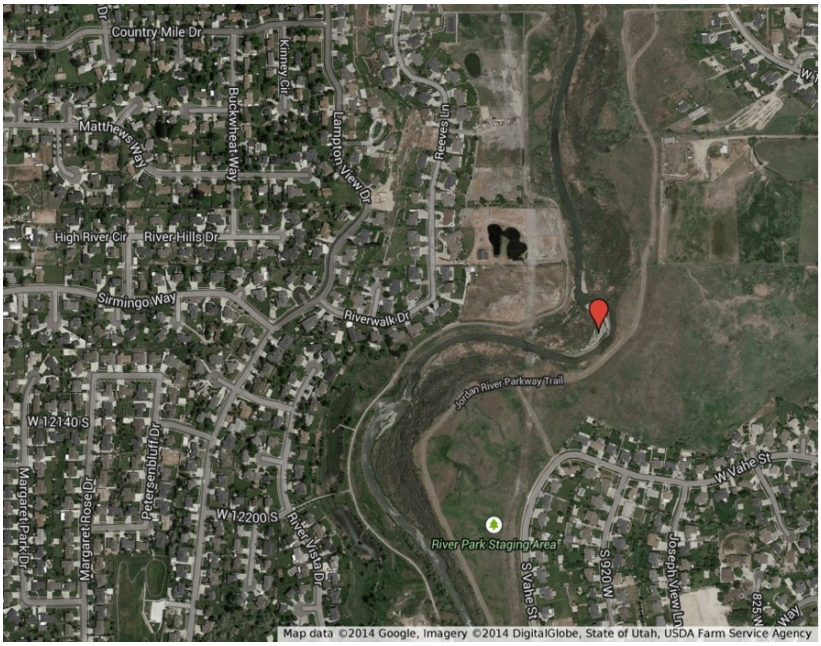


**Figure 10. Location of *Fluminicola coloradoensis* BLM/USU BugLab collection site in 2004. A total of nine individual were collected from combined qualitative and quantitative data.**

**(http://www.cnr.usu.edu/wmc/htm/data). Unprecedented urbanization has occurred in this area since 2004 and may have caused their demise.**

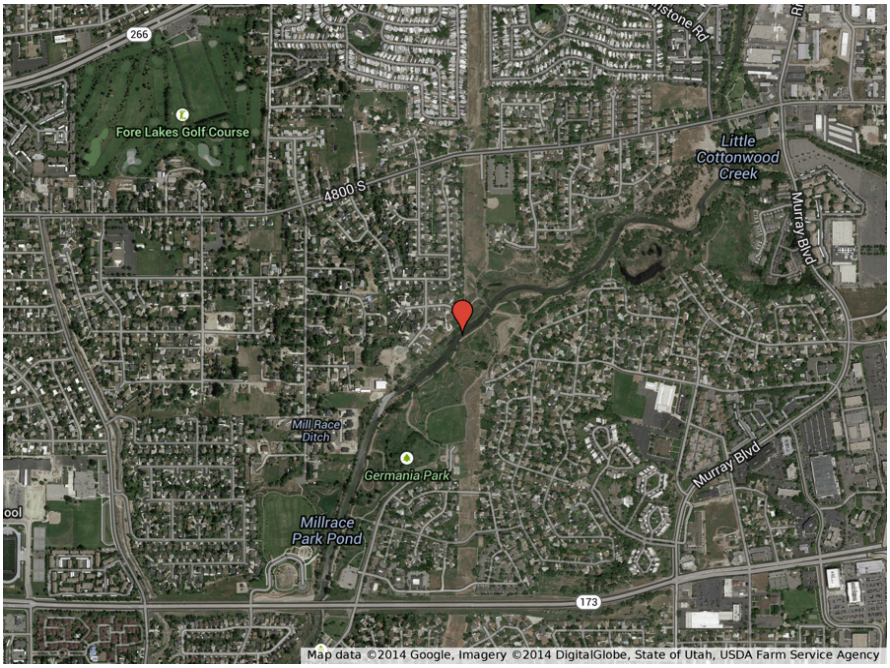


**Figure 11. Location of *Fluminicola coloradoensis* BLM/USU BugLab collection site in 2004. A total of 11 individual shells were collected from qualitative data(http://www.cnr.usu.edu/wmc/htm/data).Unprecedented urbanization has occurred in this area since 2004 and may have contributed to their demise.**

***Pyrgulopsis, spring snails***

*Pyrgulopsis* spp. (Figure 12) are known as 'springsnails' 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 13)(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 13). 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 14) and two individual *Pyrgulopsis* spp. collected from the Jordan River, in a 2002 qualitative sample (Figure

15). The pyrgs in the BLM/USU BugLab database could be more than one or two species due to difficulty in taxonomy.

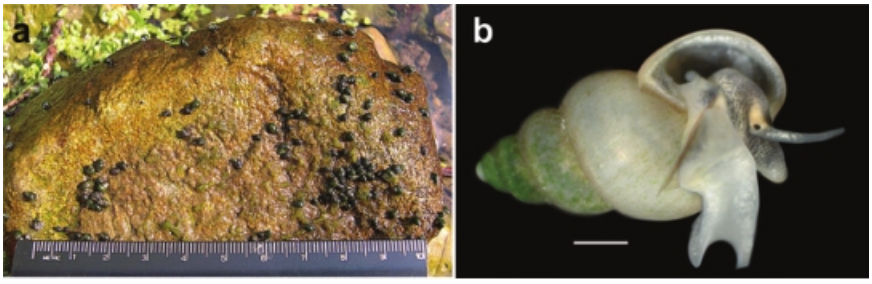


**Figure 12. (a) *Pyrgulopsis* sp. on rock (East Fork Rock Creek, Idaho). Photograph: Daniel Gustafson. (b) *Pyrgulopsis robusta* (Snake River, Idaho). The scale bar represents 1 millimeter. Photograph: Robert Hershler. Both photos from Hershler et al., 2014.**

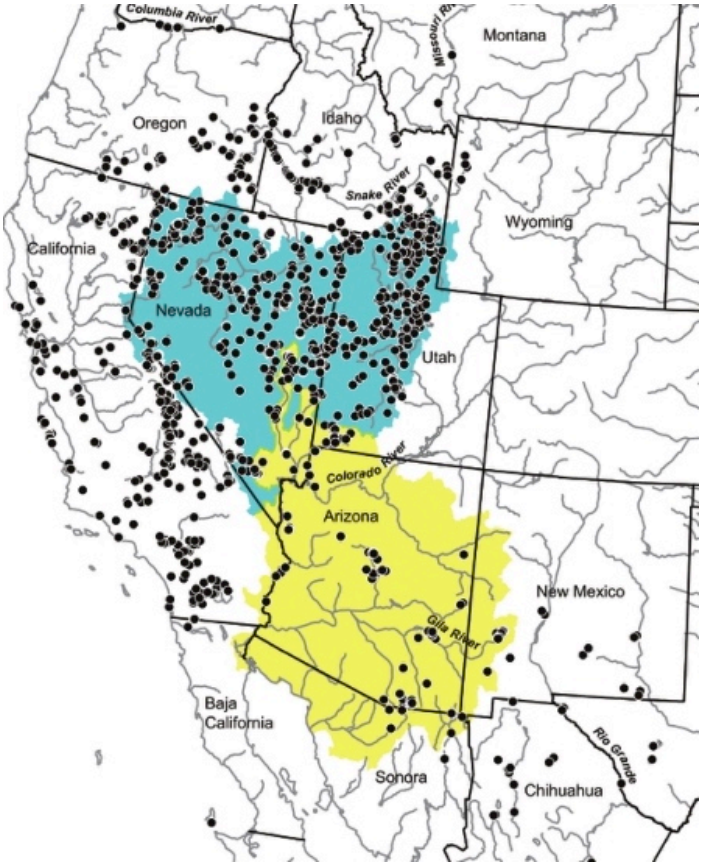


**Figure 13. The distribution of *Pyrgulopsis*, based on records in the Smithsonian National Museum of Natural History and several other repositories. The Great Basin and lower Colorado River Basin are shaded in cyan and yellow, respectively. (Figure from Hershler et al. 2014)**

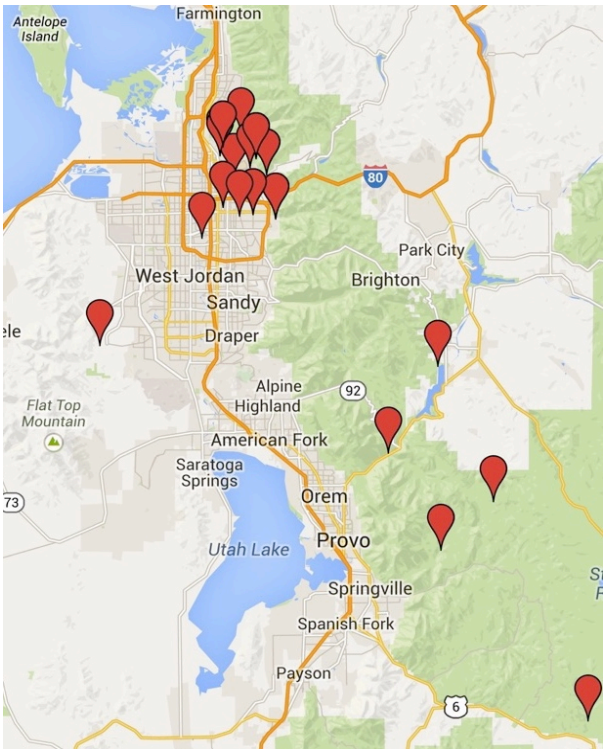


**Figure 14. Reported locations of *Pyrgulopsis* spp. in Salt Lake and Utah counties from BLM/USU BugLab database (http://www.cnr.usu.edu/wmc/htm/data).**

