PHYSIOLOGICAL PROCESSING OF SUSPENDED MATTER BY FRESHWATER MUSSELS IN RIVERS OF EASTERN OREGON

A FINAL REPORT FOR THE
FRESHWATER MUSSEL RESEARCH
AND RESTORATION PROJECT

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INTRODUCTION

Freshwater mollusks of the Unionacea are common constituents of the benthic macroinvertebrate assemblage in North American streams, rivers, and some lakes (Negus 1966, Kryger and Riisgard 1988, Strayer et al. 1994). North America is also home to the greatest biodiversity of freshwater mussels in the world (Baker 1928, Ortmann 1911, Banarescu 1990). Unfortunately, more than 100 species of freshwater mussels are currently at risk of extinction in the U. S (Williams et al. 1993). Not only are we losing biodiversity, the abundance of most species of freshwater mussels is also declining at an alarming rate. Reduced water quality, lost and altered habitat, and introduced species appear to be primary agents impacting freshwater mussel populations (Chaffee 1993, Bogan 1993). Because of their unusual life history traits, freshwater mussels (unionids) do not recover rapidly once populations have been depleted (McMahon 1991).

For these reasons, there is growing interest in the conservation and recovery of freshwater mussels (e.g., 1998 formation of the Freshwater Mollusk Conservation Society with membership >300). Despite the elevated interest in these animals and efforts to protect their biodiversity, we still have a very limited understanding of the roles of populations of freshwater mussels in the functional ecology of rivers and streams. It is becoming increasingly clear, however, that where still abundant, freshwater mussels can serve as "ecosystem engineers" in the same way as their marine counterparts such as oysters. Like reefs of oysters, beds of freshwater mussels may regulate key trophic and biogeochemical processes, improve water quality, enhance habitat for fish and other organisms, and more.

Freshwater mussels can grow to large sizes (>1-10 g dry tissue mass per animal), and where they are present, beds can range achieve densities of up to 70 mussels m^{-2} (Negus 1966, Duncan & Thiel 1983, Holland Bartels 1990, Miller & Payne 1993, Strayer et al. 1994; Kreeger 2004). Clarke (1973) reported beds of over 100 mussels m^{-2} in a number of rivers in Canada, and Hardy (1991) reported mussels >100 m^{-2} in undisturbed locales in the St. Croix River in Minnesota. Thus, a typical bed may contain at least 100 g dry weight m^{-2}, representing a much higher biomass than that of other aquatic fauna living in river and stream habitats (Strayer et al. 1994). In a recent comparison of some dominant bivalves in the Delaware Estuary watershed of the mid-Atlantic, Kreeger (2007) estimated that the combined population biomass of the common freshwater mussel, *Elliptio complanata*, living in the watershed was comparable to that of oysters, *Crassostrea virginica*, living throughout Delaware Bay, and they also have similar clearance rates per unit body mass during summer. The population-level ecosystem services of oysters are widely reputed, so much so that oyster restoration is considered a key to the overall ecosystem improvement of the Chesapeake Bay.

SUSPENSION-FEEDING ANIMALS AND SESTON

One of the reasons why suspension-feeding bivalves often dominate as a functional guild in aquatic ecosystems is because of their physiological ecology, feeding mode, and lifestyle. By feeding at the base of the food chain on a rich soup of microparticulate material, they can exploit resources that are comparatively more abundant or productive than macroscopic foods. Suspended microparticulate material (hereafter referred to as "seston") can represent one of the largest pools of organic matter in aquatic habitats, and its quantity and quality are widely regarded as a key component of water quality (e.g., TSS in stormwater runoff and erosion, algae blooms associated with eutrophication). Seston also represents a base-of-food-web resource in virtually all aquatic systems where myriad forms of invertebrate and vertebrate consumers have evolved a fanciful array of suspension-feeding (a.k.a., “filter-feeding”) approaches to capture small particles for meeting dietary needs. Seston includes inorganic material such as fine sediments, non-living organic aggregrates, non-living detrital particles, and an assortment of live microbial organisms such as microalgae, bacteria and heterotrophic protests (e.g., Kreeger and Newell 2000). Since seston comprises the diet of so many of the functionally dominant consumers in aquatic habitats, the quantity and quality of seston can govern rates of secondary production by animals that capitalize on this rich soup of material.

Because the population biomass of suspension-feeding animals is often high and their secondary production is usually tightly coupled to seston quantity and quality, it is no surprise that these animals often serve as function dominants in aquatic systems (Dame 1996). Where abundant, even subtle shifts in population biomass or weight-specific rates of material processing can have important repercussions at the ecosystem level where their population-level processing of seston and ther pools of organic matter can control biogeochemistry and affect physical processes such as water clarity, benthic organic enrichment, and food availability for other organisms.

Freshwater bivalves feed just like other suspension-feeding bivalves. They satisfy their nutritional demands by pumping large amounts of water over inflated gills where microscopic particles are removed en masse by mucociliary mechanisms. Hence, a dense population of freshwater mussels can process a large amount of microparticulate material during suspension feeding (e.g., typically 1 L per h per g dry tissue weight), and suspension feeding might therefore represent an important "filtering" mechanism for limiting algal blooms, maintaining water clarity for benthic producers, etc.

FUNCTIONAL IMPORTANCE OF FRESHWATER MUSSELS

The fate of material cleared by mussels is also likely to be ecologically meaningful. A portion of the material consumed is assimilated for maintenance and growth, but usually a greater portion is quickly returned to the environment as excreted DOM, feces, and pseudofeces.
Depending on the chemical form, excreted DOM can be bioavailable to microalgae and microheterotrophs. If ingested material is not used for production, catabolized, or converted to dissolved compounds, then it gets transformed physically into forms that precipitate to the bottom (feces and pseudofeces). This repackaging of microparticulate matter in the water column as macroparticulate matter on the benthos (biodeposits) might enrich the sediment organic content for other benthic organisms or facilitate burial of excess nutrients in eutrophic streams. The degree to which mussels transform suspended microparticulate matter into either mussel tissue, DOM, or course biodeposit matter on the bottom, will therefore be important organic matter processing controls in any aquatic community where suspension-feeding bivalves are abundant.

The pelagic-benthic coupling by suspension feeding bivalves is increasingly cited in the marine literature as a key functional process that helps transform "pelagic" food webs into "benthic" food webs (Newell 1988). For example, the loss of extensive oyster populations from Chesapeake Bay is considered one of the two main reasons that the bay ecosystem has shifted from a clear water system dominated by benthic biota (e.g., seagrass, benthic algae, oysters, sturgeon) to a turbid system dominated by pelagic biota (phytoplankton, zooplankton, jellyfish, striped bass). A converse ecosystem transformation has occurred in the Lake Erie with the introduction of zebra mussels (*Dreissena polymorph*a). Increased awareness of these ecological relationships is now guiding policy in some coastal systems where the importance of bivalve shellfish for ecosystem functioning is gaining traction. For example, in Chesapeake Bay there is growing support for introducing a non-native oyster species as a replacement for the disease-prone native Virginia oyster, and the motivation for doing so includes both commercial and ecological reasoning.

Although unionid mussels are believed to be primary agents in the functional ecology of freshwater ecosystems, few researchers have examined whether unionids can perform similar roles in lotic systems as demonstrated for zebra mussels or their marine counterparts. Drawing on nearly 40 years of research in marine systems, we are beginning to develop a better understanding of the role that freshwater mussels play in river and stream systems (e.g., Strayer et al. 1994; Vaughn and Hakenkamp 2001; Vaughn et al. 2004; Kreeger 2005a, 2005b; Howard and Cuffey 2006). Strayer et al. (1994) reported that the population of native freshwater mussels in the freshwater tidal portion of the Hudson River filtered a volume of water equivalent to the total volume of downstream flushing. Kreeger (2005) reported that a bed of mussels in a six-mile reach of the Brandywine River of southeast PA is capable of filtering approximately 6% of the total suspended solids in base flow conditions. Much of the material removed from suspension is in turn biodeposited in feces, and so the actions of these animals also enrich the sediments with organic matter (e.g., Howard & Cuffey 2006).

There is not much known about whether the functional importance varies among different mussel species, or whether seasonal or basin-specific factors interact with species to affect their ecological importance. Vaughn et al. (2001) reported that rates of respiration, algal clearance, biodeposition and ammonia excretion by unionid populations are similar among species, and the importance of these physiological rate functions for the system depended entirely on total mussel biomass. Physiological rate functions do not scale linearly with body size (Christian et al. 2001); the size structure of the mussel population is likely to be much more important than species composition in determining material processing rates. Weight specific rates of processing are also likely to vary with animal physiological condition and nutritional status as well as an array of abiotic factors (e.g., temperature, flow rate, pH). Nevertheless, biomass (per reach length, or per flow volume) is likely to be the principal determinant of whether unionids can significantly influence system functionality.

