Distribution and Status of Freshwater Mussels in the Umatilla River System

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The Distribution and Status of Freshwater Mussels in the Umatilla River System

2003 Annual Report
(September 30, 2002 – September 30, 2003)

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EXECUTIVE SUMMARY

Freshwater mussels are valuable components of intact salmonid ecosystems and are culturally important to Native Americans. An inventory of freshwater mussels in the Umatilla, Middle Fork John Day and North Fork John Day rivers in Oregon was conducted in the summer of 2003. Mussels were found at all sites surveyed in the Middle and North forks of the John Day River, but at less than 10% of the sites sampled in the Umatilla River system. All three genera of mussels known for the western United States were found in the Middle Fork John Day River, and co-occurred at almost 50% of the sites sampled. In the Umatilla River, two genera were found, *Anodonta* and *Gonidea*, but only in the lower main stem and in one tributary. Live *Margaritifera* were not found in the Umatilla River, although historically they occurred in the system. Shell material collected in the current survey suggests they occurred in the Umatilla river main stem until very recently. Based on preliminary data, speckled dace (*Rhinichthys osculus*) serve as a host for *Anodonta* glochidia in the Middle Fork John Day River. Habitat degradation, including active channel change, and the decline of salmonid and other native fish populations may have contributed to the extirpation of mussels from historical locations. The data collected in this survey will be used to provide essential information for designing a recovery plan for freshwater mussels in the Umatilla River system.

INTRODUCTION

Freshwater mollusks are an integral component of aquatic ecosystems and are indicator species for assessing the health of freshwater environments. The richest freshwater mollusk fauna in the world is found in North America north of Mexico, and is represented by about 600 species of gastropods and 340 species of bivalves. Freshwater mussels are considered the most endangered faunal group in North America (Master 2000), with over 70% of species either imperiled or extinct (Neves et al. 1997). Extinction rates for freshwater mussels are an order of magnitude higher than expected background levels (Nott et al. 1995), and mussels are imperiled disproportionately relative to terrestrial species (e.g., birds and mammals) (Williams et al. 1993). In addition, freshwater mollusks have the dubious distinction of experiencing the highest number of documented extinctions of any major taxonomic group (Lydeard et al. 2004).

Although the greatest diversity of freshwater mollusks occurs in the southeastern United States, the western states (i.e., the 11 states, excluding Alaska and Hawaii, wholly or partially located west of the Rocky Mountains) contain at least six endemic mussel species, and many endemic snail species. Historically, at least seven mussel species occurred in Oregon and Washington: the western pearlshell, *Margaritifera falcata* (Gould, 1850); western ridged mussel, *Gonidea angulata* (I. Lea, 1838); Yukon floater, *Anodonta beringiana* Middendorff, 1851; California floater, *Anodonta californiensis* I. Lea, 1852; western floater, *Anodonta kennerlyi* I. Lea, 1860; winged floater, *Anodonta nuttalliana* I. Lea, 1838; and Oregon floater, *Anodonta oregonensis* I. Lea, 1838 (USDA Forest Service 2004, Williams et al. 1993, Frest and Johannes 1995).

Records of western freshwater mussels date from the mid-1800s, and isolated collections were made throughout the region over the next century. However, there is a dearth of current information on the distribution and abundance of western freshwater mollusks, mainly because comprehensive surveys throughout their distributional ranges have not been completed. There is also considerable confusion regarding the taxonomic status of western species, and the exact number of valid species that occur in the western United States is not clear. For example, historically 11 species were identified from Oregon (USDA Forest Service 2004) but of these species, only seven are currently recognized as valid (Turgeon et al. 1998). Although most western states, including Oregon and Washington, recognize that mollusk populations are declining, conservation and recovery efforts are hampered by the lack of basic information on western mussel ecology, life histories, genetics, zoogeography and systematics.

Freshwater mussels, in contrast to most bivalves, have highly specialized life histories, including a life stage called a glochidium that is an obligate parasite of fish, undergoes metamorphosis, and drops off to become a free-living juvenile mussel. The mussel/fish relationship is usually species-specific, in that only certain fish species can serve as suitable hosts for a particular mussel species (Brunderman and Neves 1993, Haag and Warren 1997). However, the relationship between unionids and their fish hosts is not well understood. Although the discovery of the parasitic life stage on fishes was first reported by Leydid in 1866 (Howard 1914), only about a quarter of the fish hosts for North American unionids have been reported, most of these in taxa from the eastern United States (Watters 1994).

Anthropogenic environmental changes that affect either member in this host/parasite relationship are likely to have a serious impact on the diversity and abundance of freshwater mussels. Since the early part of this century, 7% of the native North American freshwater mussel fauna has become extinct, and an additional 72% is considered endangered, threatened, or of special concern (Williams and Neves 1995), making freshwater mussels the most imperiled fauna in North America (Master et al. 2000). During this same period, 5% of the native North American fish fauna disappeared. An additional 364 fish species are considered endangered, threatened, or of special concern (Williams et al. 1989). Because these two faunas are inexorably linked, it seems reasonable to assume that the disappearance of the host fish may also cause the extirpation of freshwater mussels from the same river reaches or entire river systems. Alternatively, the same environmental stresses (e.g., pollution, habitat alteration) may influence the abundance and distribution of fish and mussels in similar ways (e.g., causing extirpations), but independently. In addition, most western drainages also contain a number of nonindigenous fishes, and their impacts on native mussel populations are unknown.

Native freshwater mussels provide important ecosystem services and are a powerful management tool for maintaining and reclaiming water quality (Kreeger 2004). Freshwater mussels are abundant benthic-pelagic couplers in stream systems (Leff et al. 1990, Strayer et al. 1999, Vaughn and Hakenkamp 2001). As long-lived filter feeders, mussels can remove large amounts of particulate matter from the water column, and transfer those resources to the substrate as biodeposits (agglutinated mussel feces and pseudofeces). For example, in the Brandywine River in southeast Pennsylvania, it was estimated that a single population of approximately 500,000 *Elliptio complanata* removed more than 25 metric tons of suspended particulates per year during base flow conditions (Kreeger et al. 2004). Small, suspended particles that may not otherwise settle from the water are made available as a food or structural resource at the bed, thereby potentially stimulating benthic productivity. Mussels have been found to play a significant role in local food webs by increasing the flux of organic and inorganic matter to the river bed, which in turn influences macroinvertebrate assemblages (Howard and Cuffey 2004). In addition, freshwater mussels seasonally influence the trophic structure of stream ecosystems by increasing the amount of fine inorganic and organic matter on the substrate.

Mussels cycle nutrients via translocation, excretion and egestion. Translocated nutrients (pseudofeces), and egested nutrients (feces) may enrich the substrate (Roditi et al. 1997, Nalepa et al. 1991, Greenwood et al. 2001). This enrichment may in turn influence the local distribution and abundance of benthic invertebrates (Ricciardi et al. 1997), while providing food for higher trophic feeders such as fishes. Excreted nutrients are released as solutes, and provide nutrients for primary producers (Nalepa et al. 1991, Davis et al. 2000). Mussel biodeposits are a nutrient rich and easily assimilated food source (Nalepa et al. 1991), and are known to be an important source of both phosphorus (Nalepa et al. 1991) and nitrogen (Greenwood et al. 2001, Roditi et al. 1997). Mussels, therefore, may have significant trophic relevance in the benthic community structure by converting and redirecting food resources, and providing indirect links between trophic levels. In addition, freshwater mussels filter large amounts of waters and therefore contribute to maintaining water clarity (McMahon and Bogan 2001). Freshwater mussels can also be important food items for fish, mink, otters and raccoon (Dillon, Jr. 2000). Given that freshwater mussels are an endangered global resource, they are assigned tremendous ecological importance by many freshwater biologists (Corn 1994).

Throughout North America freshwater mussels were historically vital components of intact aquatic ecosystems. Over the past 200 years freshwater mussel populations have been impacted directly and indirectly by a myriad of factors, including but not limited to, dams, channel modifications, agriculture and forestry practices, and the loss of host fish species (Williams et al. 1992, Layzer et al. 1993, Brim Box and Mossa 1999). These same changes in the Columbia River Basin have likely affected the distribution of freshwater mussel populations in the Umatilla, John Day, and other mid-Columbia drainages.

Historically freshwater mussels were an important food for tribal peoples of the Columbia River Basin, and the archeological record of harvest goes back over 10,000 years in the basin (Lyman 1984). Freshwater mussels were harvested during salmon fishing or when river conditions were favorable. In addition, mussels provided a source of ornament shells, which have been found at burial sites in the lower Umatilla River (Osborne 1951). Although the use of freshwater shellfish has declined in recent decades due to changes in subsistence needs, the harvest of freshwater shellfish remains a reserved treaty right.

Tribal and federal agencies would like to restore freshwater mussels to the Umatilla River Basin as part of their ongoing efforts to rebuild ecosystem diversity, function, and traditional cultural opportunities in the basin. In addition, the Umatilla Subbasin Summary calls for strategies to "conduct initial investigations and develop a restoration plan for freshwater shellfish in the Umatilla River." However, restoration efforts face these challenges; 1) little empirical data exists on the current status and distribution of freshwater mussels to guide recovery programs; 2) if freshwater mussels have been extirpated from the Umatilla River Basin, efforts to reestablish mussels will depend on transplants from other watersheds where mussels are extant; 3) genetic and other information is lacking regarding the suitability of available mussel populations for restoration into the Umatilla Basin. In addition, transplanting mussels from other rivers may not be successful if the source animals have local adaptations that are detrimental in the new river system. Little is known about the genetic diversity of freshwater mussels in the Pacific Northwest. Because they rely on fish as hosts, freshwater mussels may have evolved similar patterns of genetic differences as their host fish populations that, in some cases, show evidence of local adaptation (Taylor 1991).

Local adaptation of parasites to genetically different hosts can result in a mosaic of geographically distinct groups (Thompson 1994). Successful transplants of mussels, therefore, may depend on choosing a source that is genetically and ecologically suitable.

PROJECT OBJECTIVES

The project had the following main objectives; to determine the distribution and status of freshwater mussels in the Umatilla and Middle Fork John Day rivers (Figure 1), examine, qualitatively, habitat variables that could influence mussel distribution in these systems, determine the historical distribution of freshwater mussels in the two rivers, and assess the degree and pattern of population-level genetic structuring within and between the Umatilla and Middle Fork John Day rivers. In addition, preliminary host fish data were obtained, although this objective was not included in the original scope of work.

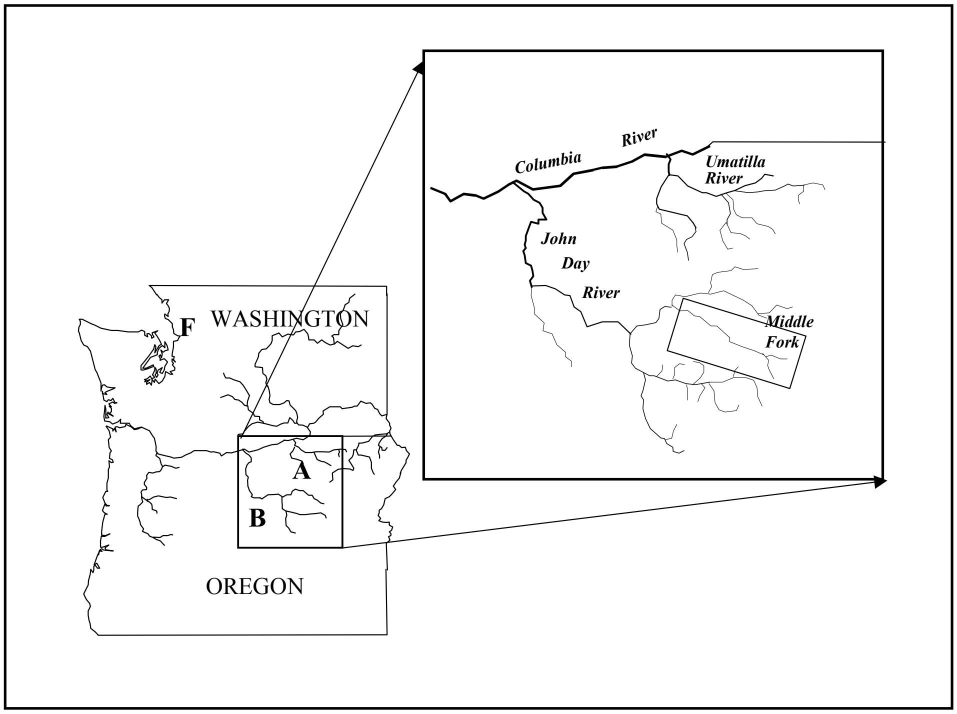

Figure 1. A map of the Umatilla and John Day rivers. The Middle Fork John Day River is highlighted on the insert.

STUDY AREA

Umatilla River Drainage

The Umatilla River Basin is located in northeastern Oregon, in the Middle Columbia Basin, and drains an area of over 6,000 km^2 (James et al. 2001) (Figure 2). The 185-km river originates in the conifer forests of the Blue Mountains, east of Pendleton, and flows northwesterly across the semi-arid shrub steppe of the Deschutes-Umatilla Plateau until it enters the Columbia River at approximately river kilometer 465 (Contor et al. 1996, Phillips et al. 2000).

