

**Utah and Colorado
Water Survey for Mussels and Snails**

Draft Study Plan

May 27, 2016

Cooperators

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Attachments:

Work Plan Calendar (Work_Plan_Calendar_27May16.xlsx)

Introduction

The United States Environmental Protection Agency has released new water quality criteria for ammonia (USEPA 2013a, Table 1). These new criteria are designed to ensure that ammonia sensitive species (specifically unionid mussels and non-pulmonate snails) are protected (USEPA 2013a). These new criteria may require that many existing facilities that discharge into waters inhabited by ammonia sensitive species be upgraded to meet the new standards, likely at significant costs to the companies and governments that operate those facilities. The USEPA recognizes that the new criteria may be overly stringent for waters that do not naturally support ammonia sensitive species, and allows states to derive site-specific criteria that reflect each waterbody's potential to support the aquatic life naturally expected at each site (USEPA 2013b,c). Site-specific (or watershed-specific) ammonia criteria may make ecological and financial sense for Utah and Colorado if ammonia-sensitive mollusk species are less common in Utah and Colorado than in other states.

Historical and current distribution records for mussels in the family Unionidae suggest that potentially suitable habitat for these sensitive species may represent a smaller fraction of the streams, lakes, and wetlands in Colorado and Utah than either eastern or far western states. Of the nearly 300 freshwater mussel species in the United States and Canada (Williams et al. 1993), only 3 species are reported by the Colorado Natural Heritage Program and just 3 others from Utah (Hovingh 2004). However, other freshwater mollusks can be much more common, especially Hydrobiidae (spring snails) in Utah and Pisidiidae (= Sphaeriidae) (fingernail and pea clams) in both states.

The synthesis of these data in a user-friendly format will enable Utah and Colorado agencies to identify specific water bodies that will be subject to the new ammonia criteria and represent the first step in identifying the types of water bodies that are either likely to contain ammonia sensitive mollusks or not. Note that, given the scope of the study, we cannot assume that those waters that have no records of occurrence by sensitive mollusks do not (or did not) support those species. Additional study based on other approaches will be needed to fully justify exclusion. These other approaches may include extensive physical surveys to document species absence, physiochemical analyses to document habit unsuitability, environmental DNA surveys, and ecological modeling to predict habitat suitability.

Goals

The overarching goal of the study is to:

Conduct a comprehensive and scientifically defensible search and synthesis of existing records on the historical (after 1800) and current presence of ammonia-sensitive freshwater mussels (Superfamily Unionoidea) and non-pulmonate snails in Utah and Colorado (Valvatidae, Ancyliidae, Hydrobiidae, and Sphaeriidae = Pisidiidae).

Resources and Constraints

The main technical challenge in implementing site-specific ammonia criteria will be in documenting exactly which waters represent both existing and potentially suitable habitat for these species (and are thus subject to the new criteria) and which waters are naturally unsuitable for them (and to which the current, less stringent criteria should apply).

The reliability of species occurrence records largely depends on (1) the accuracy of initial identifications, (2) the accuracy and precision of reported locations, and (3) the accuracy of transcription from field and lab notes into museum and database records. Following guidance in Walsh & Meador (1998), we will assess each occurrence record for errors by (1) determining if identifications were made by taxonomic authorities, lab taxonomists, or unknown, (2) determining if identifications are consistent with current or past taxonomy (ITIS), (3) viewing record locations in Google Earth to determine if reported collection locations are reasonable and unambiguous (e.g., is the collection site clearly in a river versus a nearby tributary), and (4) checking if mapped locations are consistent with reported locations. Many records may be at genus or family level and thus may not represent species of concern to this RFP. For example the spring snail family (Hydrobiidae) includes the invasive New Zealand Mud Snail, which occurs in both Utah and Colorado. For samples processed by the USU/BLM Buglab, we may be able to determine if records are native Hydrobiidae species or New Zealand Mud Snails by re-examining preserved and archived sample material. In other cases, we will note the degree of uncertainty in the record based on notes and comments associated with a record.

Assembling data from literature and database searches require careful attention to accuracy. To this end, we will use peer-reviewed references to the extent possible, and will note data that appears in databases but is not published, or for which methods are not well described. Notes on data quality will be included in sample records.