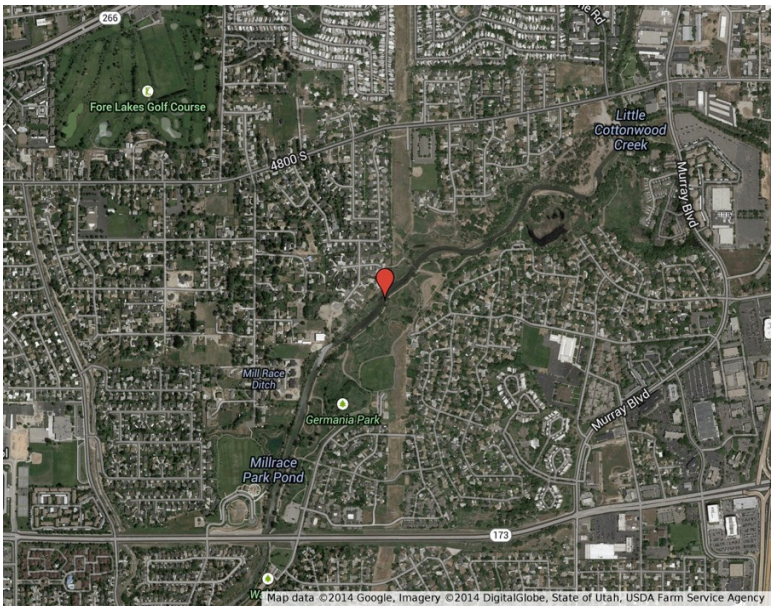


**Figure 15. Location of two individual *Pyrgulopsis* spp. reported by BLM/USU BugLab in Jordan River, in a 2002 qualitative sample. (http://www.cnr.usu.edu/wmc/htm/data).**

**Unprecedented urbanization has occurred in this area since 2002 and may have contributed to their demise.**

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/htm/data)(Figure 16).

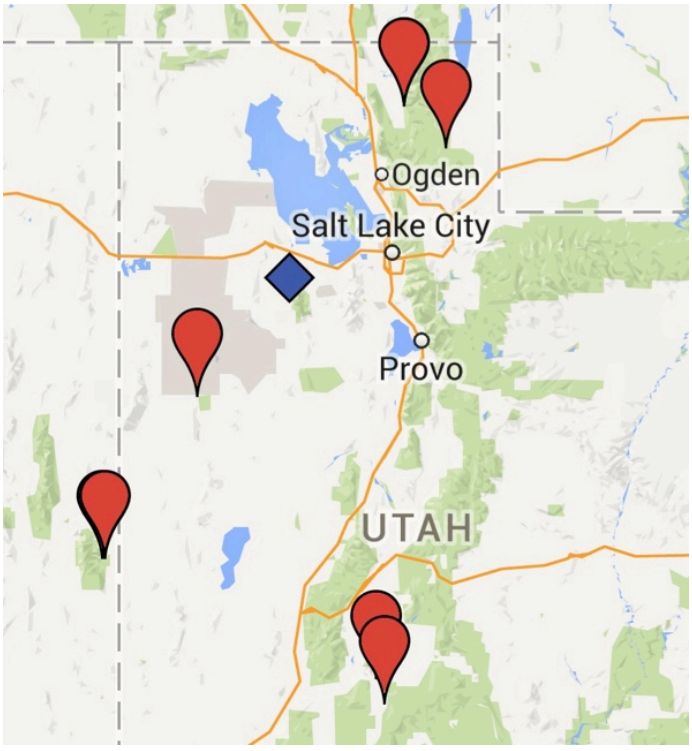


**Figure 16. *Colligyrus* greggi. (red ballons) and *Tryonia* sp. (blue diamond) locations reported from WCMAFE BLM/USU Aquatic Monitoring Center, BugLab website (http://www.cnr.usu.edu/wmc/htm/data).**

***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, 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 17) 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 37). *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 17). Live V. *utahensis* are known only to occur in the Snake River, ID (Hovingh 2004).

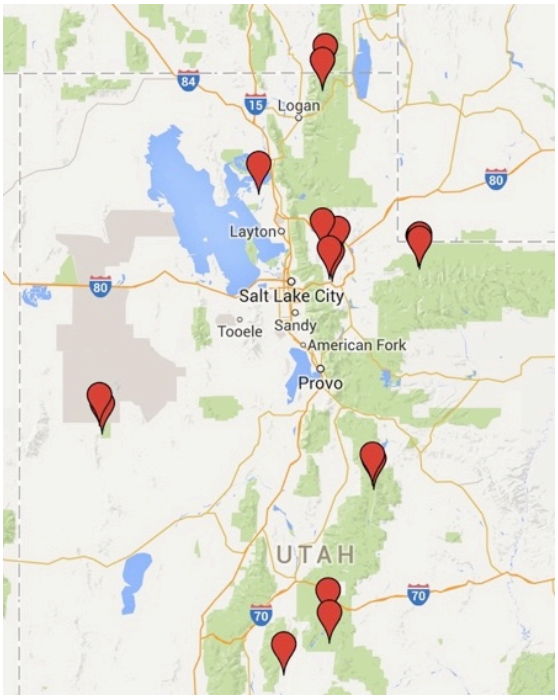


**Figure 17. *Valvata* spp. in UT locations reported from WCMAFE BLM/USU Aquatic Monitoring Center, BugLab website (http://www.cnr.usu.edu/wmc/htm/data). No *Valvata* spp. were reported in the BLM/USU BugLab database for Salt Lake and Utah counties and *Valvata* spp. and *Valvata humeralis* were the only two *Valvata* taxa reported.**

**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] |
|---|---|---|---|---|---|---|
| | **G**lobal | **N**ational | Utah | | | |
| **Unionid mussels** | | | | | | |
| *Gonidea angulata* | 3 | 3 | NA | NA | NE | Und. |
| *Anodonta californiensis* | 3Q | 3Q | 1Q | NA | LC | Und. |
| *Margaritifera falcata* | 4, 5 | 4, 5 | 1, H | NA | NE | Und. |
| **Non-pulmonate snails** | | | | | | |
| *Colligyrus greggi* | 4 | 4 | 1 | R, I, RE | LC | CS |
| *Fluminicola coloradoensis* | 2, 3 | 2, 3 | 2, 3 | R, I, RE | NE | T |
| *Pyrgulopsis pilsbryana* | 2 | 2 | 1 | R, I, RE | NT | T |
| *Pyrgulopsis spp.* | NA | NA | NA | NA | NA | NA |
| *Tryonia porrecta* | 3 | 2 | 2 | R, I, RE | LC | CS |
| *Valvata humeralis* | 5Q | 5 | H | R, I, RE | LC | CS |
| *Valvata utahensis* | 1, 2 | 1, 2 | X | R, I, RE | VU | E |

[1]Nature 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.

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

R. Rare

I. Imperiled

RE. Recently extinct or extirpated

[3]IUCN: Red List Category Codes:

LC. Least concern

NT. Near threatened

NE. Not evaluated

[4]AFS = 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 24).

## 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 and 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 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 Unionoida mussels and non-prosobranch snails in the Jordan River and nearby tributaries. In addition, reasons for their present distribution and population status will be discussed. Results of this mollusk survey can also be used by regulators to consider whether a site-specific recalculation of ammonia criteria is appropriate.