In light of these relationships, it is important to quantify the ecological role that populations of suspension-feeders play in rivers of the Columbia River Basin to better understand the complex interrelationships among land and water use impacts, distributions of functional dominant suspension-feeding organisms, and the ensuing effects on water quality and ecosystem functional integrity.

IMPORTANCE OF MUSSELS OF THE COLUMBIA BASIN

The potential functional importance of bivalve shellfish is just as relevant in the Columbia River Basin Columbia of the Pacific Northwest as elsewhere in the United States and world, but there has simply been less attention to these organisms in this area. In the Columbia Basin, freshwater mussels certainly represent an important historic assemblage of benthic suspension-feeders, seemingly having been abundant in the past throughout the region. Densities of more than 100 mussels m^{-2} have been reported by members of the CTUIR research team in rivers of eastern Oregon, for example. However, the current distribution and population abundance of these animals appears to vary widely among different drainage basins in association with varying levels of impairment. Of particular interest, the diversity, population abundance and range of freshwater mussels in the Umatilla River appears to be greatly reduced (almost absent), presumably due to a host of water quality and quantity issues, and habitat alterations, as summarized elsewhere by the CTUIR research team.

In rivers of eastern Oregon, freshwater mussels represent perhaps the most important consumers of seston for food. These “suspension-feeders” may become impaired by suboptimal seston quantity and quality, and they may also become stressed by excessive amounts of TSS in the water. But where seston quality is capable of satisfying the animals’ nutritional demands, the wealth of this material that is typically found in aquatic systems usually sustains high consumer biomass. Indeed, in eastern Oregon, like most aquatic ecosystems of the world, the biomass and material processing rates of suspension-feeders can be very high relative to those of animals that feed in other ways. Therefore, in rivers containing healthy populations of freshwater mussels, much of the suspended matter is likely to be ensnared and transformed by these animals, and so they can have important effects on water quality.

STUDY ORGANISMS

As part of the CTUIR mussel project, systematic surveys for freshwater mussels were conducted in 2003 in rivers within the study area, which consisted of the mainstem of the Umatilla River, the mainstem of the Middle Fork John Day River, and the lower two-thirds of the North Fork John Day River in eastern Oregon. Three genera were found: *Anodonta, Gonidea,* and *Margaratifera.* In the Umatilla River, only *Anodonta* sp. were encountered, and these were only found in the lowest reaches of the river despite historical reports of mussels throughout much of the system. In contrast, all three genera were inventoried in both the Middle Fork and North Fork of the John Day River.

The species consisted of *Margaratifera falcatus, Gonidea* sp., and two morphological variants of *Anodonta* sp. The two different forms of *Anodonta* were only encountered in the lower Umatilla River (see Methods, Section 3). Until genetic analyses can be performed, it remains unclear if these are two different species of *Anodonta.*

GOALS

The goal of this objective of the CTUIR freshwater mussel project was to quantify and compare weight-specific processing rates and fates of suspended microparticulate matter consumed by freshwater mussels from different drainages in Oregon. Results from this work provide the physiological basis for estimating the ecological relevance of freshwater mussel feeding in representative rivers of the Columbia Basin. To do this, results from this study can be compared to estimated historical and measured current population biomass for the representative species, yielding mass balance estimates for population-level processing of seston in the study areas. The specific objectives of this physiology component of the CTUIR Freshwater Mussel Project were to quantify:

1) how much seston is filtered, per unit biomass and time, by representative freshwater mussel species under simulated natural conditions in the laboratory;

2) weight-specific physiological rate functions (respiration, excretion, defecation, absorption) by the mussels;

3) temporal (seasonal, inter-annual) and spatial (inter-basin; intra-basin) variation in seston filtration and physiological rates;

4) interspecific variation in seston filtration and physiological rates;

These objectives were met by integrating the physiological measurements from this study with previously collected data on temporal and spatial variation in seston availability and composition (reported previously in the lamprey report, Kreeger 2006). Seston collections and analyses were performed periodically from different areas where mussels were also collected for these physiology experiments, as well as areas that historically sustained mussel populations but no longer do (e.g. upstream on the Umatilla River). As noted above, in the future the data and outcomes from this report can be compared to mussel population census data collected by other members of the Freshwater Mussel Project to provide population-level estimates of the functional importance of mussel beds in the ecology of Oregon rivers.

METHODS

1) Study Area

Freshwater mussels were collected from various locations within two river systems in the Columbia River Basin: the John Day River and the Umatilla River, Oregon. The general study sites were the same as those described by Brim-Box et al. (2004).

Table 1. Mussel sampling locations and times during 2005-2006.

River	Sampling Location Names	Site Code	Coordinates		UTM Zone 11 Coordinates		Sampling Dates
			Latitude	Longitude	Latitude	Longitude	
John Day Middle Fork	Boulder Creek	10	N 44°39'58.4"	W 118°42'59.0"	0363940	4947307	6/22/05 10/9/05 3/20/06 8/24/06
	Fishing Hole	11	N 44°45'35.4"	W 118°51'55.8"	0352358	4957963	3/23/05 6/22/05 10/9/05 3/20/06 8/24/06
	Wildcat Point	12	N 44°47'49.6"	W 118°55'52.4"	0347254	4962226	6/22/05
	Ritter Hot Springs	13	N 44°53'31.2"	W 119°08'34.9"	0330779	4973188	6/22/05
John Day North Fork	Mussel Bed	21	N 45°06'49.2"	W 118°58'27.6"	0344701	4997474	3/23/05 6/22/05 10/9/05 3/20/06
Umatilla	Hermiston	33	N 45°50'07.6"	W 119°20'09.1"	0318595	5078419	3/20/06 8/24/06

2) Seston Collection and Analysis

"Seston" is microparticulate material too small to be seen by the human eye. For this study, seston was considered to include particles that are large enough to be retained on a glass fiber filter having an effective retention of 0.7 µm (particle diameter) and small enough to pass through a 53 µm sieve, which corresponds to the range of particle sizes that can be efficiently captured by most suspension-feeding bivalves. Typically, the most nutritious particles comprising the bulk of their diet exist in a narrower size range, often between 5-20 µm (e.g. Kreeger and Newell 2001). When larger sized particles are used, it is usually because either the flows are higher during which larger particles get swept up into the seston or because the animals are somehow able to access material in the benthic boundary layer (e.g., Karlsson et al. 2003).

Water used to examine seston was sampled during base flow conditions within a day of mussel collections. When collected during low flow periods, particles larger than 30 µm are virtually absent in seston, ensuring that the seston analysis is indicative of ambient food conditions for suspension-feeding mussels. Seston was separated from natural water samples by vacuum filtration onto pre-combusted glass fiber filters, and later analyzed for particle size distribution, inorganic and organic particulate matter concentration, and percentage organic content as described by Kreeger (2006). To examine spatial and temporal variation in seston quantity and quality in relation to mussel physiological status, water samples were collected at the same locations and times listed in Table 1, as well as additional places and times as described by Kreeger (2006).

3) Mussel Collection and Holding

Up to 12 individuals of each species were collected per location where they could be found to provide sufficient replication for mussel physiology experiments. Mussels were collected five times: March, June and October, 2005, and March and August, 2006 (Fig. 1). Three species of mussels were sampled, *Margaratifera falcata, Anodonta sp.,* and *Gonidea* sp. Only M. falcata was sampled from one location on the North Fork of the John Day River, and only *Anodonta* sp. was sampled from one location on the Umatilla River. All three species were sampled at one location (Fishing Hole) on the Middle Fork of the John Day River, with only *M. falcata* collected in the uppermost site (near Big Boulder Creek) and only *Anodonta* sp. taken at the lowermost site (Ritter Hot Springs).

The genetics of *Anodonta* sp. were unclear at the time of this study; however, it appeared that two species or sub-species were present on the Umatilla (near Hermiston) based on morphological differences; whereas, only one was observed on the Middle Fork John Day River (Fig. 2).

***Figure 1**. David Wolf collecting mussels in the Middle Fork John Day River in March, 2005.*

Up to seven individuals were used per treatment in each Unionid Mussel Physiology (UMP) experiment, and any unused individuals that had been collected were either sacrificed for analysis of body metrics or returned to the field. An attempt was made to collect and run experiments on a wide range of body sizes per species and collection to facilitate allometric scaling of physiological rates to represent each population. Table 2 summarizes the number of individuals of each species that were taken at different times from the different locations, 217 mussels in total for this study.