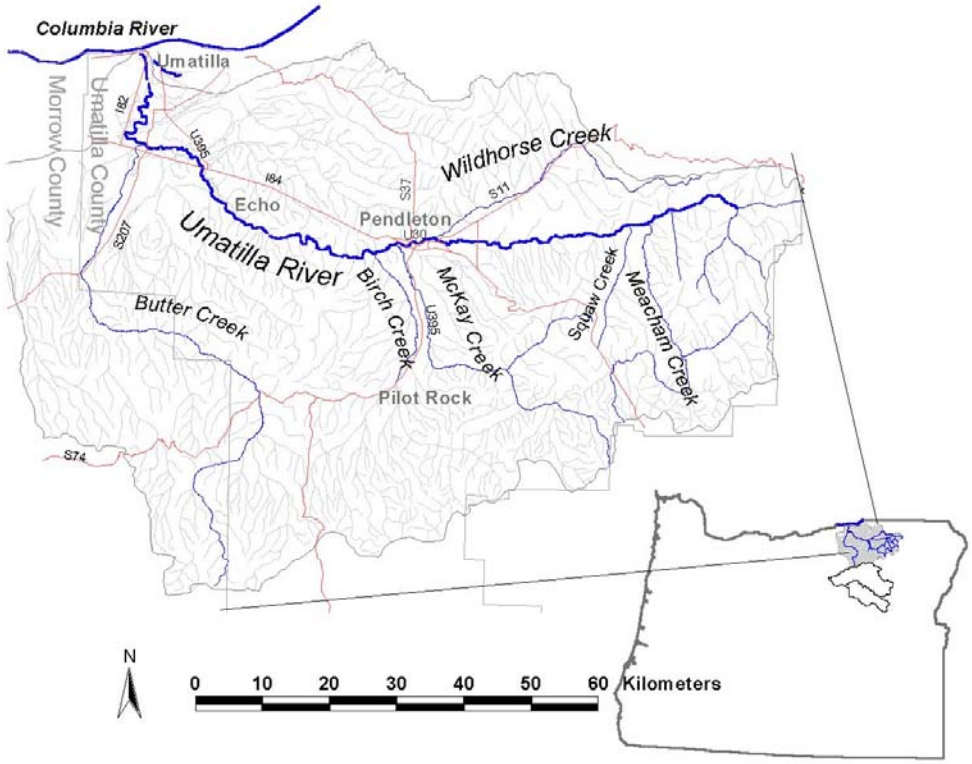

Figure 2. A map of the Umatilla River Basin.

There are nine major tributaries in the basin: The North and South forks of the Umatilla River, Meacham, Squaw, Birch, Butter, McKay, Tutuilla and Wildhorse creeks. Over the past century, approximately 70% of the main and major tributary channels have been channelized and/or levied (Phillips et al. 2000).

Agricultural and rangelands comprise more than 80% of land use in the basin (James et al. 2001) (Figure 3). The remaining land uses include roughly 15% forest and 3% urban. Eight urban areas are located within the watershed (in order of population): Pendleton, Hermiston, Umatilla, Stanfield, Pilot Rock, Athena, Echo, and Adams.

As a result of the 1855 Treaty with the US Government and subsequent federal legislation, the Umatilla River Basin contains approximately 6,000 km^2 of ceded tribal lands.

Located entirely within the Umatilla Basin, the present day reservation of the CTUIR consists of 700 km^2.

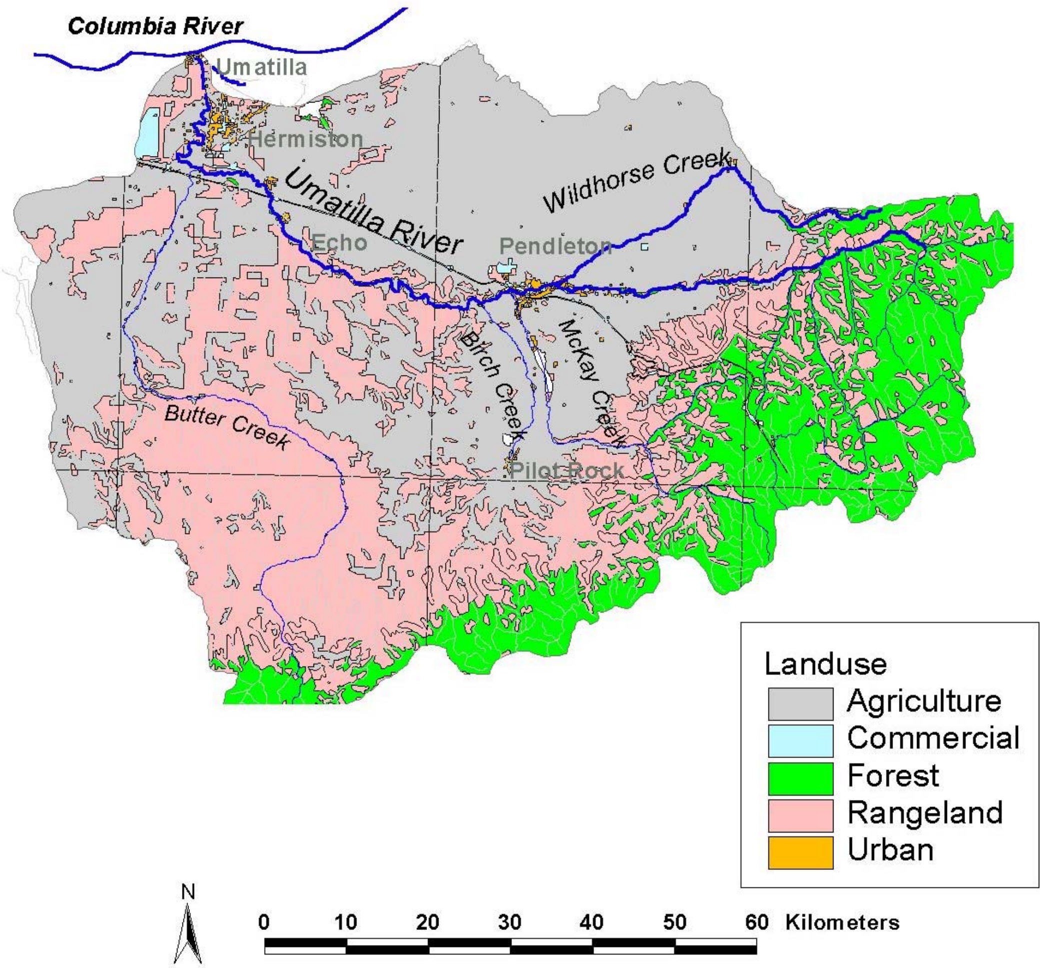

Figure 3. Major land uses in the Umatilla River Basin.

Stream flow in the Umatilla River comes mainly from snowmelt in the Blue Mountains (Oregon Department of Environmental Quality 2001). The highest flows occur during rain-on-snow events in the winter or spring. Monthly flows are usually highest in March and April, while low flows occur in July, August and September.

Several irrigation projects were completed in the early part of the century, mainly to provide water in the west part of Umatilla County (James et al. 2001). These include two major water-storage reservoirs, McKay Reservoir with a capacity of 73,800 acre-feet, and Cold Springs Reservoir with a capacity of 50,000 acre-feet. In addition, the following irrigation diversions are located in the lower basin: Stanfield Irrigation Diversion Dam, Feed Canal Diversion Dam, Westland Irrigation Diversion Dam, Dillion Irrigation Diversion Dam, and Maxwell Irrigation Dam (Figure 4).

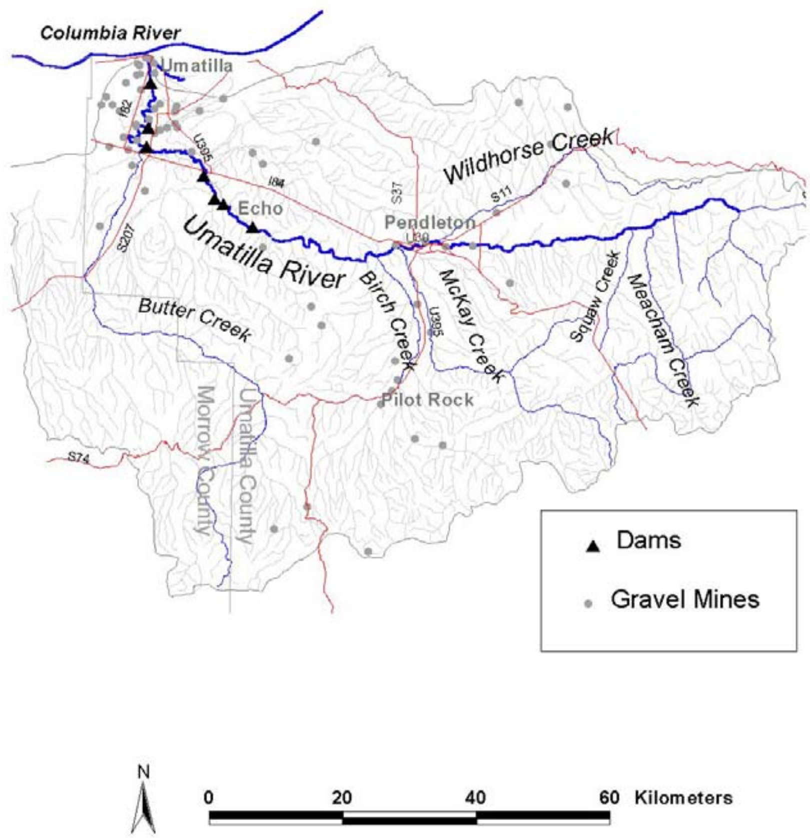

Figure 4. Location of dams and gravel mines in the Umatilla River Basin.

Middle Fork John Day River

The Middle Fork John Day River is part of the John Day Basin, the fourth largest basin in Oregon (Figure 5). The Middle Fork John Day River originates at Phipps Meadow, and flows northwest through dry juniper and grasslands before entering the North Fork John Day River 80 kms downstream (Knapp et al. 2001). The upper and middle parts of the basin are used primarily for grazing and the irrigated and non-irrigated agriculture that supports grazing (Figure 6). Uses in the lower parts of the basin include dry-land farming and recreation. The Middle Fork John Day River upstream of Big Creek is owned in mixed blocks by private individuals and the federal government, and parts are included within the Malheur National Forest (Knapp et al. 2001).

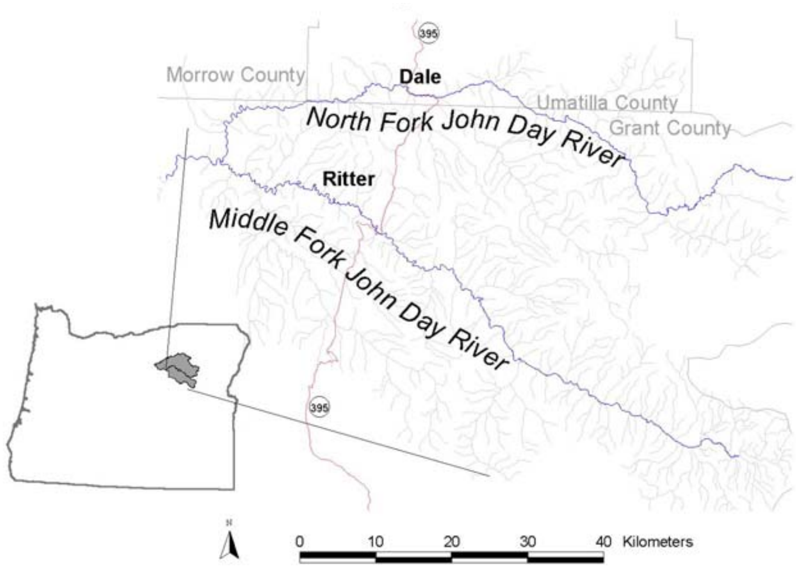

Figure 5. Middle and North Fork John Day rivers.

The discharge pattern on the Middle Fork John Day River is characterized by high spring runoff from winter snowmelt combined with spring rains (Knapp et al. 2001). Peak runoff usually occurs in April and May while low flows usually occur in August and September (Morris and Gritz 1992).

Hatchery-spawned salmon have not been released into the John Day River and its tributaries, and therefore these rivers are a key resource for the recovery of wild salmon in the Columbia Basin (Morris and Gritz 1992). The John Day River Basin supports the largest remaining wild runs of spring Chinook salmon (*Oncorhynchus tshawytscha*) and summer steelhead trout (*O. mykiss*) in the Mid-Columbia River Basin. Despite serious impacts to water quality and habitat due to anthropogenic activities, the Middle Fork John Day River has continued to support wild fish stocks throughout the past century (Morris and Gritz 1992). However, salmonid stocks are, in general, greatly reduced from historical levels (Knapp et al. 2001).