## 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 18-21) 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 |
| 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 18. Sample location in The “Narrows” section of Jordan River. Sampling occurred between the blue pins on the map.**


**Figure 19. Site 2. Sampling occurred between the blue pins on the map.**

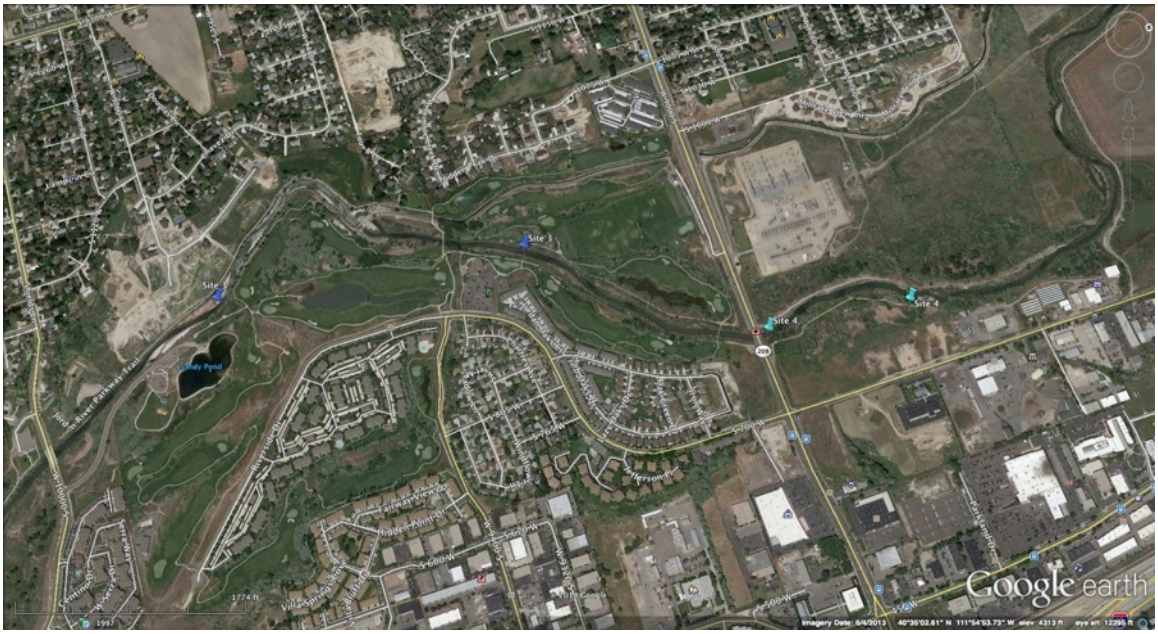


**Figure 20. Mussel survey sites 3 and 4. Sampling occurred between the blue pins on the map.**

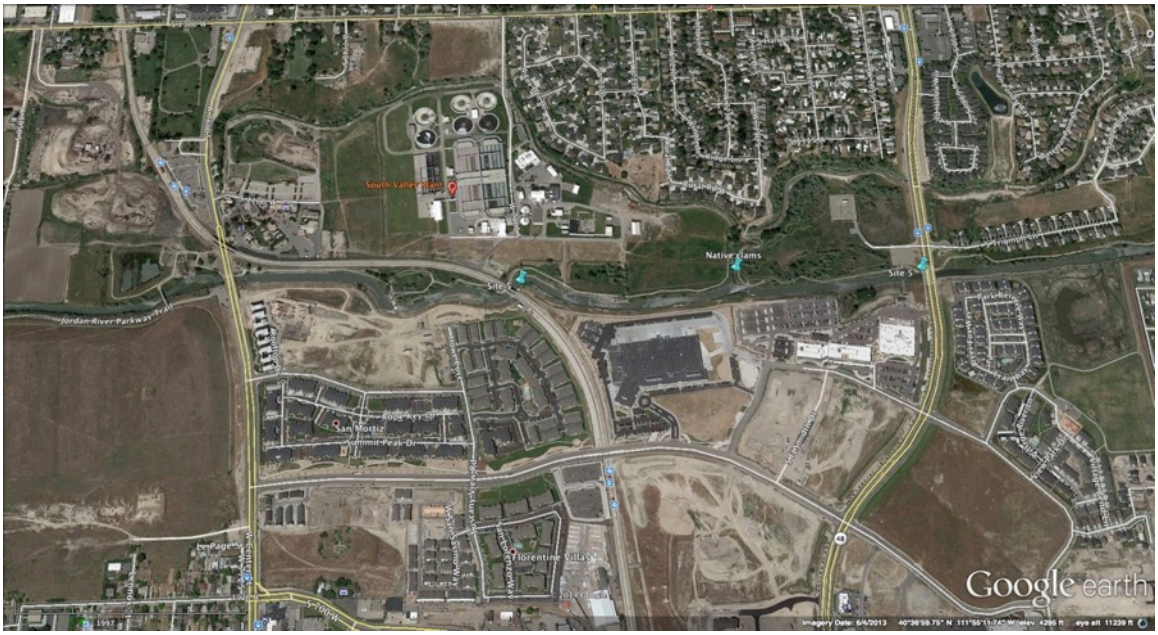


**Figure 21. Mussel survey site 5 with tributary marked where native clams were common. Sampling occurred between the blue pins on the map.**

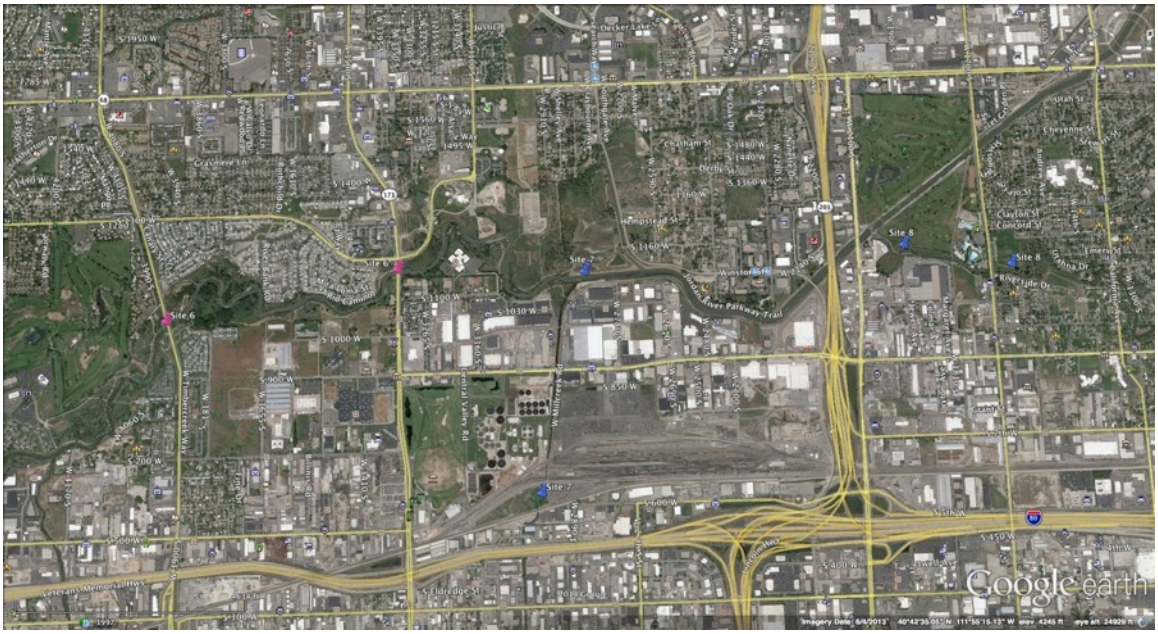


**Figure 22. Mussel survey sites 6, 7, and 8. Site 7 was Mill Creek and small portion of Jordan River. Sampling occurred between the blue pins on the map.**


**Figure 23. Mussel survey site 9. Legacy Nature Preserve. Sampling occurred between the blue pins on the map.**

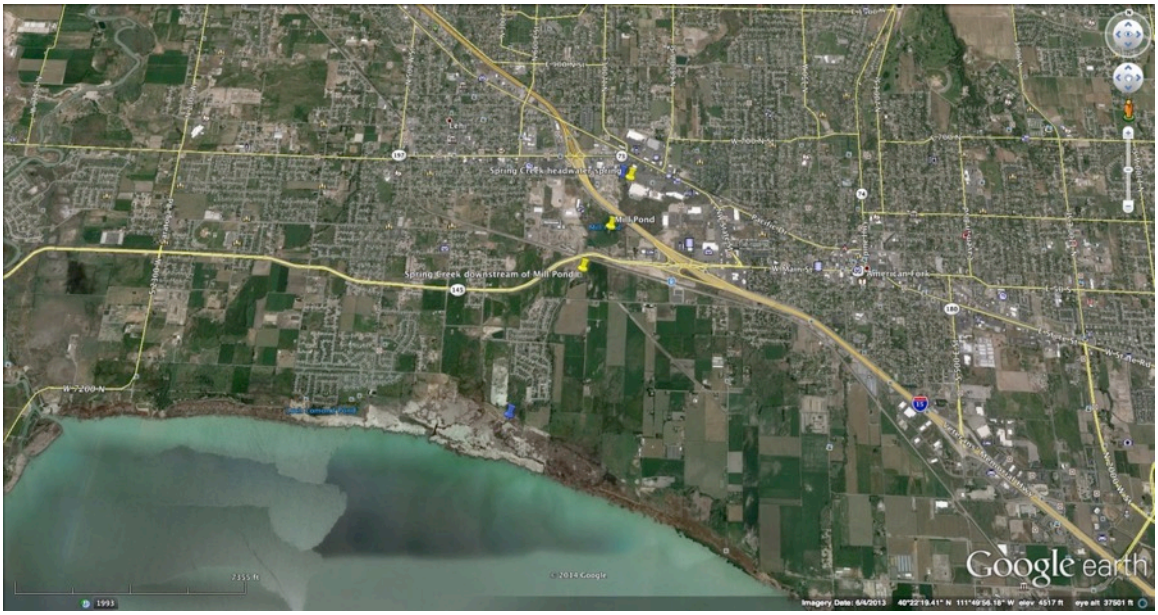


**Figure 24. Mill Pond and Spring Creek, Utah County. Unionid mussel surveys were conducted between blue pins; yellow pin at headwater spring is in a Wal-Mart parking lot and under a dumpster; yellow pin at Spring Creek downstream of Mill Pond is where the most *Anodonta californiensis* shells were found in the 2014 survey.**