***Figure 2**. Two morphological variants of* Anodonta *sp. collected from the Umatilla River near Hermiston, OR, during August 2006. The two individuals on the left had a longer posterior-anterior axis and exhibited green-tinted stripes, whereas the two on the right were dorso-ventrally elongated and more flattened laterally. The right-hand specimens most resemble* Anodonta *sp. from the Middle Fork John Day River.*

Table 2. Numbers of mussels collected for body size and condition analyses from various sampling locations and times during 2005-2006.

	Margaratifera falcata				***Anodonta sp.***				***Gonidea sp.***
	John Day North Fork	John Day Middle Fork			John Day Middle Fork			Umatilla	John Day Middle Fork
Date	Mussel Bed	Big Boulder	Fishing Hole	Wildcat Point	Fishing Hole	Wildcat Point	Ritter Hot Springs	Hermiston	Fishing Hole
3/23/05	9	-	9	-	11	-	-	-	1
6/22/05	22	5	7	3	11	3	7	-	11
10/9/05	6	8	7	-	7	-	-	-	7
3/20/06	7	7	7	-	7	-	-	4	7
8/24/06	-	8	7	-	9	-	-	13	7

Some additional mussel tissue samples were provided by CTUIR staff for analysis, representing mussels that had been transplanted among the rivers (e.g. John Day to Umatilla; sampled in October 2004 and May 2005). However, data from those analyses are not examined here because shell heights and dry shell weights were not assessed, precluding calculation of condition index and standardization of findings to mussel body size. Organic contents were analyzed for those additional samples, and freeze-dried specimens are archived for potential future analyses.

The timing of these collections and experiments was selected to ensure that seasonal variation in mussel physiology was captured. Early spring was represented by the two March collections (2005, 2006), summer by the June, 2005 and August 2006 collections, and fall was represented by the October 2005 collection. In March 2005, two physiology experiments were performed (UMP1, UMP2), and two more were performed in June 2005 (UMP3, UMP4.) One larger experiment with more replicates was performed in each of October, 2005 (UMP5), March, 2006 (UMP6), and August, 2006 (UMP7.)

No attempts were made to sex mussels, and we assumed that mean physiological measurements from random treatment groups captured any sex differences and treatment groups were indicative of the overall population. Mussels were collected by hand either by wading or snorkeling, and they were transported to the laboratory in coolers filled with ambient water taken from the same locations as the mussels.

Numerous extra carboys of river water were filled at each collection site and separately labeled to ensure that there was ample replacement water to replenish coolers and eventually experimental aquaria so that mussels were always exposed to the same water quality, seston quality and quantity, and temperature, as that in their source river. Mussels were therefore held in fresh source stream water until experimentation. Water temperatures were maintained within 3°C (usually within 1°C) of ambient stream temperatures from where the mussels were taken to ensure mussel physiological did not respond to any sudden temperature changes. Ambient water temperature in early spring ranged from 3-6°C, 18-22°C in summer, and 15-18°C in early fall (Table 3).

***Figure 3**. Adult* Gonidea *sp. shown here filtering water during a clearance rate experiment, June, 2005.*

***Figure 4**. Adult* Margaratifera falcata *collected in June, 2005.*

Table 3. Water temperature at time of mussel collection from different sampling locations and times during 2005-2006.

	John Day North Fork	**John Day Middle Fork**			**Umatilla**
Date	Mussel Bed	Big Boulder	Fishing Hole	Wildcat Point	Hermiston
3/23/05	5.6 °C	-	4.5 °C	-	-
6/22/05	17.9 °C	-	22.0 °C	-	-
10/9/05	16.2 °C	15.3 °C	17.8 °C	-	-
3/20/06	3.1 °C	3.1 °C	4.6 °C	-	10.0 °C
8/24/06	-	19.4 °C	20.0 °C	20.0 °C	18.9 °C

Physiological experiments were conducted within 24 hours of mussel collection. In March 2005, experiments were conducted at The Nature Conservancy's facility on the upper Middle Fork John Day. In June 2005, experiments were conducted at Ritter Hot Springs on the Middle Fork John Day. The rest of the experiments were conducted at CTUIR. Targeted holding temperatures were the same as ambient water temperatures, which are listed in Table 2. By maintaining mussels in the same source stream water for both pre-experiment holding and for experimental treatments, mussels did not experience any marked change in food quality, food quantity, or temperature as they moved from the river to holding tanks to experimental aquaria.

4) Mussel Body Analyses

Mussels were wiped free of excess water and placed on a scale to determine whole mussel wet weights to the nearest 0.01 g. Shell heights were measured with a micrometer to the nearest 0.01 mm. Mussels were then shucked and the tissues were added to a pre-weighed and numbered vial, which were quickly frozen and later shipped to Drexel University, Philadelphia, for further analyses. Samples were kept frozen during shipment to Drexel University. Shells were placed into number baggies, frozen, and also shipped with tissues.

At Drexel University, tissue samples were freeze-dried in the pre-weighed vials and then re-weighed to the nearest 0.00001 g to calculate total dry tissue weight by difference. These were then hand-pulverized to a fine powder with a mortar and pestle. A subsample of ground tissue was used for the weight-on-ignition method (450°C, 2 days) to determine the ash-free dry tissue weight and percentage organic content. Remaining freeze-dried and ground tissues samples were archived for potential future analysis (e.g. stable isotope ratios, proximate biochemical composition.).Shells were dried to 60°C for 2 days and were weighed to the nearest 0.00001 g

Allometric relationships of rate functions to body weight were determined from mussels used in experiments as well as any extras that were sacrificed. Mussel condition was calculated from the relationship between dry tissue mass and internal volume available between shell valves

(Kreeger 1993, as modified from Crosby and Gale 1990). This condition index (CI) calculation was obtained as follows:

$$CI = [DTW \times 1000] / [TWW - DSW]$$

where total wet weight (TWW), dry shell weight (DSW) and dry tissue weight (DTW) is measured in grams, making CI a unitless value.

An additional subsample of a subset of mussel samples was used to analyze the protein content as a partial index of proximate biochemical composition (i.e., relative percentage protein, lipid, carbohydrate, and ash). The term "content" is used to refer to the percentage of total dry tissue weight represented by the component of interest; i.e., protein content refers to the proportion of dry tissue weight comprised of protein. Protein content was analyzed as described by Kreeger and Langdon (1994). For the protein assay, a 5- to 10-mg subsample of dried and ground lamprey tissue was added to 5 ml 1 M NaOH in a 15-ml centrifuge tube, homogenized for 15 s with a Polytron, sonicated 15 s, and heated for 45 min at 60°C. The total volume in the tube was increased to 8 ml with 1 M NaOH and mixed with a vortex. The tube was then centrifuged at 1000 xg for 10 min and the supernatant was analyzed spectrophotometrically with a test kit (Pierce BCA 23225).

5) Mussel Feeding

Physiological rate functions for freshwater mussels were quantified using standard methods that have been developed for marine bivalves (e.g., see Kreeger and Langdon 1993.) Up to seven individuals of each treatment group were used for each experiment. Treatment groups consisted of a particular species collected from a specific reach at the same time, as described in Table 2 above.

For each individual, the physiological rate functions assessed will consist of clearance (feeding) rates, ingestion rates, defecation rates, excretion rates, and respiration rates. The Conover Ratio (Conover 1966) will be calculated to estimate food absorption efficiency, and the O:N ratio (rate of oxygen consumption divided by the rate of ammonia excretion) will be calculated as an index for whether protein sparing might affect nutrient remineralization rates. Since physiological rate functions do not scale linearly with body size (Christian et al. 2001), these measures will be obtained for a range of animal sizes and the rates will then be expressed according to allometric relationships

5.1 Seston Diet Preparation

Water from the same collection location was used for each treatment group. Water was pre-sieved to 53 μm to remove large particulate matter that mussels would not be able to feed on.

5.2 Clearance Rate Experiments

Clearance (water processing) rates refer to the volume of water that is "cleared" of particles per unit time (CR, L h^{-1}). CR was measured for each animal in static aquaria by monitoring the rate of particle disappearance in a 1 L container, with subsequent correction for changes in particle concentrations in 1 L controls having no live animals (Fig. 5). Experimental containers consisted of 1 L graduated plastic tripour beakers. Where needed, larger containers with larger volumes of water were used to ensure the ratio of animal biomass to water volume was sufficient to ensure that particle concentrations were not depleted by more than 50% over the experimental period.

For each Unionid Mussel Physiology (UMP) experiment, mussels were held in replicate chambers for a 2 h incubation period. Chambers were mixed and a 20 ml sample was removed prior to adding mussels at the start of each experiment. Mussels were gently scrubbed free of debris prior to each experiment. Mussel apertures typically opened within 15 min, and if they did not the mussel was replaced with a more active individual and its sampling schedule was adjusted accordingly.