Utah State University houses an extensive collection of scientific journals in the life sciences, many dating back over a century. Additionally, the USU Merrill library has a well-developed Interlibrary Loan system through which patrons can quickly obtain volumes or books that are not in the physical collections. The Government Documents section of the Merrill Library and the USU Quinney Library are known for their extensive collections of federal, state, and county-level agency reports. These resources are available to faculty and students.

Drs. Hawkins and Mock both have research laboratories, office space, and the computational resources to perform the proposed work. Additionally, the Quinney College of Natural Resources has an internationally respected Geographic Information Systems (GIS) laboratory, which is capable of producing high-quality imagery for the

final report and the database. Dr. Mock has the software and hardware necessary for phylogenetic analysis. Dr. Hawkins co-supervises the USU/BLM BugLab database.

In addition to the facilities and equipment existing in the research laboratories of Drs. Hawkins and Mock, the project will require dedicated time from both PIs, a dedicated technician, supervised by both PIs, who will compile search data and construct the database of records, and a GIS technician to construct maps for the database and final report. These items comprise the proposed budget.

Strategy and Actions

We will identify and review existing literature, reports, databases, or other sources of information to determine current or historical presence of unionid mussels and/or non-pulmonate snails in all Utah and Colorado surface waters. Tasks will include:

1. Establish a history of nomenclature (taxonomic history)
2. Search available surveys and databases for unionid mussel and/or non-pulmonate snail species with records in Utah and Colorado
3. Search available scientific journals and federal or state agency reports
4. Search museum records which are likely to have specimens from Utah and/or Colorado
5. Contact academic colleagues and agency personnel to discover additional sources of information
6. Determination of phylogeny of target species occurring in Utah and Colorado, relative to species in the national toxicology database.

The deliverables will include a digital compilation of occurrence records that can be imported and searched in Excel or similar software, as well as a final report that provides a description of methods used, a summary and details of our findings, extensive annotated references, and recommendations for next steps

Deliverables

A searchable spatial database with fields similar to those in the web-based MAPIT utility that is supported by USU's Western Center for Monitoring & Assessment of Freshwater Ecosystems. For example, tabular data will include (as available) taxonomic information, threatened or endangered status, resident vs. nonresident, survey and collection date, nature of specimen (live vs. shells), taxonomic authority of person making identification, location name, geographic coordinates, sampling method, habitat type, number of individuals, habitat type/substrate, estimated viability/threats, and any relevant comments and notes. Additional tabular data may be added or removed as deemed appropriate.

Metadata for all compiled data will include quality assurance (QA) information in terms of a metric of confidence based on the design and purpose of the survey, the detail and quality of the report, and who made the identifications. For example,

routine survey data may report some individuals at only the genus or family name. For some families (e.g., Hydrobiidae), native and introduced species may be confused or lumped (e.g., the New Zealand Mudsail). Locations where mollusks were surveyed but **not observed** will also be reported and mapped. The final report will include:

1. Documentation of search methods and results
2. A full list of annotated references
3. A set of detailed recommendations for next steps.

Taxonomic History

The advent of genetic, morphological, and computational tools has resulted in many taxonomic changes in unionid freshwater mussels and non-pulmonate snails in recent decades. As a result, searching database entries, scientific publications, and museum records for these species may require the use of multiple nomenclatures. As species records are encountered in the searches of taxonomic history, taxonomic synonymies and common names will be tracked and will be used as additional search terms.

Database and Survey Searches

The target species, genera, and families, along with their previous taxonomic designations and common species names will be used to search a variety of databases for records of occurrence and links to scientific publications.

Literature Searches

Both the Web of Science and Google Scholar will be used to search for species names of the freshwater mussels and non-pulmonate snails (as well as and their common names and past synonymies) in the scientific literature. Because many survey and occurrence reports are not published in the journals covered by Web of Science or other resources covered by Google Scholar, we will also use the services of the S.J. and Jessie E. Quinney Natural Resources Research Library on the USU campus to search the “grey literature”, i.e. information in agency reports. The Quinney Library specializes in grey literature searches, and houses many historical agency reports that are unavailable elsewhere.