**Survey methods**

**Native Unionoida 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 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 sufficient flows necessary for filtering. There was no evidence of native unionid mussel presence during reconnaissance surveys; therefore we conducted qualitative surveys. Dr. David Richards trained surveyors for approximately four hours on Mill Pond and Spring Creek, Utah County, an area where Anodonta shells were previously reported (see qualifications in Appendix 26). Several *Anodonta* shells were recovered during this training session. The surveyors continued training for four hours at Site 1 on the Jordan River the following day. For the qualitative surveys, three to four mussel surveyors using aquascopes (Figure 25), kick nets (Figure 26), and shoreline examination (Figure 27) surveyed approximately 7.5 miles of the Jordan River from April 1, 2014 to April 11, 2014 for a total of about 270 surveyor hours. April was chosen because visibility in the Jordan River typically is best and mollusks would likely be closer to the surface of the sediment than in winter. 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. Therefore, an estimated 70% of the Jordan River substrate in the 7.5 miles was viewed for an estimated total of 58,000 to 76,000 $m^2$. 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 (behind boulders, gravel, sand, pools, upstream of riffles, etc.) to help determine if mussels were buried under the sediment and not visible to aquascope surveys. Kick net sampling allowed surveyors to collect sediments and mollusks to depths of up to several inches. Shorelines were carefully examined for empty shells on sandbars, muskrat middens, and other areas of the shoreline.

**Figure 25. One of the commercial aquascope types used in the mussel survey.**

**Figure 26. Mollusk surveyor using kick net**

**Figure 27. 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 early October 2014 for ten days with two to three surveyors 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 28 and Figure 29). 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. Taxonomic identification and verification at minimum to family level was conducted in the field by the author however, many were identifiable to species or genus level. Voucher specimens are housed 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.


**Figure 28. Bingham Creek.**


**Figure 29. Springs on west side of Jordan River at "Narrows" (40°27'56.19"N; 111°56'1.87"W)**


**Figure 30. 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

**Unionoida 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 ten day, non-pulmonate snail survey in 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. The observation of native fingernail clams supports the assumption that native Unionoida mussels would have also been encountered in the survey.

One small weathered 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 31).

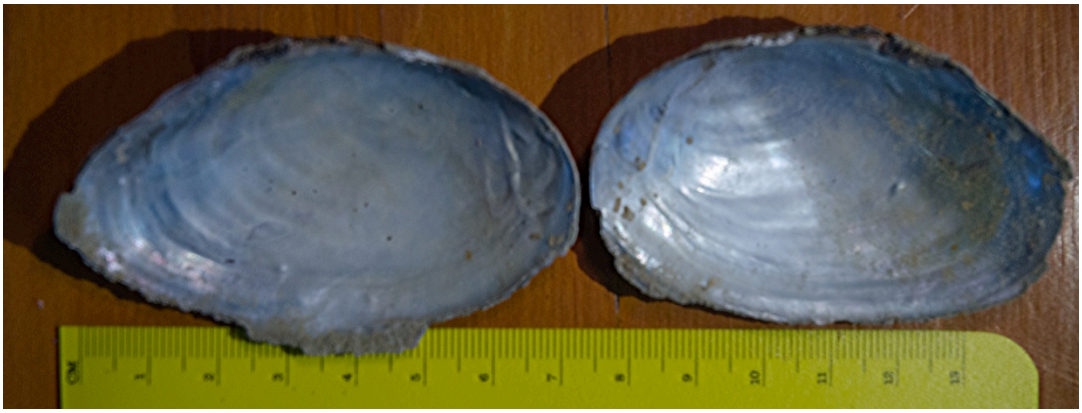

**Figure 31. Complete *Anodonta* sp. shell from Mill Pond, Utah County, April 2014. No body tissue was present and the time since death is unknown.**

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, Utah County had mostly sand, silt, and clay substrate whereas, Spring Creek, Utah County, also had gravel and small cobbles where Anodonta shells were collected. 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). *Corbicula* often occurred at

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 (e.g.black ooze with smell of sulfur) 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 24). The largest *Corbicula* shell observed by the author was collected at Mill Pond and measured about 6 cm in max diameter (Figure 32).

**Figure 32. Atypically large *Corbicula* shells for Jordan River, UT drainage. These large *Corbicula* are approaching the average size of *Anodonta* at sexual maturity. This large shelled *Corbicula* also illustrates ideal habitat conditions for this invasive species in many areas of the Jordan River 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 33– 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 (≥ 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 29), Bingham Creek, and others. The largest spring creek, Bingham Creek, flows through the Jordan

Valley Water Conservation District (Figure 38) and had the highest abundances of *F. coloradoensis* in the survey. Upstream and downstream of JVWCD 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 39 and Figure 40). It is surprising that native non-pulmonates survive in downstream sections of Bingham Creek.

**Figure 33. Empty shells of the prosobranch snail, *Fluminicola coloradoensis* from the Jordan River.**

**Figure 34. Empty shells of the prosobranch snail, *Fluminicola coloradoensis* from the Jordan River. Scale lines are 1 mm.**

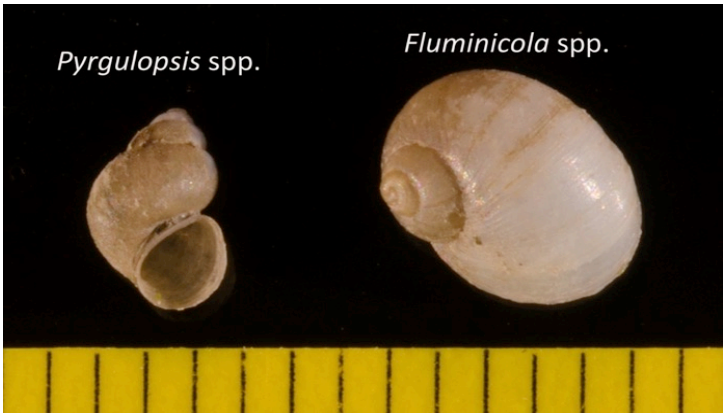


**Figure 35. Empty shells of the prosobranch snails, *Pyrgulopsis* spp., and *Fluminicola coloradoensis* and heterobranch *Valvata* spp. from the Jordan River. Scale lines are 1 mm.**

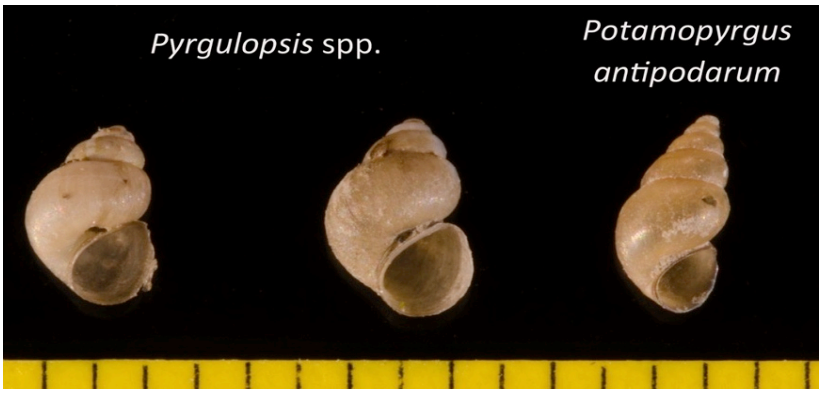


**Figure 36. Two empty shells of the prosobranch snail, *Pyrgulopsis* spp., and the invasive New Zealand mudsnail, *Potamopyrgus antipodarum* from the Jordan River. Scale lines are 1 mm. Many snail taxa are somewhat difficult to distinguish using shell morphology and often require a malacological expert in the field.**

**Figure 37. 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 38. 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 39. All too common construction that continues to impact spring creek tributaries of the Jordan River, UT. This location at the Jordan Valley Water Conservation District property was photographed October 2014.**

**Figure 40. 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 Physid taxa, two Lymnaeid taxa, 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 41 and Figure 36) 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 42). NZMS were extremely abundant at the JVWCD spring creek site and estimated to be at densities far greater than 100,000/$m^2$ (Figure 41).