***Figure 5**. Clearance rates were measured by monitoring particle disappearance in beakers containing single mussels, relative to controls with no mussels.*

After each experiment was underway, chambers were mixed at 30, 60, 90 and 120 min without disturbing mussels by gently plunging a graduated cylinder and 20 ml of water was sampled each time. Each water sample was fixed with 4 drops of Lugol's solution for later analysis. Following the 2 hr experiment, mussels were removed and each chamber's contents were examined for dissolved (excretion) and particulate (defecation) mussel by-products.

Water samples were shipped to Drexel University, Philadelphia, where they were analyzed for their particle concentration and size distribution for all particles having diameters between 2-63 µm using a Coulter Multisizer system (Multisizer II) following protocols described by Kreeger et al. (1997). Before analysis, samples were diluted 1:1 v/v with 10 ml isotonic diluent (Fisher Scientific, Isotone) and mixed by inverting the vials. The Multisizer was calibrated to analyze seston particles between 2 and 63 µm, with particle concentrations quantified separately within five additional ranges: between 2-3 µm, 3-4 µm, 4-6 µm, 6-10 µm, 10-15 µm, and 15-63 µm. Analysis of these size fractions, in addition to the total range, enables potential later determination of filtration efficiencies, which can indicate small or large size preferences. Comparison of ambient particle size distributions to actual particle sizes that are preferentially filtered by mussels may also indicate whether a mussel species can adapt to natural food conditions that vary in time and space, potentially affecting their ecological impacts. This size-specific analysis was not a focus of this work, and so data are reported simply as the total particle concentration for the entire 2-63 µm range.

For each mussel in each UMP experiment, a regression curve was fitted to the change in particle concentration (2-63 µm) that was observed across the experimental period (up to 5 sample times). Sample times were omitted from the regression in cases where particle concentrations fell to less than 50% of the initial concentration. This rule was applied uniformly for all mussels in all experiments to ensure that measured clearance rates were indicative of ambient food condition and not potentially altered (e.g., lowered) by an appreciable decline in ration. Regression curves were then used to estimate the initial and final chamber concentration, considering all sample variability across the experimental period.

Clearance rates for static chambers were then calculated using the equation of Coughlan (1969):

$$\text{Clearance Rate (L/h)} = [\log Ci - \log Cf] \times [V / T]$$

where Ci = particle concentration at the start of the incubation period, Cf = particle concentration at the end of the incubation period, V = chamber volume, and T = incubation time.

At least three chambers containing water and seston only (no mussel) were established for each water type as controls to account for settling of particles throughout the experiment (Coughlan 1969).

5.3 Filtration Rate Calculations

Filtration rate (FR, $mg.h^{-1}$) is dry weight of particles cleared from suspension per unit time. It is the most common means of measuring filtration activity in bivalves and may be used to calculate a daily ingested ration, i.e., mg of dry seston consumed (Bayne et al. 1976). Clearance and filtration rates can vary with temperature (season) and also seston concentration and quality. For example, water processing and seston filtration rates typically are reduced at low temperatures and also when food availability is low (low seston concentration). Increases in temperature and concentration lead to increased filtration up to a maximum. Still further increases in seston concentration such as during turbid conditions results in decreases in filtration with further increases in concentration (Foster-Smith 1975, Winter 1978, Widdows et al. 1979, Bayne et al. 1989, Velasco and Navarro 2005). Under increasingly turbid conditions, most bivalves can reject filtered material prior to ingestion as pseudofeces; therefore, actual ingestion rates can decline at high seston loads (Winters 1978). Although the relative proportions of filtered and ingested material are important for the animal, the ecological effects on suspended matter concentrations are linked to filtration since material rejected as pseudofeces is mucous-bound and is biodeposited to the bottom similar to feces.

Clearance rates (liters of water cleared per hour) were converted to filtration rates (dry weight of seston removed per hour) by multiplying measured clearance rates by the measured seston concentration (dry weight of seston per liter of seawater), measured as part of the seston analysis reported by Kreeger (2006). Filtration rates for mussels will then corrected for values measured in controls to adjust for any changes due to microbial activity or particle settlement.

5.4 Allometric Scaling of Feeding Rates

Filtration rates increase with increasing mussel size (Winter 1978), which can also vary widely among species, and so filtration rates (as well as the other physiological rates below) were weight-adjusted. To determine weight-adjusted rates, the relationship of filtration rate and mussel dry tissue weight was determined by least squares linear regression analyses on log-log data, following the same approach as Kreeger et al. (2001). A separate regression equation was determined for each species of mussel from each river and each experiment. Where similar (e.g., among different rivers for the same species), another regression equation was generated on the pooled data to minimize error. The average mussel dry tissue weight for all individuals used in a regression equation was then inserted into the equation, resulting in weight-adjusted filtration rates for each mussel after back-transformation from the log-log relationship. These allometric-scaled filtration rates (L h^{-1} g dry tissue weight $[DTW]^{-1}$) also enable direct comparison of rate functions among species for the "average-sized" mussel of each species.

6) Mussel Defecation and Absorption Efficiency

Fecal collections will be made at the end of each clearance rate measurement (up to 56 individuals, see above).

6.1. Fecal Collection and Analysis

No pseudofeces were observed in any UMP experiment, and so all biodeposits were assumed to be true feces. Feces were removed from UMP experiment chambers by Pasteur pipet after mussels were removed. Feces were subsequently pipetted out of the chambers with a Pasteur pipet. They were then vacuum-filtered onto pre-ashed and pre-weighed glass fiber filters (Whatman GF/F). Filters frozen until later analysis at Drexel University, Philadelphia. Seston (food) was sampled as part of the regular seston collection (see above and Kreeger 2006). Fecal filters were later analyzed using the weight-on-ignition method in the same manner as seston samples that were analyzed for total particulate matter and particulate organic matter. Filters were dried in an oven (60˚C for 24 h), weighed, ashed in a furnace (450˚C for 24 h), and weighed again, to determine dry weights and ash-free dry weights of filtered feces samples.

6.2 Absorption Efficiency

Absorption efficiency (AE) represents the percentage of organic material in dietary matter (seston) that is actually ingested and absorbed by mussels (Conover 1966). Like filtration rate, absorption efficiency can vary with food quality and quantity, although it tends not to vary as much with temperature (seasonally). Typically, absorption efficiency varies inversely with food quantity and directly with food quality (Thompson and Bayne 1974, Widdows 1978, Griffiths 1980). Different bivalve species may balance their nutritional needs through different strategies of regulation of filtration rate, particle selection (pseudofecal rejection processes) and ingestion rate, and absorption efficiency, for example.

Absorption efficiencies were determined for each mussel in each experiment by comparison of the organic content of the seston delivered to each animal and the feces that it produced. Absorption efficiency, the percentage of absorption of material by mussels, was calculated per Conover (1966):

$$AE = [(F - E)/(1 - E)(F)] \times 100\ \%$$

where AE is absorption efficiency, F is the ash-free dry weight : dry weight ratio (the inorganic fraction) of the ingested food (seston), and E is the ash-free dry weight : dry weight ratio of feces egested.

7) Mussel Excretion

Ammonia excretion rates were measured following a modification to the protocol described by Kreeger & Langdon (1993). In brief, following removal of mussels from the chambers in each UMP experiment (including controls with no mussels), water was passed through a 0.45 µm filter and up to 20 ml of filtrate was collected for later analysis of ammonia concentration. Internal standards were included at least once in additional no-mussel controls, using predetermined amounts of ammonia standards (NH_4Cl; 25 - 250 mM) that were added for calibration of the method. Samples for ammonia analysis were frozen and analyzed at Drexel University, Philadelphia using standard methods (Solorzano 1969), and resulting excretion rates were control-corrected and expressed per gram of mussel dry tissue weight (µg-at NH_4+-N h^{-1} g^{-1}).

8) Mussel Respiration

Respirometry is laborious and time-consuming in comparison to the other physiological rate measurements, and so respiration rates were measured on a subset of mussels in each UMP experiment. Respiration was assessed by quantifying the animal's oxygen consumption rate, and inter-converted using standard oxycaloric conversion factors reported for metazoans. A 6-channel dissolved oxygen measurement system (Strathkelvin Instruments Ltd., Model S1928) was used to monitor oxygen losses in sealed 400 ml respirometry chambers (Strathkelvin RC400) containing a magnetic stir bar for mixing (Fig. 6). Each chamber was filled with 0.2 µm filtered river water that (to ensure that no microbial organisms are present that would substantially contribute to or remove oxygen during the respirometry measurements.) In addition to mussels, up to 4 controls (no mussels) were analyzed similarly for each of the major water treatments and times.