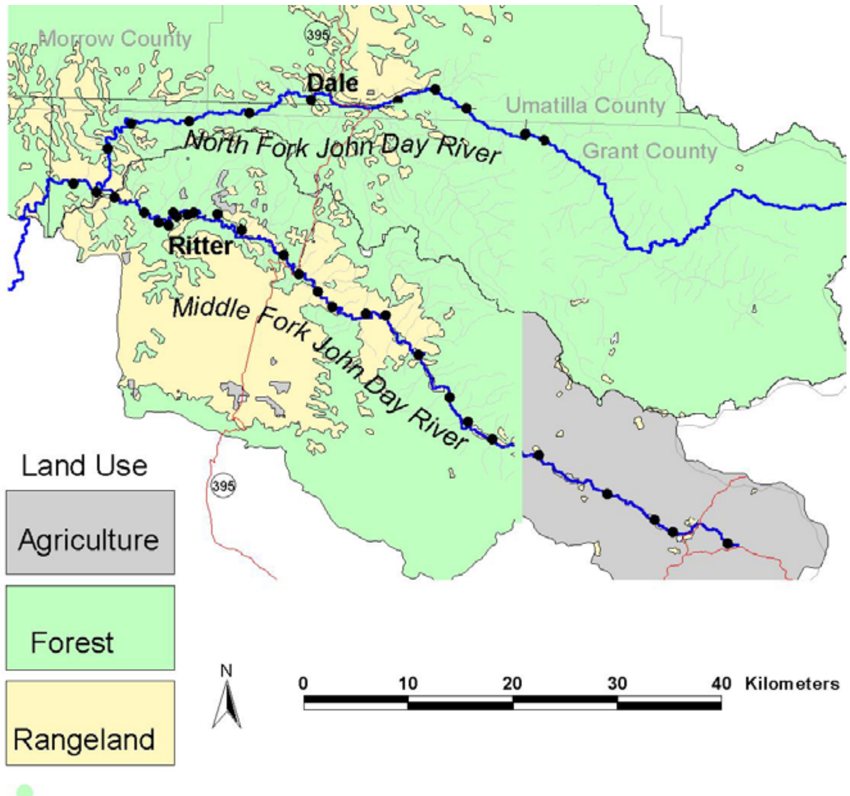

Figure 6. Major land uses in the Middle and North Fork John Day River drainages.

Since the early part of this century, portions of the Middle Fork were dredged for gold, creating tailing piles (Morris and Gritz 1992, Knapp et al. 2001) (Figure 7). Although in recent years mining activity has been closely monitored by state agencies, in some mined areas the river channel has been completely disconnected from the floodplain. Additional habitat alterations in the basin include the destabilization of stream channels by grazing, road construction, and timber harvest, resulting in channel widening and increased sedimentation. Reduction of riparian woody vegetation due to overgrazing has resulted in decreased shading, decreased bank stability, and elevated water temperatures in some reaches (Knapp et al. 2001).

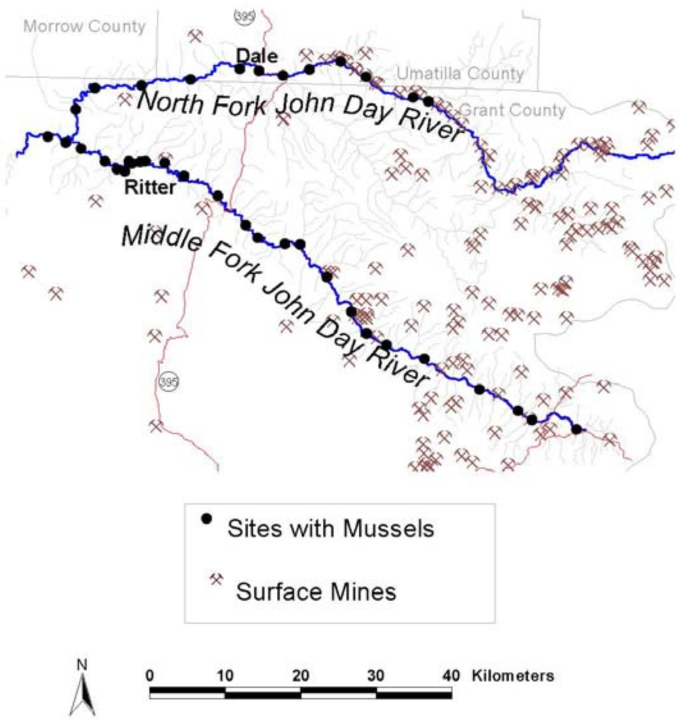

Figure 7. Placement of surface mines in the Middle and North Fork John Day drainages.

METHODS

Field Surveys

In the summer of 2003 freshwater mussels were inventoried in the Umatilla River and its tributaries, and in the main stems of the Middle Fork and North Fork John Day rivers. Sites were picked based on the following criteria: to obtain a thorough and even coverage of the target rivers; to survey sites where, based on habitat characteristics, there was the maximum chance of encountering freshwater mussels, and to re-survey sites where historically freshwater mussels were known to occur (e.g., through shell middens, museum records, published literature and reports). Collections were made at approximately 4 km intervals from the headwaters to the mouth of the main stems of the Umatilla and Middle Fork John Day rivers, and in less frequency in tributary streams and in the North Fork John Day River. In part because it was suspected that freshwater mussels could be extirpated from the main stem of the Umatilla River, the goal of this survey was to thoroughly sample all potential habitats at a particular site where freshwater mollusks could be found.

This survey was conducted using timed searches, which are effective for detecting the majority of mussel species present at a site (Miller and Payne 1993, Strayer et al. 1997, Vaughn et al. 1997, Strayer 1999, Strayer and Smith 2003). All mussels were collected by hand by snorkeling or by direct observation in shallow areas. At each site all possible habitats where mussels could occur were checked, including root and sedge mats, rock crevices, logs, aquatic vegetation, etc. At most sites density estimates were also obtained by counting all mussels encountered within defined areas. A stratified random sample for mussels was taken on one site on the Middle Fork John Day River. At other sites, quadrat samples were taken within defined mussel beds to obtain estimates of maximum densities.

The presence of all mussels encountered was recorded for each site. Auxiliary data for each site were also recorded, including drainage, locality, qualitative stream flows, time, stream dimensions and conditions. Each site was surveyed until no new species were found or all potential habitats where mussels could occur were surveyed. A minimum of one-person hour was spent at each site.

For most sites, mussels were counted and returned to the river. Voucher mussels from some sites were returned to the laboratory and live animals were relaxed using sodium pentobarbitol. Coney (1993) provided a literature review on molluscan anesthetization, and

Pantin (1946), Wagstaff and Fidler (1955), Russel (1963), and Ross and Ross (1999) also address the subject. Following relaxation, mussels were preserved in 95% ethanol for DNA analysis. Some of the material collected in this survey will be archived at Utah State University (for genetic analysis), and voucher specimens of each species were housed on site with the CTUIR.

Historical Mussel Occurrence

A variety of methods were employed to explore the historical occurrence of freshwater mussels in mid-Columbia River drainages, especially those of the Umatilla and John Day watersheds, as follows.

Historical Data Collection

A historical literature search was conducted to obtain published and unpublished records of freshwater mussels from the Umatilla, John Day, and other mid-Columbia River drainages through the USDA Forest Service Freshwater Mollusk Database at Utah State University. This database contains over 1,000 records of historical occurrences of bivalves in the western United States, dating back to the 1830s.

Museum Collections

Bivalve collections at the California Academy of Sciences (CAS) in San Francisco and at the United States National Museum (USNM) in Washington, D.C., were physically inventoried. This entailed searching the museum collections containing freshwater mussel shells, and recording accounts of all specimens from the Columbia River drainage, as well as additional drainages in the Pacific Northwest. Photo documentation of figured type specimens was obtained from the USNM to establish a template to correctly identify mussel specimens collected in the current survey, and to provide a nexus for re-naming species currently in synonymy or possibly describing new species.

Interviews

Interviews were conducted with tribal elders, and with staff members of the Cultural Resources Protection Program of the CTUIR, to obtain information on the historical usage of mussels in the Umatilla River drainage by Native Americans. These interviews were used to ascertain how tribal peoples in the Umatilla Basin utilized mussels and where historical middens, burial sites or villages once occurred in the drainage (and hence, where historically mussels might have been harvested). In addition, historical documents regarding archeological sites in the Columbia Basin were reviewed.

Genetic Analysis

A sub-set of freshwater mussel specimens (including *Gonidea*, *Margaritifera* and *Anodonta*) collected during the 2003 field season were preserved in 95% ethanol and transported to Utah State University. Each specimen was assigned a lab number, etched into the shell, and a label was attached to the soft tissue of each individual. The total length of each specimen was measured and recorded, and a laboratory database of these collections was established. The laboratory database was cross-referenced to field collection data, storage information, and laboratory data. DNA was extracted from each of these individuals using an organic extraction protocol that had been highly effective for previous molecular work (nuclear and mitochondrial) on *Anodonta*. Following extraction, the quality (amount of degradation) and concentration of the DNA was assessed using spectrophotometry and agarose gels with ethidium bromide. These extractions were archived and stored in an -80 °C freezer in preparation for future molecular work to define genetic structuring in these populations.

Host Fish Analysis

Some of the voucher mussels collected during the summer of 2003 released immature glochidia in the laboratory, and therefore a collection site with known abundant mussel populations on the Middle Fork John Day River was chosen to collect fish for host fish identification, and to excise glochidia for possible DNA analysis. Fish were collected by electrofishing on July 23 and preserved in 95% ethanol. In the laboratory the gills, fins, and external body of the fish were examined for attached or encysted glochidia. A stereoscopic microscope and dissecting microscope (5-10X) were used to examine the fish. The number of glochidia found and the species of fish they were found on were recorded.

RESULTS

Field Surveys

A total of 94 collections were made from 92 sites, and over 17,000 mussels were counted during this survey, although this number reflects only a fraction of animals encountered. All three genera of mussels (*Anodonta*, *Gonidea* and *Margaritifera*) known for the western United States were found during the survey. Of the specimens counted, approximately 65% of mussels were *Margaritifera*, 27% were *Anodonta*, and 8% were *Gonidea*. Mussels were much more common in the Middle and North Fork John Day rivers than in the main stem and tributaries of the Umatilla River. In addition, no live *Margaritifera* were found in the Umatilla River system.

Umatilla River

Mussels were rare in the main stem and tributaries of the Umatilla River. Mussels were found at only six of the 55 total sites sampled (Table 1). Only two genera, *Anodonta* and *Gonidea*, were found in the basin. No live *Margaritifera falcata* were found, although at one upstream site numerous shell fragments were scattered on the floodplain.

Table 1. Percentage of sites where mussels were found, per species and drainage.

	Umatilla main stem	Umatilla tributaries	MF John Day main stem	NF John Day main stem
Number of Sites	31	24	24	13
% Sites w/ *Anodonta*	7	8	92	46
% Sites w/ *Gonidea*	7	0	63	15
% Sites w/ *Margaritifera*	0	0	83	85
% Sites with all species	0	0	50	15

Middle and North Fork John Day rivers

A total of 39 collections were made from 37 sites. Two sites on the Middle Fork were resurveyed. Mussels were common in these two rivers, and at least one mussel specimen was found at every site sampled. All three genera were found at half of the sites surveyed on the Middle Fork John Day, and at 15% of the sites on the North Fork John Day (Table 1). The total number of mussels counted in the Middle Fork and North Fork exceeded 17,000 animals (Table 2). Given that these counts were obtained during timed searches, they are most likely but a small fraction of the total number of mussels in the two river systems.

Table 2. Number of mussels found in each river drainage.

	Umatilla main stem	Umatilla tributaries	MF John Day main stem	NF John Day main stem
No sites sampled	31	24	25	14
Number of *Anodonta*	61	10	4396	375
Number of *Gonidea*	4	0	5623	21
Number of *Margaritifera*	0	0	1982	4921
Total Mussels Counted	65	10	12001	5317

Longitudinal Distribution and Abundance

The longitudinal distribution and qualitative abundance of freshwater mussels changed from the headwaters to the confluence in each system. For example in the Umatilla River, *Anodonta* were collected from only the three most downstream sites sampled (Figure 8). *Gonidea* were found at two of the five most downstream sites sampled (Figure 9). No live mussels were found above these five most downstream sites in the main stem of the Umatilla River. However, live *Anodonta* were found at two of the four sites sampled in Wildhorse Creek, which lies approximately 90 kilometers upstream from the three sites where *Anodonta* were found in the main steam Umatilla River. In addition, although *Margaritifera* shells were found about 115 kilometers upstream, no live *Margaritifera* were found in this survey.