**Figure 41. 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 42. Clamming on the Jordan River at 1700 South. This photo illustrates *Corbicula* sp. at extreme high densities collected from approximately a 1 $m^2$ sized area. Their body sizes are much smaller than the largest sized *Corbicula* found in Mill Pond and Spring Creek, Utah County suggesting that the substrate in the Jordan River, at least in this location, is less stable than in habitats where larger individuals were found but that food resources were likely not limiting.**

## DISCUSSION

The Great Basin, including Great Salt Lake tributaries such as the Jordan River and Utah Lake, were historically native freshwater mollusk diversity 'hotspots' and are part of Utah's unique biotic heritage. However, it now appears that native Unionoida mussels and non-pulmonate snails may no longer occur in the Jordan River (based on this survey and the literature) and possibly Utah Lake (based on available literature), or they occur at such extremely low densities and in isolated locations so as to be almost non-detectable. Isolated populations of non-pulmonate snails may occur in sections of the Jordan River in very limited areas where spring creeks and other tributaries 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 (non-detection) of live Unionoida mussels and non-pulmonate snails in this survey is consistent with the Utah DWQ designation of many sections (management units) of the Jordan River downstream of the "Narrows" as a warm water, non-game fisheries (many of the focal taxa surveyed prefer cold water) and it is unlikely that these taxa can survive under present conditions. Many of the empty native mussel and non-pulmonate snail shells examined in the Jordan River are likely from tributary flushing and depositing in the benthos or possibly from extinct populations. More pollution tolerant, warm water, 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 and prime habitat for the invasive NZMS (*P. antipodarum)* and often *Corbicula*. Spring seeps and creeks in the Jordan River system are in urgent need of special protection and management and ammonia criteria based on native taxa that occur there should be developed specifically for these habitats.

### Mollusk presence/absence

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. A reasonable probability estimation for Unionoida in the Jordan River would be approximately < 1 individual for 270 hours of visual examination or about < 1 individual/ 50,000 $m^2$. 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 25. DNA Barcoding). Additional discussion of Unionoida and non-pulmonate snail status in the Jordan River drainage follows.

**Metapopulation viability, the extinction vortex, and the extinction debt**

Populations of the two Unionoida taxa that may have been resident, native to the Jordan River drainage, *Anodonta californiensis/nuttalliana* and *Margaritifera falcata* were likely continuous or metapopulations prior to Ancient Lake Bonneville's recession. Unionoida populations later became metapopulations as continuously connected freshwater suitable habitats decreased and became more isolated, starting with the recession of Lake Bonneville, approximately 11,000 to 14,500 years ago (Mock et al. 2004) and as a result of human economic activities. These two taxa likely no longer persist as metapopulations, which require some limited dispersal between populations, but now exist as isolated populations. Metapopulations consist of several distinct populations connected by areas of suitable unoccupied habitat, where each population cycles in relative independence of the other populations and eventually goes extinct as a consequence of demographic stochasticity. However, limited connectivity can provide for recolonization of the extinct populations: thus metapopulations have less extinction risk than completely isolated populations (Hanski 1999). Both of the two native Unionoida taxa in UT now occur as isolated fragmented populations due to the natural recession of Lake Bonneville and negative environmental conditions exacerbated by modern humans. There is likely no dispersal between remaining populations of either taxon within the Jordan River drainage (e.g. unsuitable Utah Lake conditions) or within the Bear River drainage or between the two drainages (e.g. Great Salt Lake salinity barrier). It is well known that isolated- fragmented populations are substantially at higher risk of extinction than metapopulations or continuous populations (Hanski 1999, MacArthur and Wilson 1967). For example, Richards et al. (2009) conducted a metapopulation viability analysis and quantitative risk assessment on a federally listed threatened hydrobiid snail that showed that colonies (populations) were more likely to go extinct in isolated spring habitats than in habitats in springs and sections of the Snake River which had limited dispersal via connectivity (i.e. metapopulations), even though the isolated spring habitats had less environmental stochasticity than Snake River habitats. Unlike hydrobiid snails, Unionoida mussels are dependent on fish hosts for larvae dispersal (e.g. parasitic glochidia). Unionoida

resident to Utah likely depended on past large populations of native fish hosts (e.g. cutthroat trout) for their dispersal. Fish populations that are currently present in the Jordan River, native or introduced, are but a small fraction of past populations and may not provide enough individual hosts for glochidia dispersal. Much of the survival of glochidia to adulthood is density dependent, both by the number of sexually mature actively reproducing Unionoida individuals and by the number (density) of potential fish hosts. In addition, the highly invasive Asian clam, *Corbicula* sp., has been documented to filter feed on Unionoida glochidia drifting in the water column. *Corbicula* sp. densities can be extremely high in both Utah Lake and the Jordan River and have the potential to consume a large portion of glochidia that may possibly be produced. Thus viability decreases and extinction probability increases for any remaining Unionoida populations as these three density dependent factors interact.

Isolated Unionoida populations in UT are at such critically low densities that they may also have entered what is known as the 'extinction vortex' (Gilpen and Soule 1986), where in addition to the factors just described; genetic factors such as inbreeding depression, genetic drift, and 'mutational meltdown' (Lynch and Burger 1993) and demographic and environmental stochasticity combine in positive feedback loops that accelerate their extinction probabilities (Lynch et al. 1993, and Lynch and Gabriel 1990, Mock et al. 2004, Fagen and Holmes 2006). It should be noted that metapopulation dynamics and genetic diversity were included as important components in Karr's 1999 original definition of 'biological integrity' but are now widely ignored by water quality management agencies. Because isolated Unionoida populations in the Jordan River drainage are at such low densities, it is likely they are now ecologically irrelevant and can be considered as part of the 'extinction debt' (i.e. the future extinction of a species due to past events)(Kuusaari et al. 2009). This may be particularly true for the long-lived native mussel, *Margaritifera falcata* colonies that survive outside of the Jordan River drainage that may only harbor adults. Successful reproduction of *M. falcata* in some populations may not have occurred in over 50 years. Most Unionoida populations, and to a lesser extent, non- pulmonate snail populations in Utah may simply no longer be viable without massive management intervention and monetary expenditures.

**Unionoida and Non- Pulmonate Snail Status in Utah and the Clean Water Act**

The Clean Water Act states as one of its goals, "to maintain and improve the physical, chemical, and biological integrity of our nations waters". The continued survival and viability of Unionoida and non-pulmonate snails in Utah is directly linked to these three interacting elements of integrity: physical, chemical, and biological.

The **physical integrity** of the Jordan River has been severely compromised. Human induced factors that have compromised the physical integrity of the Jordan River include, but are not limited to:

- Dewatering
- Non natural flow regime

- Channelization
- Sedimentation
- Urbanization
- Dredging
- Flood event scouring as a result of channelization
- Loss of floodplain connection (e.g. flood dynamics are not the same as when Jordan River was allowed to inundate flood plain. Floodplains also dissipate flood scour energy/intensity).
- Global climate change. Expected increased temperatures, decreased precipitation, and increased and unpredictable/ extreme storm events that likely will have deleterious but unquantifiable effects on physical integrity

All of these factors have negatively affected the physical integrity of the Jordan River and have been documented to strongly contribute to the rapid decline and extinction of Unionoida and non-pulmonate snails worldwide (Lydeard et al. 2004) including their rapid decline and potential extinction in the Jordan River drainage (Hoving 2004, Mock et al. 2004). Populations of already critically low densities of native mollusks in the Jordan River drainage, particularly Unionoida taxa, will likely not persist without drastic improvements to all of these physical factors that compromise the overall integrity of the Jordan River.

The **chemical integrity** of the Jordan River has also been severely compromised. Factors that have compromised the chemical integrity of the Jordan River include, but are not limited to:

- Low dissolved oxygen, particularly under winter ice
- Point and non-point sources of pollutants
- Increased salinity (evaporative loss in Utah Lake exceeding input)
- Nutrients
- High summer temperatures
- The chemical integrity of Utah Lake
- Global climate change. Expected increased temperatures, decreased precipitation, and increased and unpredictable/ extreme storm events that likely will have deleterious but unquantifiable effects on chemical integrity

As with the physical factors, until remedied, chemical factors preclude the viability of Unionoida and non-pulmonate snails in the Jordan River. For example, high summer temperatures and low dissolved oxygen are intimately linked and are detrimental to Unionoida and non-pulmonate snails. Utah Lake water dominates Jordan River, particularly in summer. Warm summer Utah Lake water which enters the Jordan River is low in DO and may be less saturated than colder water, particularly during rare occasions when Utah Lake becomes stagnant due to low surface wind velocities, which reduce surface water-atmospheric aeration. In addition, increased sedimentation in Utah Lake due to human economic activities over the last century has led to an

average depth in Utah Lake of about 10 ft. Shallow water heats up faster than deeper water and is less able to hold DO. This is in contrast to historic Jordan River water, which in addition to the Utah Lake water source was supplemented by cold-water streams originating in the Wasatch, which were much colder than irrigation return flows from Utah Lake. These tributary waters were also well oxygenated via turbulence from higher velocities and riffles/cascades in the canyons. Likely these waters were near saturation when entering the Jordan River. More importantly, winter ice cover can reduce DO in Utah Lake to very low levels.