Museum Record Searches

Many museums curate specimens which were collected across several states, and have their collections accessible online. The following museums and museum collection references will serve as a starting place for identifying records of target species occurrence in Colorado and Utah. We anticipate that these records will lead to others at other museums, and we will follow those linkages.

Personal and Agency Contacts

Some universities and state agencies maintain survey records and collections that are not part of more generally accessible databases. In order to discover these records, we will contact invertebrate biologists at the Departments of Natural Resources in both Utah and Colorado. We will also attempt to contact aquatic invertebrate researchers at other colleges and universities in both states about these types of records and collections. The PIs are particularly well-qualified to perform this task since they are frequently in contact with invertebrate biologists at state agencies and other academic institutions.

Phylogenetic Analyses

For each species in the target families found to be historically present in Utah or Colorado, the current taxonomic designation (Family, Genus, Species) according to the Integrated Taxonomic Information System (ITIS) will be provided. Most of the taxa identified in our proposed search will not be present in the national toxicity dataset (USEPA 2013a). In such cases, the EPA recommends "...to consider which tested species are most closely related to those occurring at the site and to delete those for which another tested species would better represent the species occurring at the site" (USEPA 2013b). Anticipating that the request for phylogenetic analysis of taxa identified in our search is motivated by this recommendation, for each identified taxon in our search we will identify the most closely related taxa in the national toxicity dataset (USEPA 2013a) and will include this information both in the final report and in the resulting database. Generally, closely related taxa are presumed to be toxicologically similar (USEPAa,b), and taxa that are only distantly related to tested taxa may warrant separate testing in the future. However, we emphasize that phylogenetic similarity may not predict toxicological similarity, which we will discuss in our final report. Toxicological similarity may be influenced by common ancestry, but it may also be influenced by local selection pressures (Blomberg et al. 2003; Losos 2008). Thus, historical local conditions may also influence toxicity responses and may be important to consider in future work.

To assess phylogenetic affiliations, we will use published phylogenies (peer-reviewed literature with clear and defensible methods), based on either genetic or morphological data or both (where well developed and appropriate). Co-PI Mock is particularly well qualified to make this determination, since her research focuses on phylogenetic and phylogeographic relationships. Additionally, co-PI Mock is one of a team of international researchers currently revising the phylogenetic relationships among the Unionidae. If necessary, we will use existing genetic data (available on NCBI GenBank) to reconstruct phylogenies, using currently accepted computational methods (e.g. PAUP4.0 (Swofford 2002), MEGA 4.0 (Tamura et al. 2013), Geneious 8.1 (Kearse et al. 2012), and NCBI GenBank tools).

Appendix A – Schedule

See attached Work Plan Calendar (Work_Plan_Calendar_27May16.xlsx) for study plan timeline.

USU Collaborators will hold weekly meetings to discuss study progress, identify concerns and ensure project is on schedule.

Monthly meetings will be held between USU Principal Investigators, and representatives from Utah and Colorado tentatively scheduled for the 1st Wednesday of every month starting June 1, 2016.

Work Schedule

April 6, 2016 – Contract Issuance

May 2016 -

- Prepare and submit draft study plan.
- Create literature and species databases.

June 1, 2016 – Draft Study Plan to Utah and Colorado for review.

July 7, 2016 – End public comment period of study plan by UDWQ.

July 28, 2016 – Response to study plan comments.

July 2016 –

- Identify and query governmental, non-governmental, and academic mollusk specialists.
- Populate database.

August 4, 2016 – UDWQ and Colorado approval of comment responses.

August 2016 to February 2017 – Continue activities, incorporating changes to study plan.

September 1, 2016 – Final Study Plan to Utah and Colorado.

November 2016 – Perform quality assurance/quality control on databases.

2017

January 2017 – Map species occurrences.

Appendix A – Schedule

February 2017 – Prepare and submit final report.

April 6, 2017 – Draft final report including tabular database output and geospatial locations.

May 13, 2017 – End of public comment period of draft report.

June 3, 2017 – Respond to comments of draft report.