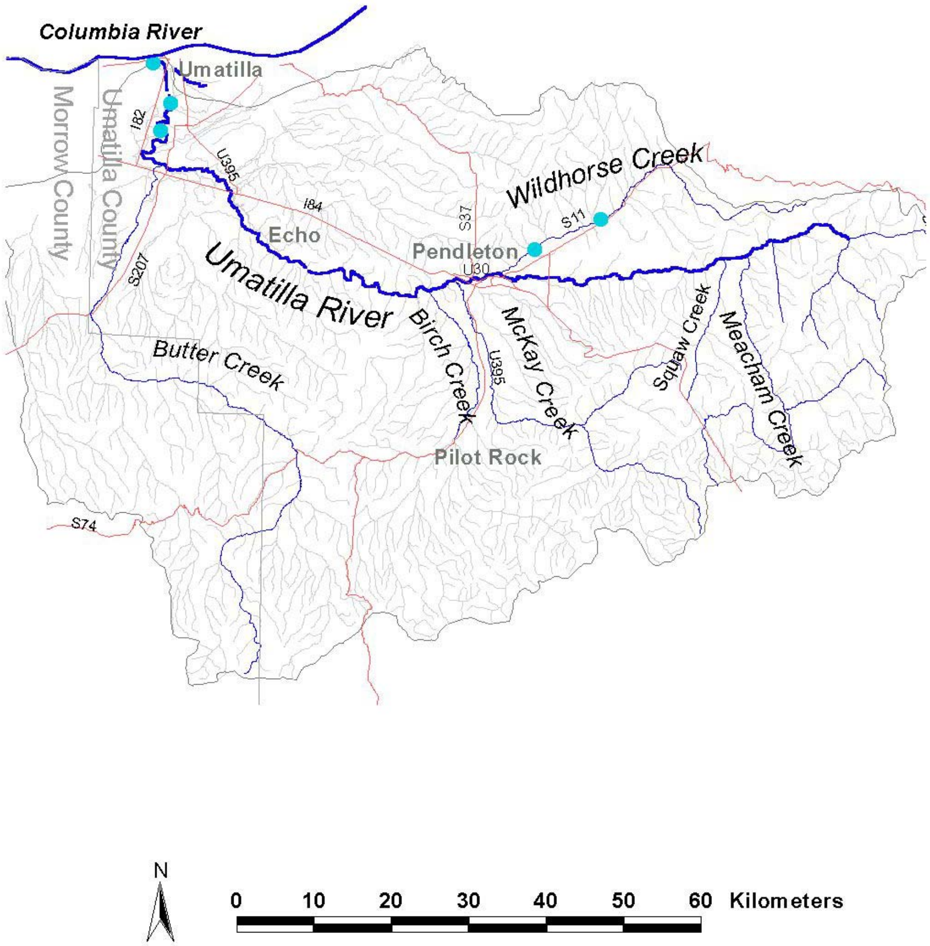

Figure 8. Sites where *Anodonta* were found in the Umatilla River Drainage.

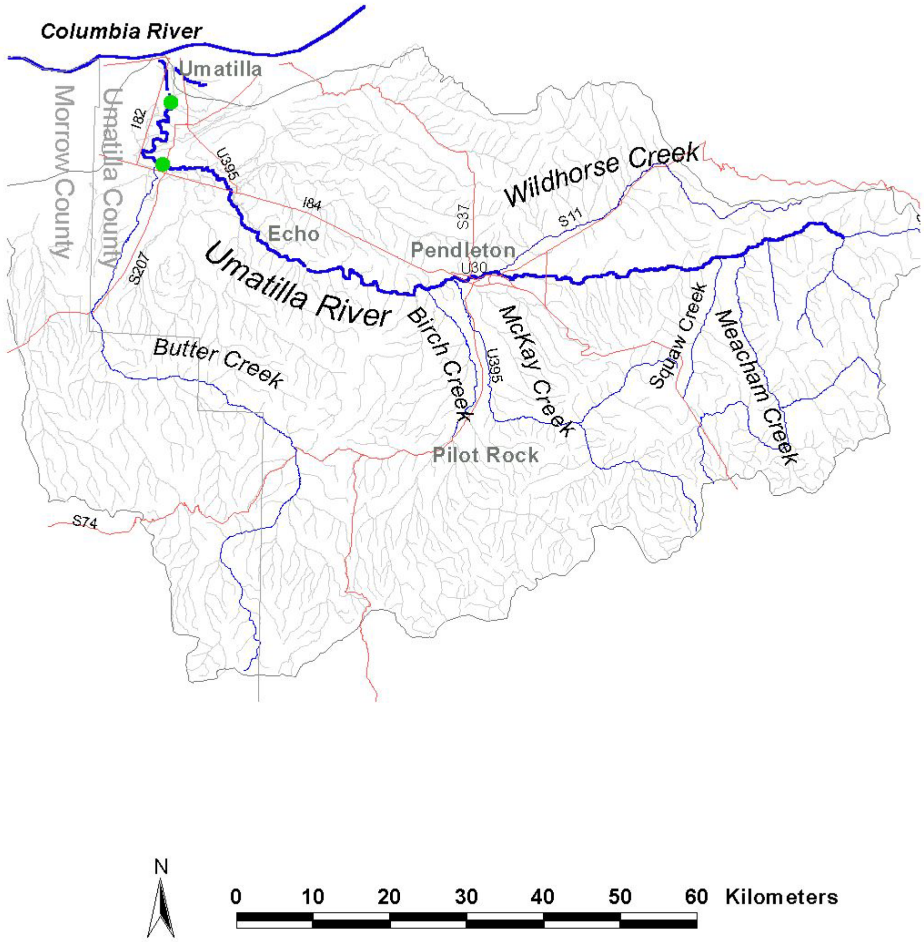

Figure 9. Sites where *Gonidea angulata* were found in the Umatilla River Drainage.

In the Middle and North Fork John Day rivers, mussel occurrences exhibited similar distributional patterns (Figures 10, 11, 12).

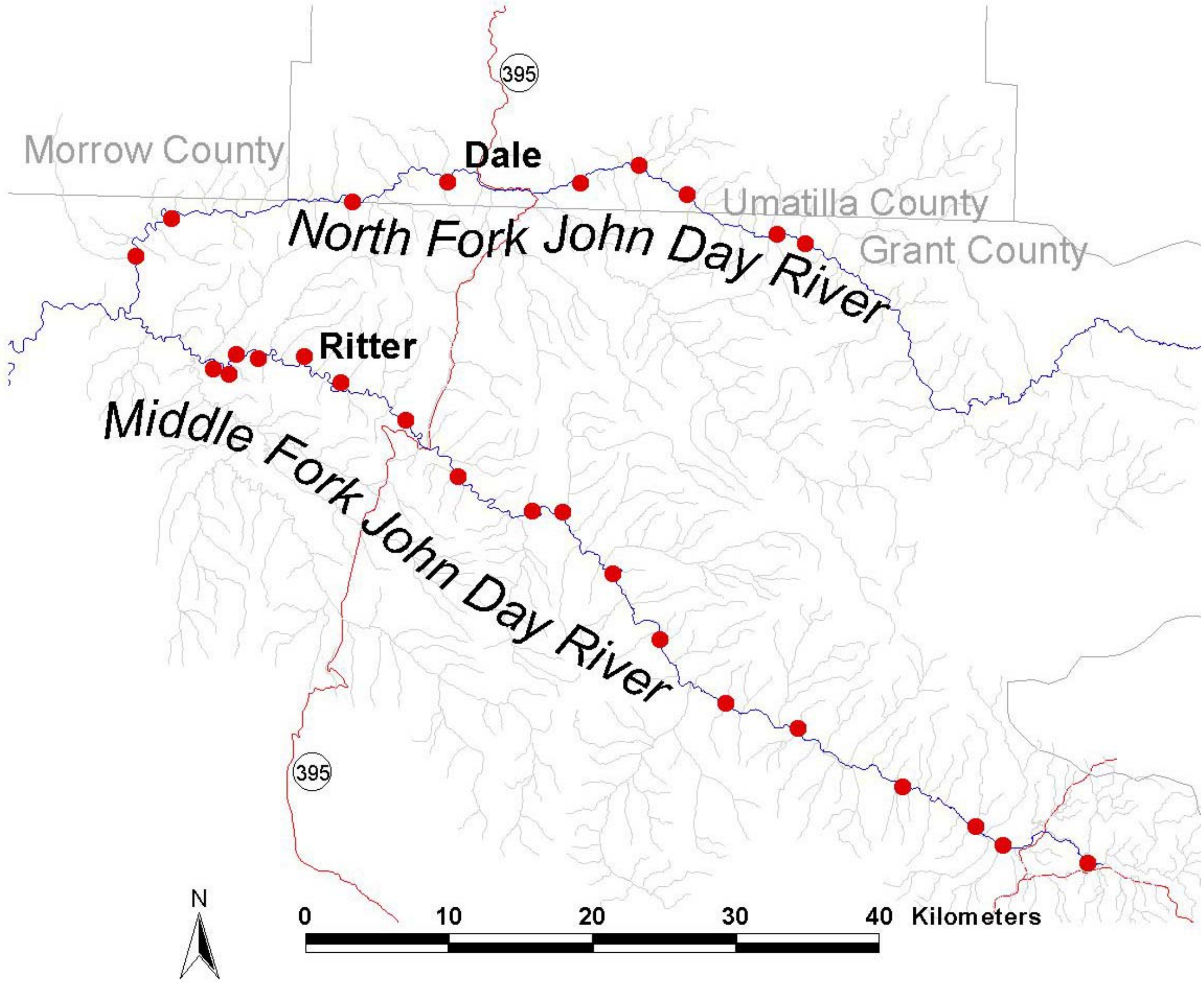

Figure 10. Sites where *Margaritifera* were found in the Middle and North Fork John Day rivers.

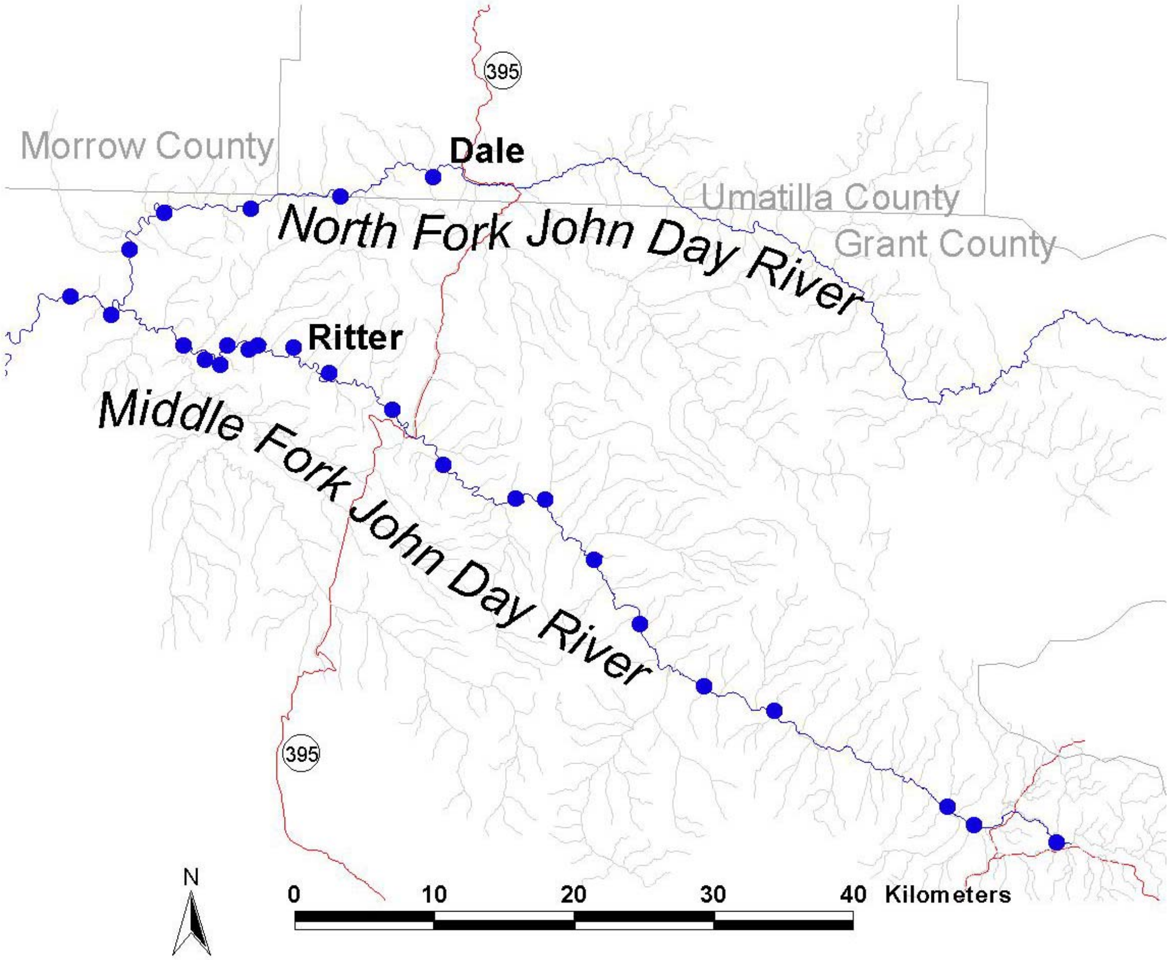

Figure 11. Sites where *Anodonta* were found in the Middle and North Fork John Day rivers.