Chambers were mixed using magnetic stirring bars for incubation periods lasting up to 2 hours. Oxygen electrodes (Strathkelvin, 1302 microcathode) were calibrated to zero with a solution of sodium sulphite (anhydrous) and to 100% with aerated water. Respirometry trials lasted between 30-150 min, depending on mussel activity (i.e., whether apertures were open or closed) and monitored by observing the decline in chamber oxygen with the software. Oxygen consumption rates were calculated from the decline in oxygen concentration per

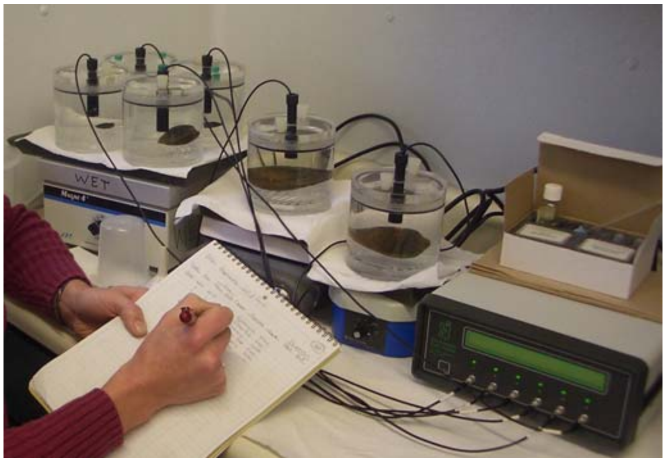

Figure 6. *Use of a Strathkelvin respirometry system to measure rates of oxygen consumption by freshwater mussels.*

time, and the were later control-corrected and expressed per gram of mussel dry tissue weight (µg-at O_2 h^{-1} g^{-1}) using allometric principles (see above). The animal biomass : water volume ratio was not sufficient to deplete oxygen by more than 40% during this time period, and the short incubation period also precluded significant microbial breakdown of any fecal or pseudofecal products that might have been carried over and defecated (as determined in preliminary tests by observing whether any significant changes in oxygen concentration occurred over 2 hours after removing mussels that had defecated during incubation.

9) Net Absorption Rate and Scope-for-Growth

The net absorption rate and scope for growth are indicators of physiological status, suggesting whether the mussels are in a state of active growth (positive values), quiescence (zero values), or loss of condition (negative values). The net absorption rate (NAR, mg hr^{-1}) can be calculated by multiplying ingestion rates (IR) and absorption efficiencies (AE) together (Bayne et al. 1989). The ingestion rate can be measured as the amount of filtered material that is not rejected as pseudofeces, and in cases such as this study where no pseudofeces are produced the ingestion rate can be assumed equivalent to the filtration rate (FR), as follows.

$$NAR = IR \times AE = FR \times AE.$$

Like net absorption rate, the scope-for-growth (SFG) is a measure of an animal's actual physiological growth potential. SFG was developed as a health assessment metric for aquatic organisms, but it also represents a potentially useful way to examine how rates and fates of material processing can vary spatially and temporally. SFG summarizes the information on various physiological rate functions and is a closer approximation of an animal's actual growth rate, closely correlating with long-term growth performance (Beiras et al. 1994). Unlike traditional growth measurement, SFG is a near instantaneous measure, thereby avoiding need to resample and measure the body size of individuals over protracted time periods (Bayne et al. 1976).

SFG is calculated from the results of component measures of feeding rate, oxygen consumption rate, ammonia excretion rate, and food absorption efficiency. SFG is best assessed using units of energy as per Widdows and Donkin (1992). The goal is to construct a mass balance for energy usage:
:

$$C = P + R + E + F$$

where C = energy consumed, P = energy used for animal productivity, R = energy lost in respiratory processes, E = energy excreted in dissolved by products, and F = energy lost in defecation. C was calculated by converting filtration rates from units of mg seston filtered to units of energy using established POM:energy conversion factors. Respiration was measured directly as the oxygen consumption rate (see above), which was converted to units of energy using standard oxycaloric quotients. The excretion term (E) was calculated similarly, by relating measured ammonia excretion rates (see above) to established energy loss conversion formulae. Defecated biomass was measured (see above) and converted to the energy loss term using established POM:energy conversion factors. By difference, P was estimated as the energy available for growth and reproduction; i.e., the scope-for-growth.

$$SFG = P = C - (R + E + F)$$

In addition, we also calculated the same value (P) in a second way for comparison, as per Widdows and Donkin (1992):

$$SFG = P = NAR - (R + E)$$

whereby NAR = net absorption rate (see above), converted to energy as noted above for filtration and defecation rates.

10) Ratio of Oxygen Consumption to Ammonia Excretion (O:N Ratio)

The oxygen:nitrogen ratio (O:N ratio) is indicative of nutritional status (Bayne and Widdows 1978, Widdows 1978, Kreeger 1993, Baker and Hornbach 1997), providing evidence for which dietary substrate is being catabolized for a metabolic fuel. O:N ratios of less than 20 indicate that an animal is energy-limited and its productivity is largely being governed by its ability to ingest, digest and assimilate energy from natural diets. Catabolic substrates can consist of protein, lipid or carbohydrate, but the relatively high loss of ammonia suggests that nitrogen and protein are ample in the diet. O:N ratios exceeding 25 indicate that an animal is preferentially catabolizing non-nitrogenous substrates and conserving nitrogen (a.k.a. “protein-sparing”) (Bayne et al. 1985). At such times, an animal’s physiological behavior may not follow standard energy optimization patterns, and protein-rich seston components may be especially important from the mussel’s standpoint (Kreeger et al. 1994). Under such conditions, mussel populations may be biogeochemical sinks for a greater proportion of particulate nitrogen than usual, and less nitrogen-rich biodeposits may be produced for bottom organisms.

11) Comparison of Physiology and Seston Data

Seasonal and spatial variation in seston concentration and character was contrasted with similar variation in mussel physiological rate functions and temperature to discern whether mussels may adapt their physiology to changing conditions, or to potentially suggest effects of mussels on seston in those areas where mussels still remain in abundance.

12) Statistical Analyses

All statistical analyses were performed with Statgraphics Plus Version 5.0 for Windows. Only parametric statistics were required; however, various data transformations were used to achieve normality. When transformations were applied, reported means, derived from the statistical procedures, may differ slightly from arithmetic averages calculated on non-transformed data. All means and standard errors shown in figures are from statistical output. See individual sections for a description of the actual statistical tests applied to each data set.

RESULTS AND DISCUSSION

Temporal and spatial variation in microparticulate seston that comprises the diet of freshwater mussels, and which can be affected by mussel populations in rivers, is examined in Section 1 below. Data are presented for numerous seston collection times and locations that span the period of mussel physiological studies. Since more seston samplings were completed than the number of mussel samplings or physiological experiments, variation in seston quantity and quality is discussed in Section 1 separate from the mussel physiological analyses. However, the subset of seston data that comprised actual diets in physiological experiments is presented later in Section 3.1.

Section 2 summarizes all analyses of mussel physiological status, including body sizes and condition indices for different species that were sampled at different times and from different places. Mainly, these data consist of mussels that were sacrificed at the end of Unionid Mussel Physiology (UMP) experiments, however additional mussels were sampled at a few other times and the entire dataset was analyzed for each parameter to yield the best possible assessment of seasonal and spatial differences in size and condition data for various species.

Sections 3-7 describe and discuss physiological rate functions and energetic models measured in seven UMP experiments. Two physiology experiments were performed in March 2005 (UMP1, UMP2), two in June 2005 (UMP3, UMP4,) one in October, 2005 (UMP5), one in March, 2006 (UMP6), and one in August, 2006 (UMP7.) Since no significant differences were (t-tests, $p>0.05$) detected in any species- and site-specific physiological parameter between UMP experiments that were conducted back to back during the same month (i.e., UMP1 versus UMP2, UMP3 versus UMP4), data were lumped per sample month for all species-site pairings. Therefore, data were statistically compared and are presented in Sections 3-7 for various experiment months, river/reaches, and species, but not necessarily for individual UMP experiments.

Table 4. Experimental design of seasonal Unionid Mussel Physiology (UMP) experiments conducted on mussel species collected at different times and from different places in eastern Oregon, 2005-2006.