June 6, 2017 – Deliver final report and tabular data.

Appendix B – Resources

Initially, the following publications (and references within) will be searched for information on both the presence and documented absence of target species in Utah and Colorado (below). The references and links within these resources will also be located and searched as appropriate.

Note:

This is not a complete list and more will be added or removed depending on relevancy to the project.

Taxonomic History

Basch P (1963) A review of the recent freshwater limpet snails of North American
Bulletin of the Museum of Comparative Zoology Harvard 129: 399-461.

Catalogue of Life: 2015 Annual Checklist

Cummings KS, & Mayer CA (1992) Field Guide to Freshwater Mussels of the Midwest.
Illinois Natural History Survey, Manual 5. 194 pp.

Encyclopedia of Life portal (in collaboration with the Biodiversity Heritage Library, the Barcode of Life, the Catalog of Life, and the Global Biodiversity Information Facility.

Freshwater Mollusk Conservation Society (FMCS). 2013. Freshwater gastropods.

Hershler R (1994) A review of the North American freshwater snail genus
Pyrgulopsis (Hydrobiidae). Smithsonian Contributions to Zoology 554: 1-115.

Hershler R (1998) A systematic review of the hydrobiid snails (Gastropoda: Rissooidea) of the Great Basin, western United States. Part I, Genus Pyrgulopsis Veliger 41: 1 - 132.

Hershler R (1999) A systematic review of the hydrobiid snails (Gastropoda: Rissooidea) of the Great Basin, western United States. Part II, Genera Colligyris, Genera Colligyris, Eremopyrgus, Fluminicola, Pristinicola, and Tryonia. Veliger 42: 306 - 338.

Hershler R, Liu H-P, Sada DW (2007) Origin and diversification of the Soldier Meadow springsnails (Hydrobiidae: Pyrgulopsis): A species flock in the northwestern Great Basin, USA. Journal of Molluscan Studies 73: 167 - 183.

Huff SW, et al., 2004. Investigations into the phylogenetic relationships of the threatened freshwater pearl-mussels (Bivalvia, Unionoidea, Margaritiferidae) based on molecular data: implications for their taxonomy and biogeography. Journal of Molluscan Studies Journal of Molluscan Studies, 70, pp.379-388.

Appendix B – Resources

Integrated Taxonomic Information System (ITIS)

Turgeon DD, Quinn Jr. JF, Bogan AE, Coan EV, Hochberg FG, Lyons WG, et al.. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks, 2nd edition. American Fisheries Society, Special Publication 26. American Fisheries Society, Bethesda, Maryland.

Walker B (1902) A revision of the carinate Valvatas of the United States. Nautilus 15: 121-125.

Database and Survey Searches

BLM/USU BugLab database

Colorado Natural Heritage Program (and referenced reports/records)

Freshwater Mollusk Conservation Center at Virginia Tech

Illinois Natural History Survey and listed museum resources

MUSSEL Project

National Parks Service Integrated Resource Management Applications (IRMA) portal:
NPS Species database

Natural Heritage New Mexico, Museum of Southwestern Biology, University of New Mexico

NatureServe Explorer

Ohio State University Freshwater Bivalve Collection

The Xerces Society

USEPA National Aquatic Resources Surveys

USEPA Technical Support Document (USEPA 2013c)