The **biological integrity** of the Jordan River has also been severely compromised. Factors that have compromised the biological integrity of the Jordan River include, but are not limited to:

- Invasive species
- Loss of biodiversity
- Loss of species interactions (the extinction or loss of ecological interactions often accompanies or even precedes loss of biodiversity (Valiente-Banuet 2015))
- Loss of population interactions (e.g. metapopulation dynamics, isolated populations)
- Loss or change in genetic diversity
- Unknown changes in species interactions resulting from loss of biodiversity and species interactions
- Effects of demographic and environmental stochasticity on small, isolated populations
- Global climate change. Expected increased temperatures, decreased precipitation, and increased and unpredictable/ extreme storm events that likely will have deleterious but unquantifiable effects on biological integrity

As with the physical and chemical factors and until remedied, these biological factors reduce the viability of Unionoida and non-pulmonate snails in the Jordan River.

Additional reasons for the non-detection of native Unionoida mussels and non-prosobranch snails in the Jordan River likely include a combination of the following:

- High sediment loads, particularly clay.
- Intensive and extensive urbanization, industrialization, and agriculture impacts, including dewatering and channelization of Jordan River.
- Water quality impairment (see Appendix 23a and 23b).
- High densities of the invasive *Corbicula* clam limited available native bivalve habitat (for other impacts of *Corbicula* see Appendix 24).
- Absence of native fish hosts for native larval mussel glochidia. Very low fish abundances of any species other than carp in Jordan River compared to historic abundances of native fish species.
- High flows (e.g. 2011) in the exceedingly channelized Jordan River may have covered any remaining mussel habitat and may have removed mussel shells.

- 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. Native mussels require an abundance of fish hosts to reproduce whereas, *Corbicula* does not.
- Historically there was a trout hatchery 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 unintentionally introduced native mussels when its flows were stable, water quality and habitat were less impaired, and a hatchery existed.
- 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 24). 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.

Note: EPA and UDWQ use what is known as “G factors” and “resident” vs. “non-resident” criteria to help determine the status and likelihood of reoccurrence of taxa and habitat conditions that may preclude that likelihood. An attempt was made to address these criteria and can be found in Appendix 23a and 23b, however, these criteria are not necessarily useful for the taxa surveyed in this report and are somewhat vague in their meaning and consequently their interpretation.

## CONCLUSION

Most Unionoida mussels and non-pulmonate snail populations are under threat or are in serious decline in Utah’s freshwaters. Unionoida taxa, primarily *Anodonta californiensis/nuttalliana* and *Margaritifera falcata* are likely absent from the Jordan River and viable populations in the Jordan River drainage may not persist into the foreseeable future. Native non-pulmonate snails are also becoming scarce in the Jordan River drainage and spring -stream tributary habitats may be the last refugia for these species in the Jordan River if they are able to continue to coexist with the already present invasive New Zealand mudsnails and Asian clams. Additional surveys are urgently needed and comprehensive metapopulation viability analyses should be conducted for

all of these taxa and particularly for *A. californiensis/nuttalliana*. The multitude of physical, chemical, and biological impairments discussed in this report and by others combine to prevent re- establishment of Unionoida taxa into the Jordan River. Proposed efforts to further reduce ammonia concentrations in the Jordan River will likely have no net benefit until these other more deleterious factors are remedied.

**RECOMMENDATIONS**

The following surveys and analyses are recommended to determine the distribution and status of Unionoida and non-pulmonate snails in the Jordan River drainage:

- Expand the mollusk survey area and revisit Jordan River sites at least every 3 years
- Coordinate, share, and annually update private, government, and non-profit data on mollusk distributions and status.
- Survey the location 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, particularly native mussel, survey efforts in Utah Lake and tributaries. These could be the only remaining potential sources of recolonization in the Jordan River.
- Develop and add eDNA sampling methods to the program. Genetic biomarkers for *Anodonta* and *Margaritifera* eDNA are expected to be developed and in use, summer 2015.
- Resurvey known locations of *Anodonta* populations in the Jordan River drainage and conduct qualitative surveys to estimate abundances and size classes for each population.
- Conduct metapopulation viability analyses and quantitative risk assessments for Unionoida and non-pulmonate snails in Jordan River drainage.
- Conduct acute and chronic ammonia toxicity tests on Utah's native mussels.
- Conduct detailed distribution, life history, and ecological studies of invasive New Zealand mudsnails and Asian clams in the Jordan River drainage. Determine their impacts on water quality including nutrient cycling and ammonia.
- Immediate and increased protection of remaining Unionoida populations and their habitat in the Jordan River drainage.
- Immediate and increased protection of spring tributaries of the Jordan to help insure that native non-pulmonate snail populations do not travel down the path towards extinction in UT that *Anodonta* appears to be following.
- Educate Utah citizens regarding their unique natural heritage of native mollusks, which is rapidly being lost, and encourage active participation in mollusk recovery.

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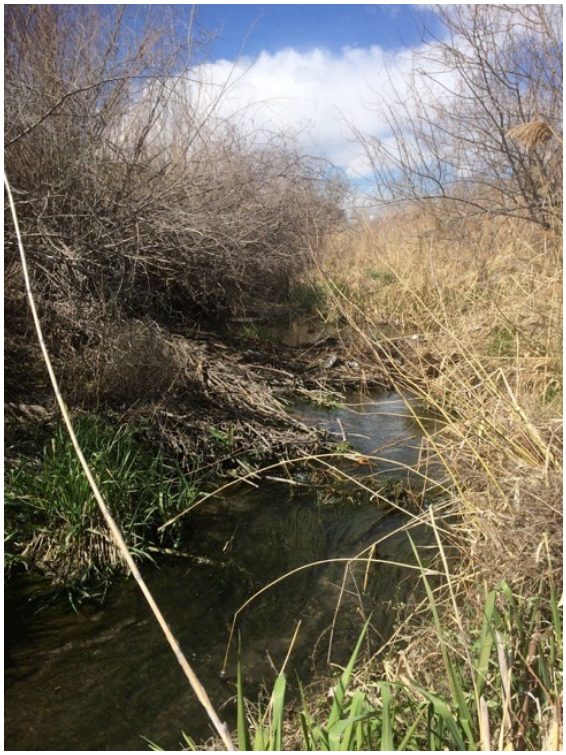
## APPENDICES

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

| | | | | | | |
|---|---|---|---|---|---|---|
| | Hydrobiidae | *Pyrgulopsis variegata* Hershler, 1998 | Northwest Bonneville Pyrg | T | G2 | R, I, RE |
| | Hydrobiidae | *Pyrgulopsis transversa* | southern Bonneville springsnail | **?** | **?** | R, I, RE |
| | Hydrobiidae | *Fluminicola coloradoensis* Morrison, 1940 | Green River pebblesnail | T | G2G3 | R, I, RE |
| | Valvatidae | *Valvata humeralis* Say, 1829 | Glossy *Valvata* | CS | G5Q | R, I, RE |
| | *Valvatidae* | *Valvata tricarinata (Say, 1817)* | *Threeridge Valvata* | *CS* | *G5* | ***?*** |
| | Valvatidae | *Valvata utahensis* Call, 1884 | Desert *Valvata* | E | G1 | R, I, RE |
| ***Pulmonates (lunged)*** | Ancylidae | *Ferrissia rivularis* | creeping ancylid | **?** | **?** | R, I, RE |
| | Lymnaeidae | *Fisherola nuttalli* (Haldeman, 1841) | Shortface Lanx | T | G2 | **?** |
| | Lymnaeidae | Galba bulimoides (Lea, 1841) | Prairie Fossaria | CS | G5 | R, I, RE |
| | Lymnaeidae | Galba dalli (Baker, 1907) | Dusky Fossaria | CS | G5 | **?** |
| | Lymnaeidae | Galba modicella (Say, 1825) | Rock Fossaria | CS | G5 | **?** |
| | Lymnaeidae | Galba obrussa (Say, 1825) | Golden Fossaria | CS | G5 | **?** |
| | Lymnaeidae | Galba parva (Lea, 1841) | Pygmy Fossaria | CS | G5 | R, I, RE |
| | Lymnaeidae | Galba rustica (Lea, 1841) | Rusty Fossaria | CS | G5Q | **?** |
| | Lymnaeidae | Galba techella Haldeman, 1867 | [uncertain classification] | V | G3G4Q | R, I, RE |
| | Lymnaeidae | Stagnicola apicina (Lea, 1838) | Abbreviate Pondsnail | CS | G5 | **?** |
| | Lymnaeidae | Stagnicola bonnevillensis (Call, 1884) | Fat-Whorled Pondsnail | E | G1 | R, I, RE |
| | Lymnaeidae | Stagnicola caperata (Say, 1829) | Wrinkled Marshsnail | CS | G5 | **?** |
| | Lymnaeidae | Stagnicola elodes (Say, 1821) | Marsh Pondsnail | CS | G5 | **?** |
| | Lymnaeidae | Stagnicola montanensis (Baker, 1913) | Mountain Marshsnail | V | G3 | R, I, RE |
| | Lymnaeidae | Stagnicola pilsbryi (Hemphill, 1890) | Fish Springs Marshsnail | X | GX | R, I, RE |
| | Lymnaeidae | Stagnicola traski (Tryon, 1863) | Widelip Pondsnail | V | G3 | R, I, RE |
| | Lymnaeidae | Stagnicola utahensis (Call, 1884) | Thickshell Pondsnail | X | GX | R, I, RE |
| | Physidae | Aplexa elongata | lance aplexa | CS | G5 | R, I, RE |
| | Physidae | Physa megalochlamys Taylor, 1988 | Cloaked Physa | V | G3 | R, I, RE |
| | Physidae | Physa skinneri Taylor, 1954 | Glass Physa | CS | G5 | R, I, RE |
| | Physidae | Physella cooperi (Tryon, 1865) | Olive Physa | V | G3 | **?** |

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

[1]The 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.