Species and Experiment No.	Date	Middle Fork John Day	North Fork John Day	Umatilla
		n	n	n
Margaratifera falcata				
UMP 1, 2	3/22/05	**8**	**7**	**-**
UMP 3, 4	6/22/05	**16**	**6**	**-**
UMP 5	10/9/05	**15**	**5**	**-**
UMP 6	3/20/06	**12**	**4**	**-**
UMP 7	8/24/06	**12**	**-**	
***Gonidea* sp.**				
UMP 1, 2	3/22/05	**1**	**-**	**-**
UMP 3, 4	6/22/05	**6**	**-**	**-**
UMP 5	10/9/05	**7**	**-**	**-**
UMP 6	3/20/06	**5**	**-**	**-**
UMP 7	8/24/06	**6**	**-**	**-**
***Anodonta* sp.**				
UMP 1, 2	3/22/05	**7**	**-**	**-**
UMP 3, 4	6/22/05	**11**	**-**	**-**
UMP 5	10/9/05	**7**	**-**	**-**
UMP 6	3/20/06	**5**	**-**	**1**
UMP 7	8/24/06	**6**	**-**	**10**

Section 8 contrasts results presented in Sections 1 through 7 to ascertain whether and how any differences in mussel physiological status and functional processes vary with either dietary or environmental factors.

1) Seston Composition

Seasonal and spatial variation in seston quantity and quality were partially examined previously for samples collected in 2005 (Kreeger 2006). For this report, additional seston analyses were completed.

1.1 Seston Particle Size Distribution and Concentration

The size spectrum and concentration of seston microparticles with mean diameters 2 and 63 µm is summarized in Table 5 for all samplings for which we examined these particle metrics. Mean (±SE) particle concentrations were quantified for the total size range (2-63 µm) as well as separately for each of the six following specific size ranges: between 2-3 µm, 3-4 µm, 4-6 µm, 6-10 µm, 10-15 µm, and 15-63 µm (Table 5).

Of the 15 samplings summarized in Table 5 from up to six river locations sampled in May, June and August, 2005, the greatest total particle concentration was recorded in May from the Fishing Hole site on the Middle Fork John Day River where 28210 (± 1760) particles were measured per milliliter. In contrast, the lowest total concentration was measured at the Cayuse Bridge site on the Umatilla in June, 4950 (± 2430).

Spatial and temporal differences in total particle concentration were examined using one-way ANOVA's and multiple range analyses ($\alpha=0.05$). To examine spatial variation, statistically significant differences among river sites for each sampling month were first discerned. The results of these tests are depicted in Table 5 as different letters (for each metric in a column, the same color represents one MRA). At all sampling times, significant differences were found among at least some of the river sites. For example, in June 2005 six sites were sampled, two from each of the John Day Middle Fork, John Day North Fork, and Umatilla Rivers, and in general the Umatilla River seston contained fewer particles than the John Day River seston (Fig. 7). As depicted in Fig. 7, in most situations there was little difference in total particle concentration between upstream and downstream samplings for the same river and month, and so data were lumped for subsequent tests. The one exception to this was found in the North Fork John Day River, as described at the end of this section.

A two-way ANOVA was used to contrast variation in total particle concentrations among months and rivers, with data summarized in Fig. 8. Although there tended to be more particles in seston during May than in June and August, the most interesting overall pattern was found among rivers (Fig 8). The effects of river and month also interacted. In May, seston from the Middle Fork John Day contained significantly more total particles than in the North Fork John Day, which in turn had more than in the Umatilla (Fig. 8, Table 5). Between May and June there was little change in seston particles in the North Fork John Day, but concentrations in the Middle Fork John Day were significantly lower in June than May or in the North Fork. In June, the Umatilla again contained significantly fewer seston particles in the overall 2-63 µm size range (Fig. 8). No significant differences among rivers were found in August, but this was partly due to high variability in the model for this sampling time.

Table 5. Average concentrations and pooled standard errors (sample sizes are in parentheses) of particulate material (PM) and different-sized particles in water collected from different rivers during 3 different months in 2005. For each parameter and month, significant differences among sites (or rivers in grey) are denoted as different letters (for the same color per column) as determined with a LSD multiple range analysis (α=0.05).

River	Site	Month	Numerical Concentration by Mean Diameter (#/ml)							PM	Proportion >15 µm	Proportion <3 µm
			2-3 µm	*3-4 µm*	*4-6 µm*	*6-10 µm*	*10-15 µm*	*15-63 µm*	2-63 µm			
John Day Middle Fork	Boulder Creek	May	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
		June	7710 ±1730 (4) abc	1680 ±205 (4) ab	1158 ±120 (4) b	5966 ±82 (4) b	207 ±19 (4) bc	337 ±43 (4) a	11690 ± 2110 (4) ab	1.42 ±0.33 (4) ab	4.7 ±0.9 (4) bc	65.9 ±2.2 (4) a
		August	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
	Fishing Hole	May	21010 ± 1630 (8) a	3190 ±199 (8) a	2309 ±152 (8) a	1247 ±82 (8) a	320 ±28 (8) a	129 ±16 (8) ns	28210 ± 1760 (8) a	4.69 ±0.18 (8) a	1.6 ±0.2 (8) ns	73.8 ±1.8 (8) ns
		June	5470 ±1730 (4) bc	1355 ±205 (4) bc	1217 ±120 (4) b	580 ±82 (4) b	159 ±19 (4) cd	114 ±43 (4) b	8900 ± 2110 (4) b	1.10 ±0.33 (4) abc	3.2 ±0.9 (4) c	61.2 ±2.2 (4) ab
		August	10920 (1)	3096 (1)	2268 (1)	1134 (1)	276 (1)	108 (1)	17800 (1)	1.61 (1)	2.2 (1)	61.3 (1)
	Pooled	May	21010 ± 1645 (8) a	3190 ±202 (8) a	2309 ±150 (8) a	1247 ±78 (8) a	320 ±27 (8) a	129 ±15 (8) ns	28210 ± 1800 (8) a	4.69 ±0.24 (8) a	1.6 ±0.2 (8) ns	73.8 ±1.7 (8) ns
		June	6593 ±1201 (8) **b**	1517 ±140 (8) **b**	1187 ±83 (8) **b**	588 ±57 (8) **b**	183 ±21 (8) **b**	226 ±41 (8) **ns**	10290 ± 1440 (8) **b**	1.26 ±0.22 (8) **a**	3.9 ±0.6 (8) **b**	63.6 ±2.1 (8) **ns**
		August	10920 (1)	3096 (1)	2268 (1)	1134 (1)	276 (1)	108 (1)	17800 (1)	1.61 (1)	2.2 (1)	61.3 (1)
John Day North Fork	Forest Service Rd 3963	May	10630 ± 2310 (4) b	1944 ±281 (4) bc	1483 ±215 (4) bc	936 ±116 (4) b	233 ±40 (4) ab	127 ±22 (4) ns	15350 ± 2490 (4) bc	4.17 ±0.24 (4) ab	2.5 ±0.3 (4) ns	68.5 ±2.5 (4) ns
		June	9140 ±1730 (4) ab	2249 ± 205 (4) a	2344 ±120 (4) a	1082 ±82 (4) a	325 ±19 (4) a	257 ±43 (4) a	15390 ± 2110 (4) a	1.69 ±0.33 (4) ab	3.9 ±0.9 (4) c	59.2 ±2.2 (4) b
		August	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
	Mussel Bed	May	15120 ±2310 (4) ab	2542 ±281 (4) ab	1824 ±215 (4) ab	1002 ±116 (4) ab	241 ±40 (4) ab	109 ±22 (4) ns	20840 ± 2490 (4) b	4.68 ±0.24 (4) a	1.7 ±0.3 (4) ns	72.1 ±2.5 (4) ns
		June	12410 ±1990 (3) a	2211 ±237 (3) a	2360 ±139 (3) a	1100 ±95 (3) a	231 ±22 (3) b	117 ±49 (3) b	18430 ± 2430 (3) a	1.86 ±0.33 (4) a	2.2 ±1.0 (3) c	64.1 ±2.6 (3) ab