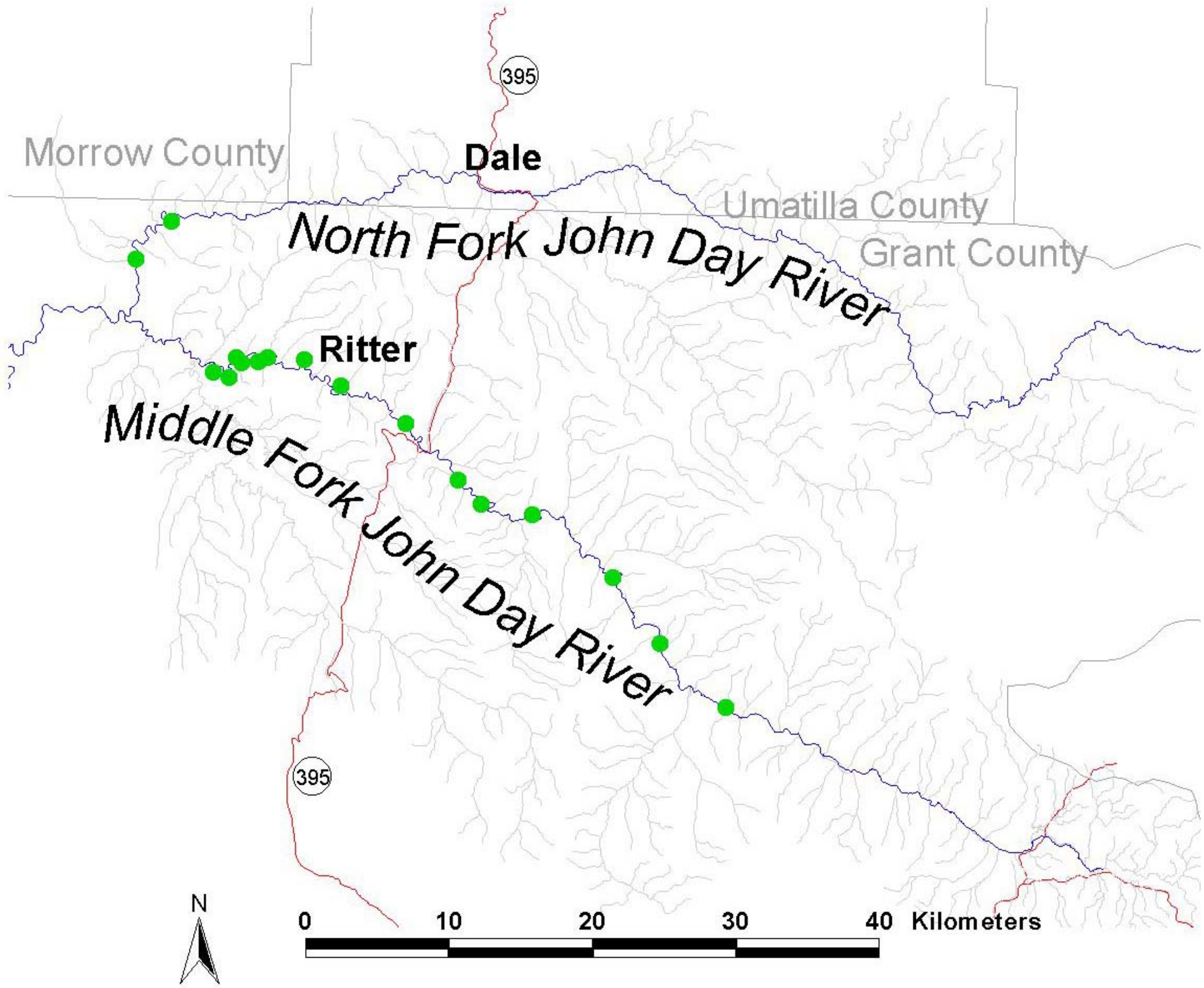

Figure 12. Sites where *Gonidea* were found in the Middle and North Fork John Day rivers.

For example, although *Margaritifera* were found at multiple sites in both rivers, generally *Margaritifera* abundance per site declined from the headwaters to the confluence. At approximately river kilometer 50 in the Middle Fork, the species composition changes from a dominance of *Margaritifera* to greater abundances of *Anodonta* and *Gonidea* (Figure 13). These two genera were absent from the five most upstream sites sampled. One site in the lower half of the Middle Fork John Day, however, did not fit this distributional pattern, and more *Margaritifera* were found there than at any other site on that river.

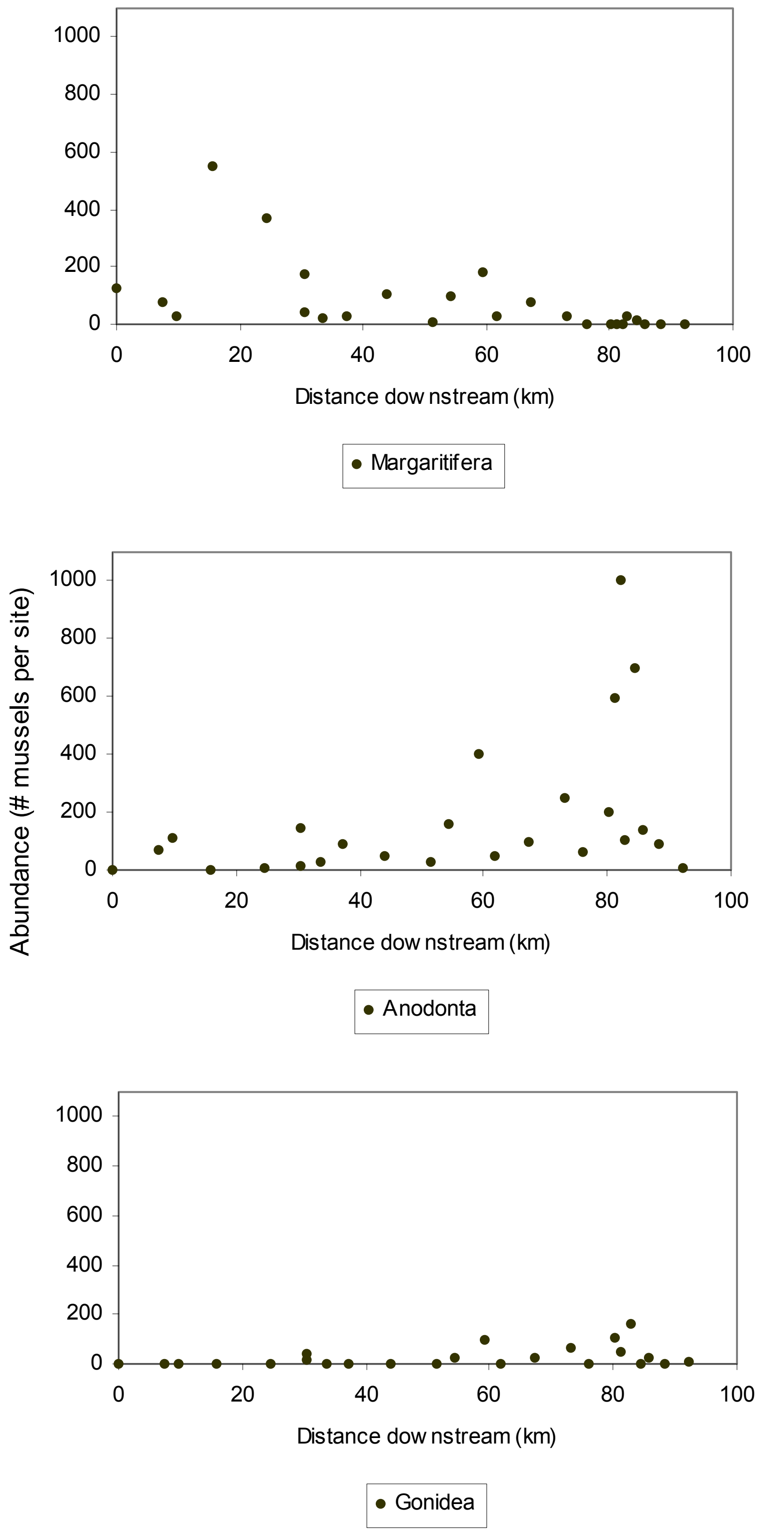

Figure 13. Changes in longitudinal abundance for three genera of mussels found in the Middle Fork John Day River.

Anodonta and *Gonidea* were more common in downstream than headwater sites, in both the Middle Fork and the North Fork John Day rivers. For example, *Gonidea* in the North Fork John Day River were only found at the two of the most downstream sites sampled (Figure 11), and in the Middle Fork John Day River, were absent from the five most upstream sites sampled.

At selected sites where mussel beds were present, quantitative estimates of maximum mussel densities were obtained. Dense beds of *Gonidea* (~575 individuals/m^2) and *Anodonta* (~275 individuals/m^2) were found in the Middle Fork John Day River, and dense beds of *Margaritifera* (~ 230 individuals/m^2) were found on the North Fork John Day River. At multiple sites in both rivers, mussel beds were a conspicuous component of benthic environment (Figures 14 and 15). No mussel beds were found on in the Umatilla River. The maximum number of mussels counted in the Umatilla River at one site was 52 *Anodonta*. Although *Anodonta* were more abundant at this site than at other sites in the Umatilla River, they were too dispersed to sample quantitatively.

Figure 14. Mussel bed consisting of both *Anodonta* and *Gonidea* in the Middle Fork John Day River.

Figure 15. Mussel bed containing *Margaritifera falcata* in the Middle Fork John Day River.

Historical Mussel Data

Historical Data Collection

Ninety-seven records of historical mussel occurrences in Oregon were obtained, dating back to 1838, from the USDA Forest Service Freshwater Mollusk Database. Of these records, only two do not list a specific drainage. Accounts from the Columbia River drainage comprise about a third of these records. These records from the Columbia Basin include seven of the eight species known to currently occur in the western United States: *Anodonta beringiana, Anodonta californiensis, Anodonta kennerlyi, Anodonta nuttalliana,* *Anodonta oregonensis, Gonidea angulata and Margaritifera falcata.* No records were found from the rivers that were the focus of this study, although records include nearby drainages (e.g., the Walla Walla).

Museum Collections

Approximately 600 historical records (i.e., shell material reposited in museum collections) of freshwater mussels from the western United States were found at the USNM and CAS. Many of these records (similarly to what was found in the historical publications search) of freshwater mussels were from the Columbia River Drainage. Although all eight species known from the western United States were present in the museum collections, none was from the three rivers targeted in this study, although a collection of *Gonidea* shells from the main stem John Day River was found at the USNM, dating from 1971.

Interviews

Although we found no historic records for freshwater mussels in the Umatilla, Middle or North Fork John Day rivers, several tribal elders who were interviewed remembered gathering mollusks at the mouth of the Umatilla and Walla Walla rivers and at the mouth of Squaw Creek. One tribal member commented, "at one time mussels were plentiful in all tributaries and bigger mussels were found in the main stem of the Umatilla River" (personal communication, Armand Minthorn, CTUIR tribal member, 2003). In the mid-1940s, freshwater mussel shells were observed scattered along the upper reaches of the banks of the Umatilla River (personal communication, Bernadette Nez, CTUIR tribal member, 2003).

In addition, in the book Nch'I-Wana (Hunn 1990), "The Big River", tribal elders of the Umatilla, Nez Perce and Cayuse tribes recalled eating the freshwater mussel *Margaritifera falcata:*

> "A last river denizen's story needs telling, that of the fresh water mussels (*Margaritifera falcata* and relatives; xistu, NWS: siwaala). Elders recall eating these mollusks, which grow to large size in concentrated masses where river bottom and current conditions are favorable. No one to my knowledge bothers with them today and the knowledge of where to find them and how to harvest and prepare them is being lost" (Hunn 1990).

Archaeologists also report finding shell middens at old village sites, indicating that mussels may have been an important part of diets (Lyman 1984). In addition, *Margaritifera falcata* shells were found in Umatilla burial sites along the Columbia River (Osborne 1951).

Genetic Analysis

DNA was extracted from 25 *Anodonta* from four sites in the Umatilla River, 17 *Anodonta* from three sites from the Middle Fork John Day River, four *Gonidea* from two sites from the Umatilla River and five from one site on the Middle Fork John Day River, and from five *Margaritifera* from one site on the Middle Fork John Day River. Although sequencing these samples was beyond this scope of work, they will be sequenced as part of a larger, on-going project of western freshwater mussel genetics currently underway at Utah State University. That data set includes over 300 samples of DNA from individual mussel specimens from throughout the western United States (Table 3). In addition, 19 encysted glochidia on speckled dace fins were archived in order to extract DNA from these glochidia for host fish verification.

Table 3. Genetic data (e.g., location, species, DNA extracted) available from study.