USGS BioData

Utah Conservation Data Center

Utah Natural Heritage Program

Wyoming Natural Diversity Database

Appendix B – Resources

Literature Searches

- Burch JB (1975) Freshwater Unionacean Clams (Mollusca: Pelecypoda) of North America. University of Michigan, Ann Arbor. 204 pp.
- Chong JP, Brim Box JC, Howard JK, Wolf D, Myers TL, Mock KE (2008) Three deeply divided lineages of the freshwater mussel genus *Anodonta* in western North America. *Conservation Genetics* 9, 1303-1309.
- Clarke AH (1976) Endangered freshwater mollusks of northwestern North America. *Bulletin of the American Malacological Union* 1:18–19.
- Cordeiro JR (1999) Natural history inventory of Colorado No. 19: distribution and habitat of freshwater mussels (Bivalvia: Unionoida: Unionidae) in Colorado. University of Colorado Museum, Boulder, Colorado.
- Clarke AH, Hovingh P, Clarke J (2003) Final report: a survey of the freshwater mollusks and crayfishes of eastern Colorado, at altitudes of less than 6000 feet, carried out during 2001 and 2002 by Ecosearch Inc. for the Colorado Division of Wildlife, State of Colorado. Contract No. PSC-701-2001.
- Freshwater Mollusk Bibliography Database (last updated 18 March 2014), Illinois Natural History Survey, University of Illinois
- Hershler R. (1998) A systematic review of the hydrobiid snails (Gastropoda: Rissooidea) of the Great Basin, Western United States. Part I. Genus *Pyrgulopsis*. *Veliger* 41:1–132.
- Hovingh P (1993) Zoography and paleozoology of leeches, molluscs, and amphibians in Western Bonneville Basin, Utah, USA. *Journal of Paleolimnology* 9:41-54.
- Hovingh P (2004) Intermountain freshwater mollusks, USA (*Margaritifera*, *Anodonta*, *Gonidea*, *Valvata*, *Ferrissia*): Geography, conservation, and fish management implications. *Monographs of the Western North American Naturalist* 2:109–135.
- Keleher MJ, Rader RB (2008) Bioassessment of Artesian Springs in the Bonneville Basin Utah, USA. *Wetlands* 28:1048–1059.
- Mock KE, Brim Box JC, Miller MP, Downing ME, and Hoeh WR (2004) Genetic diversity and divergence among freshwater mussel (*Anodonta*) populations in the Bonneville Basin of Utah. *Molecular Ecology* 13, 1085-1098.
- Oesch RD (1984) Missouri Naiades. Missouri Department of Conservation. Jefferson City. 270 pp.

Appendix B – Resources

Oliver GV and Bosworth III, WR (1999) Rare, imperiled, and recently extinct or extirpated mollusks of Utah: a literature review. Publication 99-29. Utah Division of Wildlife Resources, Salt Lake City. 230 pp.

Taylor DW (1987) Freshwater mollusks from New Mexico and vicinity. New Mexico Bureau of Mines and Mineral Resources Bulletin 116:1–50.

University of Colorado Museum, Freshwater Mollusks literature database. Boulder, Colorado.

Watters GT (1994) A Guide to the Freshwater Mussels of Ohio (Rev Ed.) Division of Wildlife, Ohio Department of Natural Resources, Columbus. 106 pp.

Williams JD, Warren Jr. ML, Cummings KS, Harris JL, Neves RJ (1993) Conservation status of freshwater mussels of the United States and Canada. Fisheries 18:6–22. (including museum records and references within)

Wu S, Liu H (1989) Natural History Inventory of Colorado No. 11: Colorado.

Museum Record Searches

Hovingh P (1993) Zoography and paleozoology of leeches, molluscs, and amphibians in Western Bonneville Basin, Utah, USA. Journal of Paleolimnology 9:41-54.

(including museum records and references within)

Hovingh P (2004) Intermountain freshwater mollusks, USA (Margaritifera, Anodonta, Gonidea, Valvata, Ferrissia): Geography, conservation, and fish management implications. Monographs of the Western North American Naturalist 2:109–135.

(including museum records and references within)

Monte L. Bean Life Science Museum, Brigham Young University, Mollusk Collections.

Natural History Museum of Utah, Malacology Collection.

North Carolina Museum of Natural Sciences Invertebrates database.

Williams JD, Warren Jr. ML, Cummings KS, Harris JL, Neves RJ (1993) Conservation status of freshwater mussels of the United States and Canada. Fisheries 18:6–22. (including museum records and references within)

University of Colorado Museum of Natural History Mollusc Collection database.

Appendix B – Resources

Phylogenetic Analyses

Cooley LR, Foighil DÓ (2000), Phylogenetic analysis of the Sphaeriidae (Mollusca: Bivalvia) based on partial mitochondrial 16s rDNA gene sequences. *Invertebrate Biology* 119: 299–308.

Molecular Systematics and Phylogeography of Mollusks. C. Lydeard and D. R. Lindberg, eds. Smithsonian Institution, Washington, DC.