River	Site	Month	Numerical Concentration by Mean Diameter (#/ml)							PM	Proportion >15 μm	Proportion <3 μm
			2-3 μm	*3-4 μm*	*4-6 μm*	*6-10 μm*	*10-15 μm*	*15-63 μm*	2-63 μm			
		August	4230 ±3840 (4) b	1860 ± 289 (4) ab	1217 ±177 (4) ns	601 ±75 (4) ns	216 ±36 (4) ns	168 ±29 (4) ns	8300 ± 3840 (4) b	1.19 ±0.08 (4) c	5.7 ±0.9 (4) a	47.3 ±4.4 (4) b
	Pooled	May	12877 ±1645 (8) b	2243 ±202 (8) b	1653 ±150 (8) b	967 ±78 (8) b	237 ±27 (8) b	119 ±15 (8) ns	18090 ± 1800 (8) b	4.42 ±0.24 (8) a	2.1 ±0.2 (8) ns	70.3 ±1.7 (8) ns
		June	10540 ±1284 (7) **a**	2233 ±149 (7) **a**	2350 ±89 (7) **b**	1090 ±61 (7) **a**	284 ±23 (7) **a**	197 ±44 (7) **ns**	16690 ± 1540 (7) **a**	1.77 ±0.22 (8) **a**	3.1 ±0.7 (7) **b**	61.3 ±2.2 (7) **ns**
		August	4235 ±5490 (4) *ns*	1860 ±286 (4) *ns*	1217 ±168 (4) *ns*	601 ±75 (4) *ns*	216 ±35 (4) *ns*	168 ±30 (4) *ns*	8300 ± 5520 (4) *ns*	1.19 ±0.16 (4) *b*	5.7 ±1.1 (4) *ns*	47.3 ±7.4 (4) *ns*
Umatilla	Cayuse Bridge	May	8550 ±2310 (4) b	1377 ±281 (4) c	843 ±215 (4) d	475 ±116 (4) c	188 ±40 (4) b	88 ±22 (4) ns	11520 ± 2490 (4) c	2.14 ±0.24 (4) c	2.3 ±0.3 (4) ns	74.6 ±2.5 (4) ns
		June	3210 ±1990 (3) c	660 ±237 (3) d	482 ±139 (3) c	276 ±955 (3) c	118 ±22 (3) d	209 ±49 (3) ab	4950 ± 2430 (3) b	0.38 ±0.33 (4) c	6.9 ±1.0 (3) ab	63.9 ±2.6 (3) ab
		August	23120 ±3840 (4) a	1935 ±289 (4) ab	1219 ±177 (4) ns	527 ±75 (4) ns	216 ±36 (4) ns	116 ±29 (4) ns	27130 ± 3840 (4) a	2.09 ±0.08 (4) a	1.7 ±0.9 (4) b	81.8 ±4.4 (4) a
	Emaceus	May	10880 ±2660 (3) b	1595 ±325 (3) c	954 ±248 (3) cd	540 ±134 (3) c	208 ±46 (3) ab	79 ±26 (3) ns	14260 ± 2870 (3) bc	3.78 ±0.29 (3) b	2.0 ±0.3 (3) ns	76.4 ±2.9 (3) ns
		June	2720 ±1990 (3) c	875 ±237 (3) cd	760 ±139 (3) c	489 ±95 (3) bc	246 ±22 (3) b	207 ±49 (3) ab	5300 ± 2430 (3) b	0.74 ±0.33 (4) bc	8.5 ±1.0 (3) a	51.4 ±2.6 (3) c
		August	4750 ±3840 (4) b	1568 ±289 (4) b	1216 ±177 (4) ns	620 ±75 (4) ns	244 ±36 (4) ns	175 ±29 (4) ns	8580 ± 3840 (4) b	1.49 ±0.08 (4) b	5.0 ±0.9 (4) b	54.8 ±4.4 (4) b
	Pooled	May	9648 ±1758 (7) b	1470 ±215 (7) c	891 ±160 (7) c	502 ±84 (7) c	196 ±29 (7) b	84 ±16 (7) ns	12690 ± 1920 (7) b	2.84 ±0.26 (7) b	2.2 ±0.2 (7) ns	75.4 ±1.9 (7) ns
		June	2964 ±1387 (6) **b**	767 ±161 (6) **c**	621 ±96 (6) **b**	382 ±66 (6) **c**	182 ±25 (6) **b**	208 ±47 (6) **ns**	5120 ± 1660 (6) **c**	0.56 ±0.22 (8) **b**	7.7 ±0.7 (6) **a**	57.6 ±2.4 (6) **ns**
		August	13937 ±3882 (8) *ns*	1751 ±202 (8) *ns*	1217 ±119 (8) *ns*	674 ±53 (8) *ns*	230 ±25 (8) *ns*	145 ±22 (8) *ns*	17850 ± 3900 (8) *ns*	1.79 ±0.11 (8) *a*	3.4 ±0.8 (8) *ns*	68.3 ±5.2 (8) *ns*

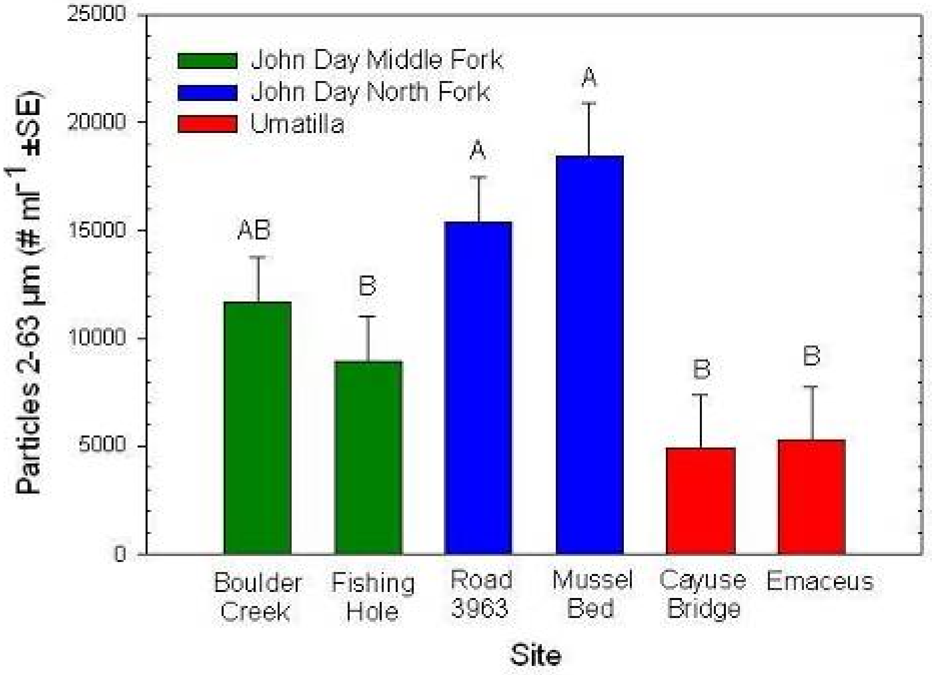

***Figure 7**. Mean (±SE) concentration of seston particles having diameters between 2-63 µm in water sampled from specific locations in three rivers in eastern Oregon during summer, 2005. For each location, different letters above bars denote statistical differences as determined by a LSD multiple range analysis from a one-way ANOVA (α=0.05).*

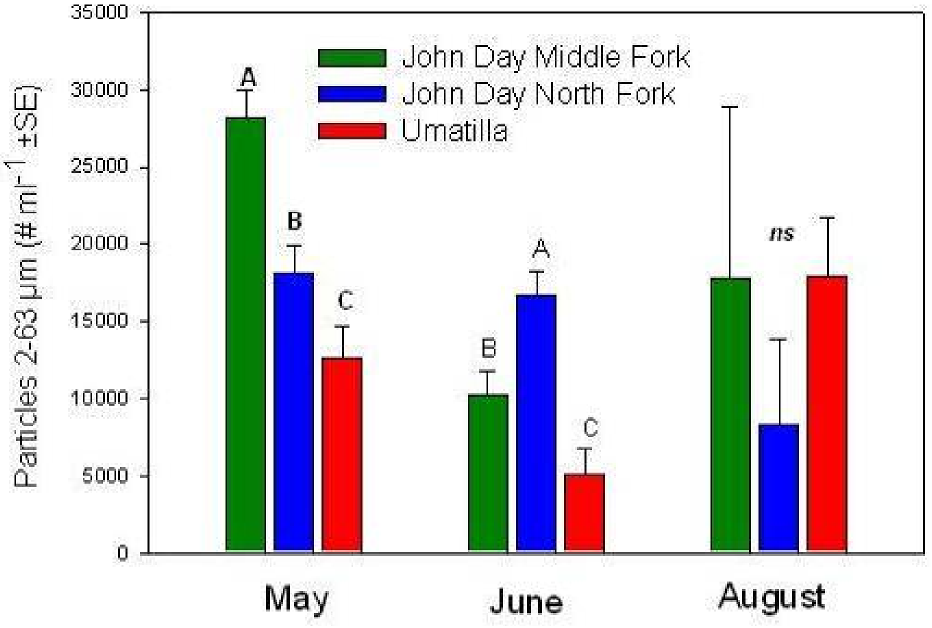

***Figure 8**. Mean (±SE) concentration of seston particles having diameters between 2-63 µm in water sampled from three rivers in eastern Oregon during summer, 2005. For each month, different letters above bars denote statistical differences as determined by a LSD multiple range analysis from a one-way ANOVA (α=0.05).*

The particle size distributions also differed among rivers, with the Middle and North Forks of the John Day River having more mid-sized particles than in the Umatilla River (Fig. 9). Averaged across all sampling months, concentrations of 4-6 µm particles averaged 1790 (±140) and 1816 (±126) per ml in the Middle and North Fork John Day, respectively, which was approximately twice the concentration as in the Umatilla, 930 (±118) per ml (significantly lower, $p<0.0001$). For this size range, there was no overall significant pattern among the summer months. Similarly, for 6-10 µm particles, the Middle and North Forks of the John Day contained an average of 917 (±68) and 923 (±61) per ml, respectively, again significantly greater and approximately twice that measured in the Umatilla 492 (±57) per ml. The same pattern was apparent for particles in the 10-15 µm size range, although the differences were not significant ($p=0.09$). These findings may be important in relation to the feeding habits and relative food availability for suspension-feeding animals living in these rivers, since most suspension-feeders favor particles in the 3-15 µm size range. Assuming these data for summer 2005 are representative for other times of the year, then the John Day drainage would appear to have a more favorable seston food environment for mussels in quantitative terms.