Location	**Species ID**	**n**	**Data available**
Humboldt River, Elko Co., Nevada	*Anodonta cf. oregonensis*	11	Mitochondrial COI sequence data
Glenn Co., California	*Anodonta cf. wahlametensis*	5	Mitochondrial COI sequence data
Solano Co., California	*Anodonta cf. wahlametensis*	5	Mitochondrial COI sequence data
Monterey Co., California	*Anodonta sp.*	10	Mitochondrial COI sequence data
Baker Co., Oregon	*Anodonta cf. oregonensis*	5	Mitochondrial COI sequence data
Mendocino Co., California	*Anodonta sp.*	5	Mitochondrial COI sequence data
Black River, Apache Co., Arizona	*Anodonta californiensis*	2	Mitochondrial COI sequence data
Bear River, Utah	*Anodonta sp.*	20	Specimens, extracted DNA, mitochondrial COI seq. data, AFLP Data
Redden Springs, Utah	*Anodonta sp.*	19	Specimens, extracted DNA, mitochondrial COI seq. data, AFLP Data
Pruess Lake, Utah	*Anodonta sp.*	20	Specimens, extracted DNA, mitochondrial COI seq. data, AFLP Data
Piute Reservoir, Utah	*Anodonta sp.*	14	Specimens, extracted DNA, mitochondrial COI seq. data, AFLP Data
Otter Creek Reservoir, Utah	*Anodonta sp.*	20	Specimens, extracted DNA, mitochondrial COI seq. data, AFLP Data
Burriston Ponds, Utah	*Anodonta sp.*	20	Specimens, extracted DNA, mitochondrial COI seq. data, AFLP Data
Umatilla River, Umatilla Co., Oregon	*Anodonta sp*	8	Specimens, extracted DNA
Middle Fork John Day River, Malheur Co., Oregon	*Margaritifera falcata*	5	Specimens, extracted DNA
Middle Fork John Day River, Malheur Co., Oregon	*Anodonta sp.*	1	Specimens, extracted DNA
Middle Fork John Day River, Grant Co., Oregon	*Anodonta sp.*	7	Specimens, extracted DNA (all degraded)
Middle Fork John Day River, Grant Co., Oregon	*Gonidea angulata*	5	Specimens, extracted DNA
Middle Fork John Day River, Grant Co., Oregon	*Anodonta sp.*	9	Specimens, extracted DNA (8 usable)
Umatilla River, Umatilla Co., Oregon	*Anodonta sp.*	1	Specimens, extracted DNA (degraded)
Umatilla River, Umatilla Co., Oregon	*Gonidea angulata*	3	Specimens, extracted DNA
Umatilla River, Umatilla Co., Oregon	*Anodonta sp.*	13	Specimens, extracted DNA
Umatilla River, Umatilla Co., Oregon	*Anodonta sp.*	4	Specimens, extracted DNA (1 usable, 3 degraded)
Umatilla River, Umatilla Co., Oregon	*Gonidea angulata*	1	Specimens, extracted DNA
Sycan River, Klamath Co., Oregon	*Margaritifera falcata*	44	Specimens, extracted DNA (25), not extracted (19)
Sycan River, Klamath Co., Oregon	*Anodonta sp.*	21	Specimens, not extracted
Summer Lake, Lake Co., Oregon	*Anodonta sp.*	21	Specimens, not extracted
South Eel River, Mendocino Co., California	*Anodonta californiensis*	5	Specimens, not extracted

Host Fish Analysis

A total of 92 fish representing five families were collected from a single site in the Middle Fork John Day River on July 23, 2003. A total of 74% of the speckled dace (*Rhinichthys osculus*) inspected had attached and encysted glochidia in various stages of development (Table 4). The glochidia were found on the fins, body, and gills of speckled dace (*Rhinichthys osculus*). Only one attached (non-encysted) glochidium was found on the gill of a redside shiner.

Table 4. Number of fish collected and percentage infected with glochidia.

Fish species	Total # fish inspected	# Fish with glochidia	Total # glochidia found
Largescale sucker (Catostomus macrocheilus	12	0	--
Redside shiner (Richardsonius balteatus)	28	1	1
Smallmouth bass Micropterus dolomieu.	1	0	--
Speckled dace *Rhinichthys osculus*	46	34	112
Northern pikeminnow Ptychocheilus oregonensis	5	0	--

The glochidia found encysted on the fish were most likely *Anodonta* because the size (200-250 microns) and shape (triangular) of the glochidia are consistent with those found in the genus *Anodonta* (Hoggarth 1999) (Figure 16). Glochidia of the remaining two mussel species found in the John Day River system (*Margaritifera falcata* and *Gonidea angulata*) are much smaller and white in color. These preliminary results suggest that *Anodonta* use speckled dace as a host fish.

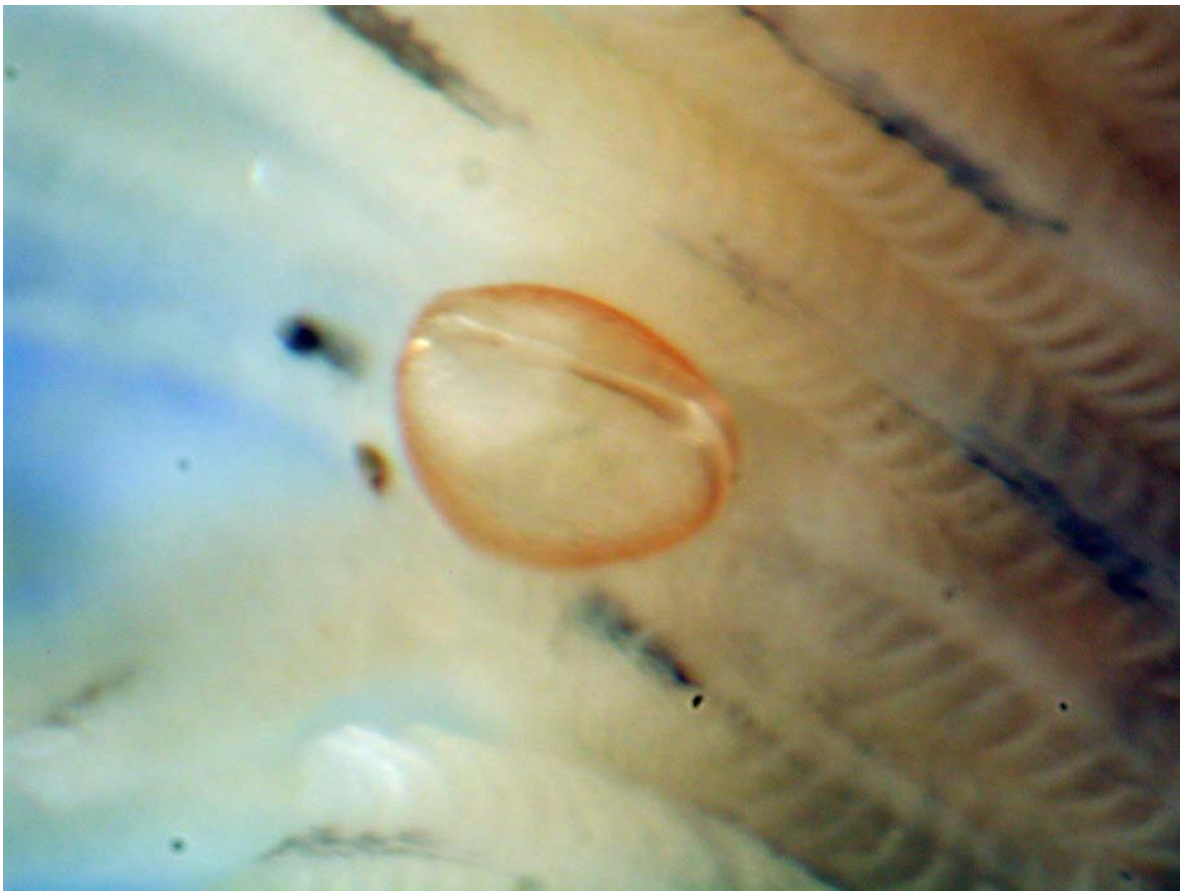

Figure 16. Glochidium on fin of speckled dace (glochidium is approximately 250 microns in length).

DISCUSSION

Cultural Significance

Historically freshwater mussels were an important food for tribal peoples of the Columbia River Basin. Native Americans in the interior Columbia River Basin harvested freshwater mussels (*Gonidea* and *Margaritifera*) for at least 10,000 years (Lyman 1984). Ethnographic surveys of Columbia Basin tribes reported that Native Americans collected mussels in late summer and in late winter through early spring during salmon fishing (Spinden 1908, Ray 1933, Post 1938). A few tribal elders from the Columbia and Snake River basins recalled that mussels were collected whenever conditions of the rivers were favorable (Hunn 1990, Chatters 1995). Tribal harvesters collected mussels by hand. When wading was not possible they used forked sticks (Post 1938). They prepared mussels for consumption by baking, broiling, steaming, and drying (Spinden 1908, Post 1938). The Umatilla Tribe preferred to boil freshwater mussels for consumption (Ray 1942).

Native American use of freshwater mussels decreased during the last 200 years, probably due to declines in Native American populations and assimilation following Euro-American settlement (Chatters 1987). A Umatilla tribal elder, however, remembered his parents trading fish for dried mussels as late as the 1930s (personal communication, Eli Quaempts, CTUIR tribal member, 1996). In addition, shell middens found at village sites near the mouth of the Umatilla River (Lyman 1984), as well as the presence of mussels at burial sites in the same area (Osborne 1951) suggest that historically freshwater mussels were important to the indigenous peoples of the mid-Columbia River Plateau for multiple reasons. In addition, unlike the traditional Euro-

American view where humans have greater intrinsic value than other animal or plant species, traditionally mid-Columbia Plateau tribal cultures placed humans at the same level with other beings, partially because animals, plants, water and rocks were believed to have a *shukwat* (spirit) and a conscience, and this worldview promoted respect for all things in nature (Close et al. 2002). This worldview is consistent with an ecosystem-level approach to aquatic conservation and recovery efforts.

Genus Accounts

The western pearlshell, *Margaritifera falcata,* was historically known from southern Alaska south to central California and east to Utah. In Oregon it historically occurred in the Klamath River system, rivers of the Coastal Range, and the main stem and tributaries of the Columbia River, including the Snake, Willamette and Walla Walla rivers (USDA Forest Service 2004). We did not find historical records of this species for either the John Day or Umatilla River systems. This is somewhat surprising, given that this species is common in both the North and Middle Fork John Day rivers and based on shell evidence also occurred until probably very recently in the Umatilla River system.

The conservation status of *Margaritifera falcata* throughout its range is apparently secure (NatureServe 2003). In Oregon it is currently under consideration for a conservation status of vulnerable by the Oregon Natural Heritage Program. The loss of salmonid host fish has been suggested as a probably cause of *Margaritifera* extirpations in other areas (Cosgrove et al. 2000, Bauer 2001). Given the long period when several of *M. falcata's* probable host fishes were absent or occurred in reduced numbers in the Umatilla River, the decline of host fish populations could have contributed to the extirpation of *M. falcata* in that river system. However, additional data are needed to verify that assertion. Additional threats to this species include human-induced sedimentation and stream-channel instability (Vannote and Minshall 1982) and a reduction of available stream habitats due to damming (Taylor 1981).

The western ridged mussel, *Gonidea angulata,* was historically known from southern British Columbia to southern California, Idaho and Nevada (Taylor 1981). In Oregon it historically occurred in rivers of the Coastal Range, and the main stem and tributaries of the Columbia River, including tributaries to the Snake and Malheur rivers (USDA Forest Service 2004). In addition, there are a few historical records of this species in the USNM from the main stem John Day River.

The conservation status of *Gonidea angulata* throughout its range is vulnerable (NatureServe 2003). In Oregon this species is currently under consideration for a conservation status of imperiled by the Oregon Natural Heritage Program. There is limited evidence that *G. angulata* may be more tolerant of habitat disturbances than other species of western mussels. For example, in laboratory trials meant to mimic excess sedimentation caused by environmental degradation, *G. angulata* were able to move vertically through sediments deposited at various rates in laboratory trials, whereas *Margaritifera falcata* remained buried until they died (Vannote and Minshall 1982). These results may partially explain why populations of *M. falcata* in the Salmon River Canyon in Idaho were buried alive in canyon reaches that were aggrading with sand and gravel caused by mining, logging, irrigation diversions, and massive slope failure of a tributary stream caused by hydraulic mining activities (Vannote and Minshall 1982). The dead, buried populations of *M. falcata* were found intact in beds that were covered by sand and gravel bars, and *G. angulata* replaced *M. falcata* in reaches aggrading or inundated with sand.

Historically, at least five species of *Anodonta* occurred in Oregon: the Yukon floater, *Anodonta beringiana* Middendorff, 1851; California floater, *Anodonta californiensis* I. Lea, 1852; western floater, *Anodonta kennerlyi* I. Lea, 1860; winged floater, *Anodonta nuttalliana* I. Lea, 1838; and Oregon floater, *Anodonta oregonensis* I. Lea, 1838 (Williams et al. 1993, Frest and Johannes 1995, USDA Forest Service 2004). There is considerable confusion concerning the taxonomy of western *Anodonta*. For example, some researchers continue to recognize *A. wahlametensis* as a valid species, although it was placed in the synonomy of *A. nuttalliana* by Turgeon et al. (1998). *Anodonta wahlametensis, A. nuttalliana* and *A. oregonensis* were described by Isaac Lea from the same site (i.e., "Wahlamet [Willamette River], near its junction with the Columbia River" [Oregon]) and in the same publication (Lea 1838). Under the International Laws of Zoological Nomenclature, the Rule of the First Reviser applies to these three species. Call (1884) was the first to place *wahlametensis* in the synonymy of *nuttalliana*. Carpenter (1856) and Carlton (1870) recognized both *wahlametensis* and *nuttalliana*. All three names could be recognized at the species level, however, if new information (e.g., genetic data) becomes available to warrant species status.