Tree of Life Web Project. 1995. Mollusca. Snails, clams, mussels, squids, octopi, chitons, and tusk shells. Version 01 January 1995.

Appendix C – References

- Blomberg SP, Garland Jr. T, Ives AR (2003) Testing for phylogenetic signal in comparative data: behavioral traits are more labile. *Evolution* 57: 717-745.
- BLM/USU BugLab database (www.usu.edu/buglab/)
- Burch JB (1975) Freshwater Unionacean Clams (Mollusca: Pelecypoda) of North America. University of Michigan, Ann Arbor. 204 pp.
- Burch JB (1989) North American freshwater snails. Malacological Publications, Hamburg, Michigan.
- Clarke AH (1976) Endangered freshwater mollusks of northwestern North America. *Bulletin of the American Malacological Union* 1:18–19.
- Clarke AH, Hovingh P, Clarke J (2003) Final report: a survey of the freshwater mollusks and crayfishes of eastern Colorado, at altitudes of less than 6000 feet, carried out during 2001 and 2002 by Ecosearch Inc. for the Colorado Division of Wildlife, State of Colorado. Contract No. PSC-701-2001.
- Colorado Natural Heritage Program (and referenced reports/records) (<http://www.cnhp.colostate.edu/download/reports.aspx>)
- Cordeiro JR (1999) Natural history inventory of Colorado No. 19: distribution and habitat of freshwater mussels (Bivalvia: Unionoida: Unionidae) in Colorado. University of Colorado Museum, Boulder, Colorado.
- Cummings KS, & Mayer CA (1992) Field Guide to Freshwater Mussels of the Midwest. Illinois Natural History Survey, Manual 5. 194 pp.
- Freshwater Mollusk Conservation Society (FMCS). 2013. Freshwater gastropods. (http://molluskconservation.org/Snails_Ftpage.html).
- Freshwater Mollusk Conservation Center at Virginia Tech (<http://fishwild.vt.edu/mussel/>)
- Freshwater Mollusk Bibliography Database (last updated 18 March 2014), Illinois Natural History Survey, University of Illinois (<http://ellipse.inhs.uiuc.edu:591/mollusk/default.html>)
- Hershler R. (1998) A systematic review of the hydrobiid snails (Gastropoda:Rissooidea) of the Great Basin, Western United States. Part I. Genus *Pyrgulopsis*. *Veliger* 41:1–132.
- Hovingh P (1993) Zoography and paleozoology of leeches, molluscs, and amphibians in Western Bonneville Basin, Utah, USA. *Journal of Paleolimnology* 9:41-54.

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Hovingh P (2004) Intermountain freshwater mollusks, USA (*Margaritifera*, *Anodonta*, *Gonidea*, *Valvata*, *Ferrissia*): Geography, conservation, and fish management implications. *Monographs of the Western North American Naturalist* 2:109–135.

Illinois Natural History Survey (<http://www.inhs.illinois.edu/collections/mollusk>) and listed museum resources (<http://www.inhs.illinois.edu/collections/mollusk/links/list#NA>)

Integrated Taxonomic Information System (ITIS) (<http://www.itis.gov>)

Kearse M, Moir R, Wilson ., Stones-Havas S, Cheung M, Sturrock S, Buxton S, et al. (2012) Geneious Basic: an integrated and extendable desktop software platform for the organization and analysis of sequence data. *Bioinformatics* 28: 1647-1649.

Keleher MJ, Rader RB (2008) Bioassessment of Artesian Springs in the Bonneville Basin Utah, USA. *Wetlands* 28:1048–1059.

Losos JB (2008) Phylogenetic niche conservatism, phylogenetic signal and the relationship between phylogenetic relatedness and ecological similarity among species. *Ecology Letters* 11: 995-1007.