[2]To 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 single genus *Lampsilis* are highlighted in blue.**

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

## Appendix 23. UDWQ and EPA Recalculation Criteria

**Appendix 23a.** "Resident", "Occurring" or "Not Resident", "Not Occurring" Unionoida and Non-Pulmonate Snails in Jordan River (modified from: Page 3, Revised Deletion Process for the Site-Specific Recalculation Procedure for Aquatic Life Criteria. EPA-823-R-13-001. April 2013)[a].

| | Unionoida Mussels | | Non Pulmonate Snails | | | |
|---|---|---|---|---|---|---|
| **"Resident", "occur at the site"** | *Anodonta* | *Margaritifera* | *Fluminicola* | *Pyrgulopsis* | *Valvata humeralis* | *Valvata utahensis* |
| Usually present at site | No | No | No | No | No | No |
| Present seasonally due to migration | No | No | No | No | No | No |

| | | | | | | |
|---|---|---|---|---|---|---|
| Present intermittently; periodically return to or extend ranges into site | No | No | Possibly | Possibly | ? | ? |
| Were present in the past, not currently present due to degraded conditions, expected to return when conditions improve | No | No | Yes | Yes | Yes | ? |
| Present in nearby bodies of water, not currently present due to degraded conditions, expected to be present when conditions improve | No | No | Yes | Yes | Yes | No |
| | Unionoida Mussels | | Non Pulmonate Snails | | | |
| **Not "resident", "do not occur at site"** | *Anodonta* | *Margaritifera* | *Fluminicola* | *Pyrgulopsis* | *Valvata humeralis* | *Valvata utahensis* |
| Once present but cannot exist due to permanent habitat alterations or other conditions that are not likely to change within reasonable planning horizons | Yes | Yes | No | No | No | No |
| Lentic taxon found in Jordan River because washed through from a lentic site | No | No | No | No | No | No |

[a]These 'resident' and 'non-resident' criteria do not fully reflect our ecological understanding of population dynamics. For example, there are four basic relationships between a taxon and habitat: 1) habitat suitable-taxon present; 2) habitat suitable-taxon absent; 3) habitat not suitable-taxon present and; 4) habitat not suitable-taxon absent. Also, a taxons 'expected presence when conditions improve' explicitly requires an understanding of its connectivity to other populations and dispersal abilities (e.g. metapopulation dynamics). It does not imply that a taxon can be expected to return just because conditions within the site improve.

**Appendix 23b.** G factors. The following table was generated from:
http://water.epa.gov/scitech/swguidance/standards/uses/uaa/about_uaas.cfm
In this table, substituted "the attainment of the use" for taxon "occurrence"

Under 40 CFR 131.10(g) states may remove a designated use which is not an existing use, as defined in § 131.3, or establish sub-categories of a use if the State can demonstrate that attaining the designated use is not feasible because:

| | Unionoida Mussels | | Non Pulmonate Snails | | |
|---|---|---|---|---|---|
| | *Anodonta* | *Margaritifera* | *Fluminicola* | *Pyrgulopsis* | *Valvata* |
| Natural pollutant concentrations prevent occurrence | No | No | No | No | No |
| Natural, ephemeral, intermittent or low flow conditions or water levels prevent occurrence, unless compensated for by effluent discharges | No | No | No | No | No |
| Human caused conditions or sources of pollution prevent occurrence and cannot be remedied[1] or would cause more environmental damage to correct than to leave in place | ? | ? | ? | ? | ? |
| Dams, diversions or other types of hydrologic modifications preclude occurrence and not feasible to restore the water body to its original condition or to operate such modification in a way that would result in occurrence | Yes | Yes | ? | ? | ? |
| Physical conditions related to the natural features of the water body, such as the lack of a proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude occurrence | No | No | No | No | No |
| Controls more stringent than those required new ammonia criteria would result in substantial and widespread economic and social impact | Yes | Yes | ? | ? | ? |

[1]Almost all human caused conditions and sources of pollution can be remedied. If they

are not remedied, then native mussels likely will not re establish.

## Appendix 24. 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 wree 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 Riisgaerd,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 <u>any</u> 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 mantel 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 $N_2$ 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 $H_2S$ (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 $NH_3$ (Burton 1983). Williams and McMahon (1989) showed a 20 to 40-fold increase in $NH_3$ 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 ≈ 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-' 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 25. 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 $\mu$m 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, researches 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/$m^2$ in a eutrophic $5^{th}$ 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:

$$L(\psi, \boldsymbol{p}) = \left[ \psi^{n.} \prod_{\tau=1}^{T} p_{\tau}^{n_\tau} (1 - p_\tau)^{n. - n_\tau} \right] x \left[ \psi \prod_{\tau=1}^{T} (1 - p_\tau) + (1 - \psi) \right]^{N - n.}$$

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.

**Appendix 26. Qualifications of Dr. David C. Richards**

## Summary

Dr. Richards has conducted life history, taxonomic, and ecological studies on freshwater mollusks in the western U.S.A. for over fifteen years. He is considered and expert on several hydrobiid taxa including invasive and threatened species.

- Ph.D. dissertation: "Competition between threatened Bliss Rapids Snail (BRS) and invasive New Zealand mudsnail in Snake River"
- Research Threatened hydrobiid and other gastropods in mid Snake River
    - 9 year project Metapopulation Viability and Risk assessment of BRS
    - Estimated population size of 3 mm, uncommon, non randomly distributed snail in 50 miles of Snake River
- Mollusk Survey Hells Canyon, ID
    - Included surveys for newly discovered *Taylorconcha inspirata*
    - Located and documented several unionoida colonies not previously known
- Numerous other T and E and species of concern mollusk surveys
    - *Pyrgulopsis robusta*
    - *Valvata utahensis*
    - *T. serpenticola*
    - *Margaritifera falcata, Gonidea angulata, Anodonta sp.*
- Raised/reared native and invasive hydrobiids in lab including:
    - *Fluminicola coloradensis, Taylorconcha serpenticola*, NZMS
- Merced River, CA restoration and *Margaritifera falcata* relocation
    - 100% relocation success approximately 23 tagged individuals
- Conducted freshwater mollusk identification workshop
- Mollusk Taxonomist for 10 years
- Member of Science panel for USFWS T & E mollusk species status review
- Senior author of several publications and numerous technical reports on mollusks
- Member
    - Freshwater Mollusk Conservation Society
    - American Malacological Society
    - Malacological Society of London
    - Society Freshwater Sciences

**C.V. with pertinent experience highlighted in yellow**

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February 10, 2014

**Research Interests:** Ecological studies of freshwater ecosystems; biological and ecological assessment and monitoring; and quantitative risk assessments focusing on freshwater mollusks

His complete C.V. follows:

**Professional Experiences:**

2014-Present Director and Senior Research Ecologist, OreoHelix Consulting, Moab, UT
2013- 2014 Aquatic Ecologist, Cramer Fish Sciences, West Sacramento, CA
1999-2012 Senior Research Ecologist, EcoAnalysts, Inc.
2009 Instructor. Introduction to Ecological Statistics. Northwest Environmental Training Center, Seattle WA.
2007-2009 Adjunct Assistant Professor, Department of Ecology, Montana State University, Bozeman, MT
2006-2008 Affiliate Assistant Professor, Land Resources and Environmental Sciences, Montana State University, Bozeman, MT
1997-1999 Biologist, USFWS/Puerto Rico Dept. Natural Resources, San Juan, Puerto Rico
1986-1997 Backcountry Ranger and Trail Crew Leader, Absaroka-Beartooth and Bob Marshal Wilderness, and Yellowstone and Glacier National Parks, fisheries technician Yellowstone National Park

**Education**

Ph.D. 2004 Montana State University; Biology (Dept. Ecology) with minor in Statistics
M. S. 1996 Montana State University; Entomology and Mountain Research Center
B. S. 1987 Montana State University; Biology, Fish and Wildlife Management Option

**Awards, Achievements, and Certificates**

2011 PADI Open Water Scuba Certification
1983-2004 Red Cross Advanced First Aid and CPR
1993 Montana Board of Regents Academic Scholarship
1993 Outstanding Biology Student of the Year, Flathead Valley Community College