In this survey, we did not attempt to identify *Anodonta* specimens to species, because without a thorough genetic and anatomical analysis, it is extremely difficult to distinguish specimens of this genus, in Oregon, to the species level. The shell morphology of western *Anodonta* is extremely plastic, even in cases where, genetically, individuals may be virtually indistinguishable (Mock et al. 2004). Data collected during this study from the USNM (Smithsonian Institution) supports that assertion. For example, at the USNM *Anodonta* specimens currently placed in synonymy were morphologically distinguishable, based on type specimens (Figure 17). Whether *A. wahlametensis* should be removed from the synonymy of *A. nuttalliana* will depend on future anatomical and genetic work on western *Anodonta*.

Figure 17. Type specimens of *Anodonta wahlametensis* (USNM 86363, length = 63.2mm) (above) and *Anodonta nuttalliana* (USNM 86391, length = 60 mm) (below). *Anodonta wahlametensis* was placed in the synonymy of *A. nuttalliana* by Turgeon et al. (1998).

In Oregon, historical records of *Anodonta* were found from the Columbia, Malheur, Klamath, Snake, and Willamette River basins, and from rivers in the Oregon Coastal Basin (USDA Forest Service 2004). However, historical records of *Anodonta* were not found from the John Day or Umatilla River systems. This was surprising, given that the rapids on the Columbia River immediately upstream of the mouth of the Umatilla

River was called "muscle shell rapids" by Lewis and Clark (personal communication, Teara Farrow, Cultural Resources Protection Program, CTUIR, 2003), suggesting that mussels were once common in that area. In addition, *Anodonta* were found at the four most downstream sites on the Umatilla River that were sampled in this survey.

The conservation status in Oregon is unknown for *Anodonta beringiana, A. kennerlyi, A. nuttalliana*, and *A. oregonensis*, while *A. californiensis* is listed as critically imperiled (NatureServe 2003). Regardless of the taxonomic status of Oregon *Anodonta* species, it is widely recognized that *Anodonta* in the western US are in decline (Brim Box 2002, NatureServe 2003, Mock et al. 2004).

Host Fish/Mussel Interactions

Mussels are dependent on fish hosts for larval stage development (see discussion of life cycle below) (Coker et al. 1921, Matteson 1955, Fuller 1974, Oesch 1984). Because freshwater mussels are obligate parasites on fishes, the health and viability of existing host fish populations can influence the viability of existing mussel populations. Thus, long-term declines in mussel populations can result from a substantial and sustained reduction in fish populations, even if habitat for mussels remains favorable (Watters 1992, Haag and Warren 1998). Declines in host fish populations have been identified as a causal factor of mussel reproductive failure, especially for those species that utilize a limited number of host fishes (Bauer 2001). In addition, because freshwater mussels are long-lived (e.g., individuals of some species may reach 100 years or more) existing mussel beds may be senescent for long periods before those populations are extirpated, and the loss of suitable host fishes may also go undetected during those interims of senescence. Correspondingly, mussels provide an example of how declines in fish taxa have propagating effects into other parts of the ecosystem.

Mussel Reproductive Biology

Freshwater mussels are unique among bivalves in that most require a host fish to complete their life cycle. Unlike male and female marine bivalves, which release sperm and eggs into the water column where fertilization takes place, fertilization of freshwater mussels takes place within the brood chambers of the female mussel (Jirka and Neves 1992). The female mussel carries the fertilized eggs in the gills until they develop into a parasitic stage called glochidia. Female mussels then release the glochidia into the water column where they must come into contact with a suitable host fish species. Once the glochidia are released they will survive for only a short period (e.g., from a few hours to a few days, depending on the species) if they do not successfully attach to a host fish (O'Brien and Brim Box 1999, O'Brien and Williams 2002). After successfully attaching to the host fish, the glochidia metamorphose and drop to the substrate to become free-living juveniles (Jones 1950, Howard 1951). The time required for glochidial metamorphosis varies with water temperature and among mussel species. Properly encysted glochidia will metamorphose into free-living juveniles, displaying abductor muscles, gill buds, and a ciliated foot with protractor and retractor muscles (Karna and Millemann 1978).

The mussel/fish relationship is usually species-specific (Lefevre and Curtis 1912); only certain species of fish can serve as suitable hosts for a particular mussel species. Glochidia may attach to a non-host fish, but the glochidium will fail to form a cyst and fully develop. The number of host fish utilized by a mussel species varies. Some mussel species have a very restricted number of host fish species (Watters 1994, Michaelson and Neves 1995) while other mussels parasitize a wide range of fish species (Watters 1994, Haag and Warren 1997). The salamander mussel, *Simpsonaias ambigua*, uses an aquatic salamander as a host (Howard 1951, Clarke 1981), and is the only unionoid mussel species known to use a non-fish host. In addition, to improve the chance of glochidia coming into contact with a potential host fish, some mussels release their glochidia into the water column when light sensitive spots are stimulated by the shadow of a passing fish (Kraemer 1970, Jansen 1990). Other mussel species have evolved elaborate lures resembling fish food as mechanisms to attract specific host fishes (Coker et al. 1921, Kraemer 1970, Jansen 1990, Haag et al. 1995, Hartfield and Butler 1997, O'Brien and Brim Box 1999).

Knowledge of the reproductive biology of many mussels remains incomplete (Jansen 1990). Only about a quarter of the 300 or so mussel species in North America have had their host fish identified through field and/or laboratory experiments (Watters 1994). In addition, existing studies, in general, do not distinguish between primary and secondary hosts. Few studies have examined whether the same fish species that can serve as a suitable host in lab experiments are in situ hosts. A confirmed primary host fish for a mussel species is determined via laboratory experiments and in addition, wild caught fish must be found with encysted glochidia of the same mussel species.

Known Host Fishes for Western Freshwater Mussels

The host fishes for *Margaritifera falcata* were reported to include Chinook (*Oncorhynchus tshawytscha*) and Coho (*Oncorhynchus kisutch*) salmon, rainbow (*O.*

mykiss), cutthroat (*Salmo clarkii*), and steelhead trout (*Salmo gairdneri*), Tahoe sucker (*Catostomus tahoensis*), speckled dace (*Rhinichthys osculus*) and Lahontan redside (*Richardsonius egregius*) (Murphy 1942, Meyers and Milleman 1977, Fustish and Milleman 1978, Karna and Milleman 1978).

The host fishes for this species in the Middle and North Fork John Day rivers are unknown, although Chinook salmon, summer steelhead, westslope cutthroat, brook trout, and speckled dace occur in the John Day River Subbasin (Knapp et al. 2001). In the Umatilla River, Chinook and Coho salmon were reintroduced into the basin via hatchery-reared juveniles in the 1980s, after an absence of over seventy years, and bull and steelhead trout and speckled dace are also found in the basin (James 2001).

Nothing is known about the host fishes for *Gonidea angulata*, and very little information is known about the host fishes for western *Anodonta*. D'Eliscu (1972) reported that *A. californiensis* glochidia successfully transformed on the gills and fins of *Gambusia affinis*, a species not native to the western United States. Anodontinae are the least host-specific of unionid mussels, and a wide-range of host fish have been reported for many eastern *Anodonta* species (Watters 1994). Based on the results of this study, it appears that *Anodonta* in the Middle Fork John Day system use speckled dace as a host fish. The percentage (74%) of speckled dace found in this study infested with *Anodonta* glochidia is one of the highest ever reported for wild-caught fish (Zale and Neves 1982, Weiss and Layzer 1995, Weaver et al. 1989). However, additional laboratory studies should be conducted to confirm this finding. Other researchers, after finding encysted glochidia on wild caught fish, have followed up with laboratory testing to confirm the suspected host fish is a viable host (Zale and Neves 1982, Trdan and Hoeh 1982, Weiss and Layzer 1995).

Possible Impacts from Loss of Native Fish Species

Since the early part of this century, 7% of the native North American mussel fauna have become extinct, and an additional 72% is considered endangered, threatened, or of special concern (Williams et al. 1993), making freshwater mussels one of the most imperiled faunas in North America (Master et al. 2000). During this same period, 5% of the native North American fish fauna disappeared. An additional 364 fish species are considered endangered, threatened, or of special concern (Williams et al. 1989), and that number has increased significantly in the last decade, primarily due to the subsequent listing of additional western salmonid populations (personal communication, Noel Burkhead, USGS, 2004).

Because freshwater mussels and fishes are inexorably linked, it seems reasonable to assume that the disappearance of the host fish may also cause the extirpation of freshwater mussels from the same river reaches or entire river systems. Alternatively, the same environmental stresses (e.g., pollution, habitat alteration) may influence the abundance and distribution of fish and mussels independently but along the same environmental gradients, especially because many fish species are sensitive to the same habitat alterations that affect freshwater mussel populations. For example, most of the species of fishes that are known or suspected hosts for *Margaritifera* are considered obligate benthic species (i.e., species that spawn, feed, or shelter on the stream bottom). Because these fish species depend on the benthic component of riverine systems for at least part of their life cycle, it is possible that the same habitat alternations that adversely impact mussels also impact obligate benthic fish species. For example, in northeast Missouri, the abundance of fish classified as benthic insectivores decreased as the percentage of fine sediments increased (Berkman and Rabeni 1987). In the Etowah River drainage of northern Georgia, 80% of the imperiled fish fauna was comprised of obligate benthic species, and elevated sedimentation was considered the primary source of degradation to benthic habitats (Burkhead et al. 1997). In addition, there is some evidence that fish diversity and mussel diversity is correlated, at least in larger rivers (Watters 1992), suggesting that habitat quality influences both of these taxa along similar environmental gradients.

In general, it is difficult to link the extirpation of freshwater mussel populations to the extirpation of their host fishes, and of the few studies that have made that connection, most of the evidence presented is anecdotal (Davenport and Warmuth 1965, Sickel 1982, Arter 1989). Other factors in addition to the loss of host fishes can often be implicated in the disappearance of individual mussel populations. For instance, the extirpation of many of the mussel species from the Caney Fork River system in Tennessee was not correlated with the disappearance of fish hosts as supposed, but was caused by the release of cold water from a dam in the study area (Layzer et al. 1993). Often factors such as suitable habitat are more important in delineating freshwater mussel distributions than host fish availability, and suitable host fish may be available in sufficient numbers that the relationship between these two faunal elements appears to be density-independent. In addition, factors that control the current distribution of both mussels and fish in a river basin may include stream size and habitat suitability. However, because mussels are obligate parasites on fish, it cannot be ignored that host fish must be available at suitable times and in sufficient numbers to complete the unionid reproductive cycle.

Historically, the Umatilla River supported large populations of spring Chinook and Coho salmon, as well as steelhead trout (James et al. 2001). Due to intensive agricultural development and prolonged irrigation withdrawals between 1905 and the mid-1920s, native Chinook and Coho were extirpated from the system, and steelhead abundances were greatly reduced (Phillips et al. 2000). Therefore, for over 70 years salmonid abundance in the Umatilla River was severely impacted. In contrast, the John Day River Basin supports the largest remaining exclusively wild runs of spring Chinook and summer steelhead in northeast Oregon, although these numbers are greatly reduced from historical anadromous fish abundances in the basin (Knapp et al. 2001).

The impact of the decades-long loss of salmonids in the Umatilla River system on freshwater mussels is not clear, but could be significant. After infecting a variety of fish species with *Margaritifera* glochidia in the Siletz River, Oregon, Karna and Milleman (1978) found that Chinook and steelhead salmon were more susceptible to glochidial infection than the other salmonid species. This may indicate that Chinook and steelhead are preferred hosts for *M. falcata* in Oregon. Therefore, it is possible that reductions in steelhead stocks and the extirpation of Chinook salmon from the Umatilla River in the early part of this century may have negatively impacted *M. falcata* reproductive success. In addition, the lack of sufficient suitable host fishes may, in part, explain the extirpation of freshwater mussels from most of the Umatilla River Basin, and should be explored.

Possible impacts from non-native fishes

Most western drainages contain a number of nonindigenous fishes, and their impact on native mussel populations is unknown. For example, at least thirteen species of non-indigenous fishes have been reported from the John Day and Umatilla River systems (Table 5).

Table 5. Fish species introduced into the Umatilla and/or John Day River systems.