Monte L. Bean Life Science Museum
(<http://mlbean.byu.edu/ResearchCollections/Collections/Mollusk.aspx>)

MUSSEL Project (<http://mussel-project.uwsp.edu/about.html>)

National Parks Service Integrated Resource Management Applications (IRMA) portal: NPS Species database (<https://irma.nps.gov/NPSpecies/>)

Natural Heritage New Mexico, Museum of Southwestern Biology, University of New Mexico (<http://www.msb.unm.edu/>)

NatureServe. 2014. NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.1. NatureServe, Arlington, Virginia. Available <http://explorer.natureserve.org>

North Carolina Museum of Natural Sciences (<http://collections.naturalsciences.org/>)

Oesch RD (1984) Missouri Naiades. Missouri Department of Conservation. Jefferson City. 270 pp.

Ohio State University Freshwater Bivalve Collection
(<http://www.biosci.ohio-state.edu/~molluscs/OSUM2/>)

Appendix C – References

- Oliver GV and Bosworth III, WR (1999) Rare, imperiled, and recently extinct or extirpated mollusks of Utah: a literature review. Publication 99-29. Utah Division of Wildlife Resources, Salt Lake City. 230 pp.
- Swofford DL (2002) PAUP*. Phylogenetic Analysis Using Parsimony (*and Other Methods). Version 4. Sinauer Associates, Sunderland, Massachusetts.
- Tamura K, Stecher G, Peterson D, Filipski A, and Kumar S (2013) MEGA6: Molecular Evolutionary Genetics Analysis Version 6.0. *Molecular Biology and Evolution* 30: 2725-2729.
- Taylor DW (1987) Freshwater mollusks from New Mexico and vicinity. *New Mexico Bureau of Mines and Mineral Resources Bulletin* 116:1–50.
- Tree of Life Web Project. 1995. Mollusca. Snails, clams, mussels, squids, octopi, chitons, and tusk shells. Version 01 January 1995. (<http://tolweb.org/Mollusca/2488/1995.01.01> in The Tree of Life Web Project, <http://tolweb.org/>)
- Turgeon DD, Quinn Jr. JF, Bogan AE, Coan EV, Hochberg FG, Lyons WG, et al.. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks, 2nd edition. American Fisheries Society, Special Publication 26. American Fisheries Society, Bethesda, Maryland.
- United States Environmental Protection Agency (USEPA). 2013a. Aquatic life ambient water quality criteria for ammonia - freshwater 2013. EPA-822-R-13-001. National Technical Information Service, Springfield, VA.
- United States Environmental Protection Agency (USEPA). 2013b. Revised deletion process for the site-specific recalculation procedure for aquatic life criteria. EPA-823-R-13-001. National Technical Information Service, Springfield, VA.
- United States Environmental Protection Agency (USEPA). 2013c. Technical support document for conducting and reviewing freshwater mussel occurrence surveys for the development of site-specific water quality criteria for ammonia. EPA 800-R-13-003. National Technical Information Service, Springfield, VA.
- United States Environmental Protection Agency (USEPA) National Aquatic Resource Surveys (http://water.epa.gov/type/watersheds/monitoring/aquaticsurvey_index.cfm)
- United States Geological Survey (USGS) BioData (<https://aquatic.biodata.usgs.gov/landing.action>)
- University of Colorado Museum of Natural History

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[\(\[http://cumuseum- archive.colorado.edu/Research/Zoology/zoology_coll_molluscs.html\]\(http://cumuseum- archive.colorado.edu/Research/Zoology/zoology_coll_molluscs.html\)\)](http://cumuseum- archive.colorado.edu/Research/Zoology/zoology_coll_molluscs.html)

Utah Conservation Data Center (<http://dwrcdc.nr.utah.gov/ucdc/>)

Watters GT (1994) A Guide to the Freshwater Mussels of Ohio (Revised Edition)
Division of Wildlife, Ohio Department of Natural Resources, Columbus. 106 pp.

Williams JD, Warren Jr. ML, Cummings KS, Harris JL, Neves RJ (1993) Conservation
status of freshwater mussels of the United States and Canada. Fisheries 18:6–22.

Wu S, Liu H (1989) Natural History Inventory of Colorado No. 11: Colorado
University of Colorado Museum, Freshwater Mollusks. Boulder, Colorado.

Wyoming Natural Diversity Database (<http://www.uwyo.edu/wyndd/>)

The Xerces Society (<http://www.xerces.org/mollusks/>)