**Professional and Public Service Activities**

2006-present Topic-Editor
Encyclopedia of Earth, http://www.eoearth.org/
2001–present Peer-review referee:
American Malacological Society Bulletin
Journal of North American Benthological Society
Western North American Naturalist
Southwest Naturalist
Biological Invasions
Northwest Science
North American Journal of Aquaculture
2001-2005 Initiated and organized 1st, 2nd, 3rd, 4th, and 5th Annual Conference on New Zealand Mudsnail in Western USA, July 9-10, 2001, August 26-28, 2002, August 26-27, 2003, 2005, Bozeman, MT and June 2007, Davis, CA

Field and classroom lecturer: Aquatic Ecology, Stream Ecology, Science Teachers Institute of the Rockies, Montana State University; and local grade schools, Freshwater Mollusk Identification Workshops

**Professional Societies, Conservation Organizations, and Committees**

American Malacological Society
Freshwater Mollusk Conservation Society
American Fisheries Society
Ecological Society of America
Montana Academy of Science
Society for Freshwater Science
PADI Diving Society
Snake River Snail Conservation Plan Technical Committee
Society for Conservation Biology
Working Group for Ecological Economics and Sustainability Science
Western Regional Panel Aquatic Nuisance Species

**Publications**

Carling, G.T, Richards, D.C., Hoven, H., Miller, T., Fernandez, D.P., Rudd, A, Pazmino, E., and W. P. Johnson. Accepted: November 2012. Relationships of surface water, pore water, and sediment chemistry in wetlands adjacent to Great Salt Lake, Utah and potential impacts on plant community health. Science of the Total Environment.

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Richards, D. C., J. Rensel, and Z. Siegrist. 2011. Rufus Woods Lake – Columbia River reservoir morphometrics, initial food web, and rainbow trout fishery studies. Report to Colville Confederated Tribes. Nespelem, WA. 138pp.
Miller, T. G., D. C. Richards, Hoven, H. M., Johnson, W. P., Hogset, M., and G. T. Carling. 2011. Macroinvertebrate communities in Great Salt Lake impounded wetlands and their relationship to water and sediment quality and plant communities. Preliminary report to: Jordan River / Farmington Bay Water Quality Council, Salt Lake City, UT. 67pp.

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**Invited Presentations**

Richards, D. C., J. Rensel, and Z. Siegrist. 2012. Food web and fisheries studies: Rufus Woods Lake, Columbia River, WA. Large river ecology section moderator; Society for Freshwater Science Annual Meeting. Louisville, KT.

Richards, D. C. and T. Arrington. 2012. Predicting and monitoring the effects of a habitat restoration project on metapopulation viability of two federally listed species in a tributary of the Columbia River. Columbia River Estuary Conference. Astoria, OR. May 15-17.

Farley, J. and D. C. Richards. 2008. A critique of economic valuation of ecosystem services and its applicability to sustainable economic policy. Symposium on Economic Growth and Biodiversity: The Elemental Arguments. Society for Conservation Biology Annual Meeting. Chatonooga, TN. July 13-17.

Richards, D. C. and T. Arrington. 2007. Morgan Lake restoration project: Does Lanx sp. have a problem with that? Mid-Snake River Technical Work Group: Quarterly Meeting. September 19. Boise, ID.

Richards, D. C. and T. Arrington. 2007. Evolutionary consequences of a rapidly evolving invasive species to the viability of a native threatened species. Presented Poster. International Summit: Evolutionary Consequences of a Changing Environment. University of California. Los Angeles, CA. February, 2007.

T. Arrington and D. C. Richards. 2007. Predicting the effects of a habitat restoration project on the population viability of one threatened and one endangered lotic gastropod. Mid-Snake River Technical Work Group: Quarterly Meeting. September 19. Boise, ID.

T. Arrington and D. C. Richards. 2007. Predicting the effects of a habitat restoration project on the population viability of one threatened and one endangered lotic gastropod. World Malacological Congress Annual Meeting. Antwerp, Netherlands. July.

Richards, D. C. and T. Arrington. 2006. Empirical estimates of extinction and colonization rates of the threatened Bliss Rapids Snail for use in metapopulation viability analyses. Presented Paper. Snake River Snail Technical Committee Quarterly Meeting. December 12.

Richards, D. C., C. Smith, and B. Marshall. 2006. Effects of New Zealand mudsnail on water quality bioassessment metrics. Presented paper. California Water Quality Bioassessment Annual Meeting. Davis California. November 28-29th.

Richards, D. C., C. M. Falter, G. T. Lester, and R. Myers. 2005. Mollusk survey and basic ecological studies in Hells Canyon, Snake River, USA. Presented paper. 38th Annual Western Society of Malacologists Conference. Asilomar, Pacific Grove, CA. June 26th-30th.

Richards, D. C. ,B. L. Kerans, G. T. Lester, and D. C. Shinn. 2004. Competition between a threatened and invasive snail in a freshwater spring. Presented paper. North American Benthological Society Annual Meeting. Vancouver, BC.

Richards, D. C. 2004. The invasive New Zealand mudsnail: case study. Invited speaker. Western Division American Fisheries Society Annual Meeting. Salt Lake City, Utah. March 1-4.

Richards, D. C. 2004. Conducted New Zealand mudsnail identification workshop. Western Division American Fisheries Society Annual Meeting. Salt Lake City, Utah. March 1-4.

Richards, D. C. and D. C. Shinn. 2003. Spatial distribution of Bliss Rapids Snail and New Zealand mudsnail in a freshwater spring, Idaho, USA. Presented paper. North American Benthological Society Annual Meeting. Athens GA.

Richards, D. C. and D. C. Shinn. 2003. Intra and interspecific competition between Bliss Rapids Snail and New Zealand mudsnail. Presented paper. Society for Conservation Biology Annual Meeting. Duluth, MN.

Richards, D. C. 2002. The New Zealand Mudsnail in the Western USA. 2002. Presented paper. American Malacological Society Annual Conference. Charleston, SC. August 2002.

Richards, D. C. 2002. The New Zealand Mudsnail in the Western USA. Presented paper. Orvis Fishing Guides National Rendezvous, Cody, Wyoming. April 12.

Richards, D. C. 2002. New Zealand mudsnail in the western USA.. Invited paper. Western Regional Panel on Aquatic Nuisance Species Annual Meeting. Las Vegas, Nevada. January 9-10.

Richards, D. C. 2001. The New Zealand mudsnail in the western USA. Presented paper. New Zealand mudsnail in Western USA. First Annual Conference. July 9 and 10, 2001. Montana State University, Bozeman, MT.

Richards, D. C. 2001. Competition between the invader Potamopyrgus antipodarum and a threatened snail species in the Snake River. Presented paper. Aquatic Ecology Group, Montana State University, Bozeman, Montana.

Richards, D. C., G. T. Lester, and D. Cazier. 1999. Basic ecological findings on the New Zealand mudsnail (Potamopyrgus antipodarum) in the Middle-Snake River and the Thousand Springs Complex, Southern Idaho. Presented paper. Seventh Annual Yellowstone National Park Symposium on Exotic Species in Yellowstone. October 11-12, 1999.

Richards, D. C., G. T. Lester, and D. Cazier. 1999. The invasion of the New Zealand mud snail (Potamopyrgus antipodarum) in the Middle Snake River: potential impacts. Presented paper. Ninth Annual Nonpoint Source Water Quality Workshop. Boise, Idaho.

Richards, D. C., M. Rolston, and F. V. Dunkel. 1997. The distribution and abundance of Pteronarcys californica in the Madison River, MT. Presented paper. Montana Chapter of American Fisheries Society Annual Meetings. Bozeman, MT

Richards, D. C. 1996. Macroinvertebrates as water quality indicators in Soda Butte Creek. Presented paper. The Third Interagency Conference on the Soda Butte Creek Watershed. Yellowstone National Park, September 10-11, 1996.

Richards, D. C., M. Rolston, and F.V. Dunkel. 1995. The distribution and abundance of Pteronarcys californica in the Madison River, MT. Poster presentation. Entomological Society of America. Las Vegas, Nevada.

Richards, D. C. and R. Bukantis. 1995. The use of aquatic insects as indicators of water quality in mountain streams in Montana using modified Rapid Bioassessment Protocols. Presented paper. Montana Academy of Sciences; Clark Fork Symposium, Missoula, MT.

Richards, D. C. and F. V. Dunkel. 1994. The use of aquatic insects as indicators of water quality in mountain streams in Montana. Poster presentation. Entomological Society of America. Dallas Texas.

Richards, D.C., F.V. Dunkel, L. VanPuyvelde, and S. Sriharan. 1992. Effect of insecticidal plant extracts on the pirate bug, Xylocoris flavipes. Poster presentation. Entomological Society of America. Baltimore, MD

Rodriquez, D.C., F.V. Dunkel, D.C. Richards, and D.K Weaver. 1992. Fumigative, repellent, and oviposition deterrent properties of mountain sagebrush, Artemesia tridentata, for stored grain insects. Poster presentation. Entomological Society of America. Baltimore, MD.