Fish Species
Common Carp (*Cyprinus carpio*)
Pumpkinseed (*Lepomis gibbosus*)
Bluegill (*Lepomis macrochirus*)
White crappie (*Pomoxis annularis*)
Black crappie (*Pomoxis nigromaculatus*)
Yellow perch (*Perca flavescens*)
Largemouth bass (*Micropterus salmoides*)
Smallmouth bass (*Micropterus dolomite*)
Brown bullhead (*Ictalurus nebulosus*)
Black bullhead (*Ictalurus melas*)
Channel catfish (*Ictalurus punctatus)*
Mosquitofish (*Gambusia affinis*)
Brook trout (*Salvelinus fontinalis*)

These nonindigenous fishes could potentially affect mussel populations in either a positive or negative way. If nonindigenous fishes are serving as host fish in the absence of the original host fish, their presence may allow freshwater mussels to persist. In this case, programs aimed at eradicating these nonindigenous fishes may ultimately have a negative impact on mussel populations. Alternatively, if the original host fishes are still present in the system, the nonindigenous fishes may compete for these glochidia but serve as less efficient hosts (O'Brien and Brim-Box 1999). In addition, if non-native fishes are predators on native fishes that serve as hosts for mussels, they may decrease the number of available host fish. For example, the large number of smallmouth bass found in the John Day River Basin could impact native salmonid species, as has been reported in other parts of the Columbia River Basin (Tabor et al. 1993, Zimmerman 1999). Mussels living in streams where the host fish density is low may infest the same fishes repeatedly with their glochidia. Fish that are exposed to mussel glochidia multiple times have been known to develop glochidial immunity (Coker et al. 1921, Kirk and Layzer 1997). Fish populations with an acquired immunity to glochidia will no longer be able to effectively serve as hosts for the mussel population. If a large percentage of fish present at a site are infected with glochidia, as found in this study, there is a danger that these fish may develop immunity to further encystments. However, further studies will be needed to test this assertion in the Middle Fork John Day River.

Habitat

Declines in freshwater mussel populations are thought to be due to a myriad of factors. Possible causes for their decline were summarized by van der Schalie (1938), Fuller (1974), Williams et al. (1993), and Bogan (1993). These include habitat degradation, the introduction of exotic bivalves including the Asian clam (*Corbicula fluminea*), and zebra mussel, (*Dreissena polymorpha*), pollution, impoundments, and loss of host fishes. Overharvesting, commercial dredging, in-channel gravel or sand mining, channelization, and excess sedimentation caused, in part, by poor land use practices, also negatively impact freshwater mussel populations (Cosgrove 2000, Watters 2002). van der Schalie (1938) speculated the following factors had contributed to the decline of the

North American mussel fauna in the previous decade: silting, pollution by sewage, mine and industrial wastes, power-dam developments, and unrestricted mussel gathering for the pearl button industry. Bogan (1993) suggested that the causes of unionid mussel declines are poorly known due to the cumulative lack of knowledge of unionid life history, ecology, distribution, fish hosts, and systematics. Some possible causal factors that may be apropos to the Umatilla and John Day River systems are summarized below.

Sedimentation and Sediment Characteristics

Human-induced increases in sedimentation rates in streams throughout the United States is thought to be one of the contributing factors leading to the decrease in freshwater mussel populations (Vannote and Minshall 1982, Burkhead et al. 1997, Brim Box and Mossa 1999, Brim Box et al. 2002). Increased suspended sediment clogs the gills of mussels, which has been linked to a decrease in filter time (e.g., feeding time) and overall growth rates of some mussel species (Ellis 1936, Kat 1982). However, the degree to which mussels are affected by increased sedimentation appears to be species dependent (Brim Box et al. 2002). Suspended sediment may also interfere with the delicate mussel/host fish relationship. For example, some mussel species visually attract their host fish by displaying elaborate lures that mimic fish food items (Kreamer 1970, O'Brien and Brim Box 1999, Watters and O'Dee 1999). Increased suspended sediment can reduce water clarity, which may reduce the effectiveness of these visual lures to attract host fish (O'Brien and Brim Box 1999). This, in turn, may hinder successful glochidial encystment on a viable host fish.

Channel Modifications

Freshwater mussels are sensitive to a wide variety of watershed environmental changes (Williams et al. 1992) because their riverbed habitat is dependent on channel hydraulics and sediment transport, both of which are influenced by the nature of the surrounding watershed. More specifically, mussels are nearly stationary, bottom-dwelling filter feeders, and therefore are vulnerable to alterations of substrate character and suspended sediment concentration, as well as changes to the river bed itself, including scour and deposition, especially of fine sediment (Strayer 1983, Layzer and Madison 1995, Brim Box and Mossa 1999).

Since the early part of the century, the Umatilla River has undergone intensive channel modifications. Nearly 70% of its channel has been physically modified either through straightening, mining, construction of levees, or the actual process of physically moving the channel to another part of the floodplain. Because mussels are relatively sedentary animals these direct channel modifications may have negatively impacted habitat necessary for freshwater mussel survival in the Umatilla River system.

Because currently there are so few freshwater mussels in the Umatilla River system, it is difficult to explore whether freshwater mussels historically were negatively impacted by channel modifications. However, because mussels are extant in the Middle Fork John Day River, some exploration of the possible correlation between mussel occurrence and channel changes in the upper Middle Fork John Day was possible in this study. For example, in a study of channel morphology and variation, McDowell (2001) divided the upper reaches of the Middle Fork John Day into valley segments that were associated with major channel modifications. Comparing the abundance of *Margaritifera* *falcata* within these reaches, the fewest number of mussels were found in the channelized and/or mined reaches, whereas the greatest number of mussels was found in reaches with no modifications (Table 6). Although these findings are preliminary, they do provide a nexus for generating hypotheses to examine process-based links between mussel populations and the local physical environment, in both the Umatilla River system and the Middle and North Fork John Day rivers.

Table 6. Associated channel modifications within stream segments of the Middle Fork John Day River (modified from McDowell 2003) and associated *Margaritifera falcata* abundances. Note that the highest abundances were found in stream reaches with no modifications (segments F, H), with lower abundances found in modified reaches (segments C, I, J).

Stream segment	Segment length	Type of channel modification	*Margaritifera falcata* abundance at sampling site
A	4.05	Road encroachment	177
B	3.05	Channel straightening	No sample in reach
C	4.4	Channel straightening, placer mining	45
D	3.24	None	No sample in reach
E	8.49	Channel straightening, rip rap	104
F	3.2	None	370
G	3.4	Channel straightening, placer mining	No sample in reach
H	8.34	None	550
I	5.69	Bank stabilization with barbs	24
J	1.5	Channel straightening	78
K	1.31	Channel straightening	No sample in reach
L	1.52	None	No sample in reach
M	4.21	None	No sample in reach
N	1.32	None	124

Dams and Impoundments

Impoundments and dams can potentially impact the biota of lotic systems through a myriad of factors including, but not limited to, increased and/or decreased sedimentation through channel erosion, streambed scour, and the accumulation of fine sediments behind impoundments; hydrologic and water quality changes including shifts in flows, nutrients, temperature, and the accumulation of pollutants; changes in the composition of other biotic taxa, including food resources; and by acting as ecologic barriers (Ellis 1942, Baxter 1977, Williams et al. 1993, Watters 1996, Hamilton et al. 1997, Watters 2000). The most obvious habitat alteration is the conversion of a lotic environment into a lentic one. As the water flow is reduced, suspended sediments fall to the bottom of a reservoir, providing habitat for silt-tolerant species. The changes that occur in mussel faunas (e.g., silt-intolerant to silt-tolerant species) after dam construction have been well documented (e.g., Williams et al. 1992, Williams et al. 1993). For example, the lower Tennessee River historically included a rich fauna of mostly large-river mussel species that were most common in stable, gavel substrates (Bates 1962). After the river was impounded, 12 riverine species disappeared and 6 reservoir-tolerant species appeared that had previously not been reported from that area.

Chemical changes in water quality have also been documented, such as increased temperatures and decreased oxygen levels (Allan 1995). Many dams release water in pulses as a result of dam maintenance, production of electricity, and recreation. These water pulses often can have an adverse effect on downstream habitats and biota. For example, the temperature of water released from the bottom of dams is usually cooler. Many life stages of mussels are temperature dependent including growth, gametogenesis, glochidial release, and time required for glochidial metamorphosis (Waller et al. 1988, O'Brien and Brim Box 1999, Watters 2000). These water quality changes also change the phytoplankton and zooplankton community (Allan 1995), which may alter the food source available for mussels.

Dams act as physical and genetic barriers for many riverine species including fishes (Allan 1995, Watters 1996). A common example is that of the disappearance of salmon runs as a result of dams blocking their upstream movement. Mussel populations that rely on migratory host fish for reproduction and dispersal will also be negatively affected by the construction of reservoirs (Watters 1996, Watters 2000).

There are seven dams currently maintained on the main stem of the Umatilla River (see study area). Although these are mainly small diversion dams for irrigation, they can potentially impact mussel populations by several of the mechanisms listed above. For example, *Margaritifera falcata* is known to occur in “running” streams (Clarke 1981, Taylor 1981). In the Pit River system in northern California, *M. falcata* were found only in the “free-flowing” habitat available between impoundments (Spring Rivers Ecological Sciences 2001). Similarly, *Gonidea angulata* occurred in “riverine” habitats between impounded reaches of the Pit River system (Spring Rivers Ecological Sciences 2001). Impoundments are also listed as a possible threat to existing populations of *Margaritifera* and *Gonidea* in California (Taylor 1981). In Canada, *Gonidea* were reported from both rivers and lakes (Clarke 1981). However, one of the rivers cited by Clarke (1981) was Vaseux Lake, a natural lake in British Columbia. Man-made impoundments are often unsuitable for freshwater mussels, even for species that occur in naturally-formed pools (Watters 2000). For example, 15 species of mussels were found in a man-made impoundment on the Mississippi River, while in an adjacent, naturally-formed pool, 30 freshwater mussel species were found (van der Schalie 1938).

Anodonta, however, are morphologically adapted to live in low-flow environments (e.g., they lack lateral and pseudocardinal teeth), and in some studies were commonly found in impoundments, even when other species were absent (e.g., Brim Box and Williams 2000, Mock et al. 2004). Quantitative studies of the effects of impoundments on *Anodonta* species in the western United States are lacking.

Spatial Distribution of Freshwater Mussels

The longitudinal distribution of mussel species composition changed from the headwaters to the confluence in each system; *Margaritifera falcata* appears to dominate in the upper reaches and *Anodonta californiensis* and *Gonidea angulata* in the lower reaches (Figures 8, 9, 10, 11). These results were not surprising, in that a similar spatial distribution for *Margaritifera* and *Anodonta* was recently documented in a river system in California (Howard and Cuffey 2003). Bauer (1991) suggested that differences in the distribution between the superfamilies Margaritiferidae and Unionidae could be linked to the food supply. Bauer (1991) found that *Margaritifera* had a lower metabolic rate than other species of freshwater mussels, and could grow in rivers with lower primary productivity rates. In contrast, *Anodonta* and *Gonidea* may require a richer food supply because they have higher metabolic rates. These differences in food requirements could be correlated with the longitudinal food availability in a stream system. For example, energy inputs change as streams widen in the downstream direction. Because shading and the contribution of allochthonous materials decreases, and the amount of sunlight reaching the streambed increases, algal primary productivity increases from upstream to downstream (Vannote et al. 1980). Perhaps the spatial occurrence of *A. californiensis* and *G. angulata* in the Middle and North Fork John Day rivers can be explained, in part, by their higher metabolic rates (relative to *Margaritifera*) and the differences in food availability in various stream reaches. This assertion should be tested, however, with field trials and laboratory experiments.

CONCLUSIONS

Freshwater mussels have been extirpated from most of the main stem of the Umatilla River and its tributaries. Shell evidence and historical records via interviews with tribal elders suggest that mussels were once found in the main stem of the Umatilla River, at least as far upstream as above Mission, but now are confined to a few sites near its confluence. In addition, although *Margaritifera falcata* probably until recently was extant in that system, it is now extirpated. The reasons for the extirpations are not known, although dams and the subsequent loss of salmonid species may have negatively impacted mussel populations in that basin. In addition, since the early part of the century, the Umatilla River has undergone intensive channel modifications, and channel straightening, mining, and levees have physically modified nearly 70% of its active bed. Because mussels are relatively sedentary animals, these channel modifications may have negatively impacted habitat necessary for mussel survival in the Umatilla River system. In contrast, all three genera of mussels known from the western United States were found at multiple sites on the Middle and North forks of the John Day River, suggesting that those rivers provide suitable habitat and host fishes for extant and reproducing mussel populations.

Tribal and federal agencies would like to restore freshwater mussels to the Umatilla River Basin as part of their ongoing efforts to rebuild ecosystem diversity, function, and traditional cultural opportunities in the basin. In order to do so, additional work on mussels in the basin should include a quantitative assessment of mussel densities and macro- and microhabitat variables in selective mussel beds in the Middle Fork John Day River and possible the lower Umatilla River where limited, remnant mussel populations remain; assess the geomorphic change in channel morphology of the Middle Fork John Day and Umatilla rivers to ascertain how these changes could impact mussel populations; and continue to conduct research on genetics and host fishes, as these components will be crucial for future efforts to reintroduce mussels, especially *Margaritifera falcata*, into the Umatilla River system.

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