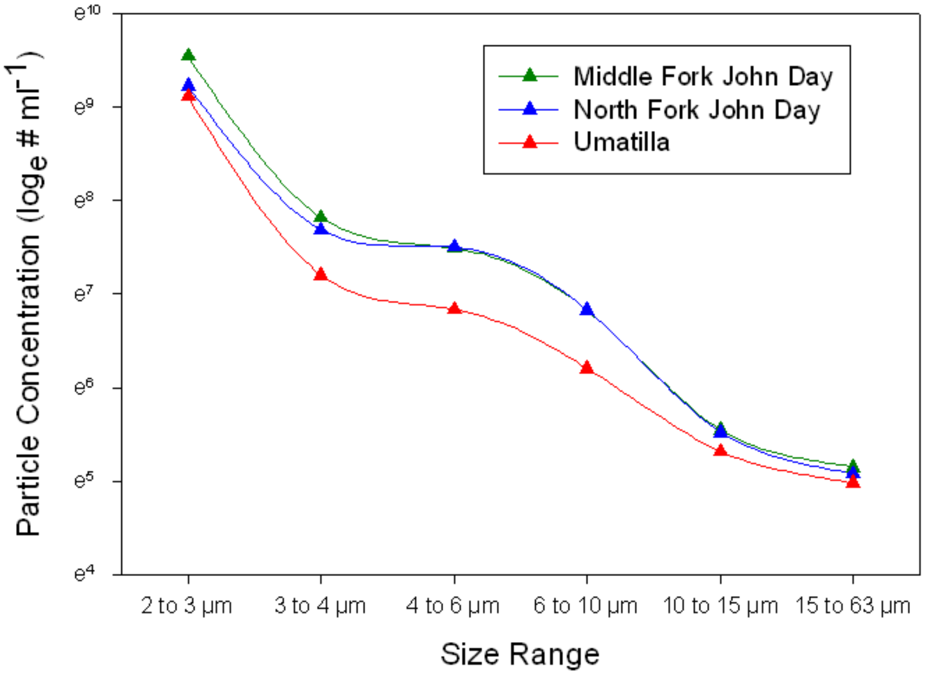

***Figure. 9**. Mean (±SE, logarithm transformed) concentrations of seston particles in various size ranges in water sampled from three rivers in eastern Oregon during summer, 2005.*

As seen in Figure 9, concentrations of the smallest and largest particles were not as variable among rivers, compared to the middle size classes. However, we were able to detect spatial differences in the relative proportions of large-sized particles. We found that the best approach to demonstrate these temporal changes was to express the largest size fraction as a percentage of the total number of 2-63 µm particles (Fig. 10). Since there were no significant differences in these attributes among reaches within rivers or among rivers all data were lumped per month. A one-way ANOVA and LSD multiple range analysis (α=0.05) indicated that water collected from the Umatilla River contained a significantly greater proportion of the largest sized seston compared to the Middle and North Forks of the John Day River, which were not significantly different (Fig. 10). Therefore, as noted above, during summer 2005 the particle size distribution in seston of the Umatilla River differed from that in the John Day drainages, which were similar between the Middle and North Forks. These findings may have implications for suspension-feeding animals. Based on particle size selection studies with bivalve mollusks and other suspension-feeders, much of these larger particles in the Umatilla may not be as efficiently captured as particles in the 4-15 µm range.

Temporal variability in particle sizes was not as pronounced as the spatial differences described above. Nevertheless, some patterns were detected in the particle size distribution among the three sampling months in 2005. But interestingly, these differences were only apparent for the largest (15-63 µm) and smallest (2-3 µm) size fractions. We found that the best approach to portray these temporal changes was to express the large and small fractions as percentages of the total number of 2-63 µm particles. A two-way ANOVA was used to discern differences among months with river as the second main effect. Figure 11 portrays the percentage of particles in the 15-63 µm size range as an average of all sites versus sampling month. A significantly greater proportion of larger particles was measured in June (4.7%) and August (4.0%) as compared to May (2.0%). In contrast, the particles in the smallest size range, 2-3 µm, were most numerous in May (73%), which was significantly greater than in June (61%) and August (61%) (Fig. 12). Therefore, when analyzed over all sampling stations, temporal variability was most apparent in the smallest and largest sizes, being characterized as smaller on average in May and larger during summer. Since the middle size ranges that are most preferred by suspension-feeders did not vary appreciably among May, June and August, it was unlikely that temporal variation in particle sizes was of much consequence to suspension-feeding animals in these rivers.

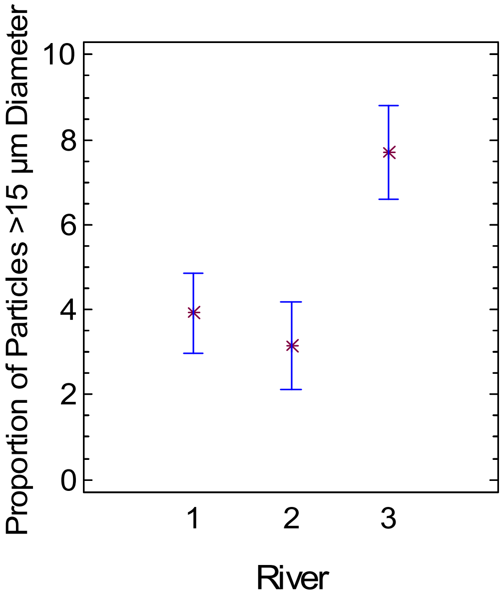

Figure 10. *Percentage of total particles analyzed that were 15-63 µm in diameter (±SE) in water sampled from the Middle Fork John Day (1), North Fork John Day (2), and Umatilla (3) Rivers in eastern Oregon during summer, 2005.*

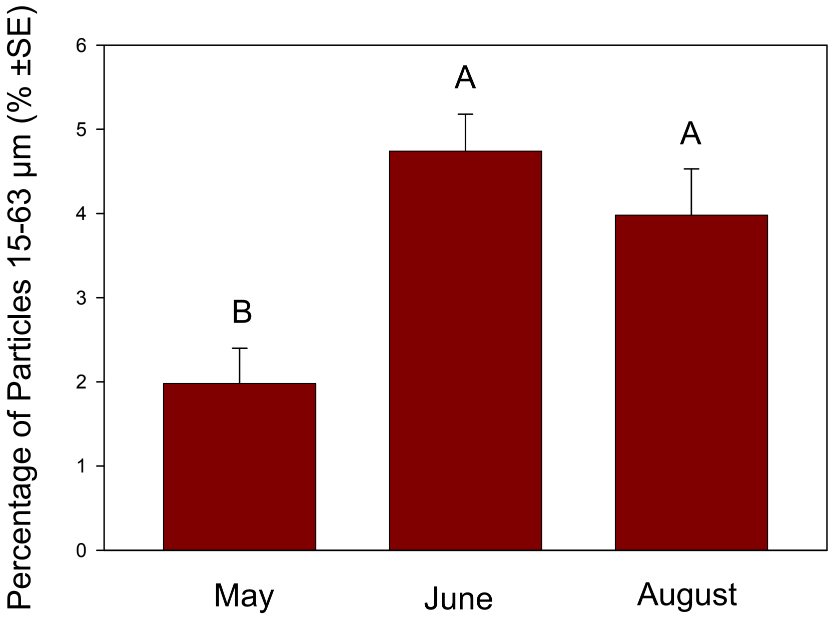

Figure 11. *Percentage of total particles analyzed that were 15-63 µm in diameter (±SE) in water sampled from three rivers in eastern Oregon during summer, 2005. For each month, different letters above bars denote statistical differences as determined by a LSD multiple range analysis from the two-way ANOVA (α=0.05).*

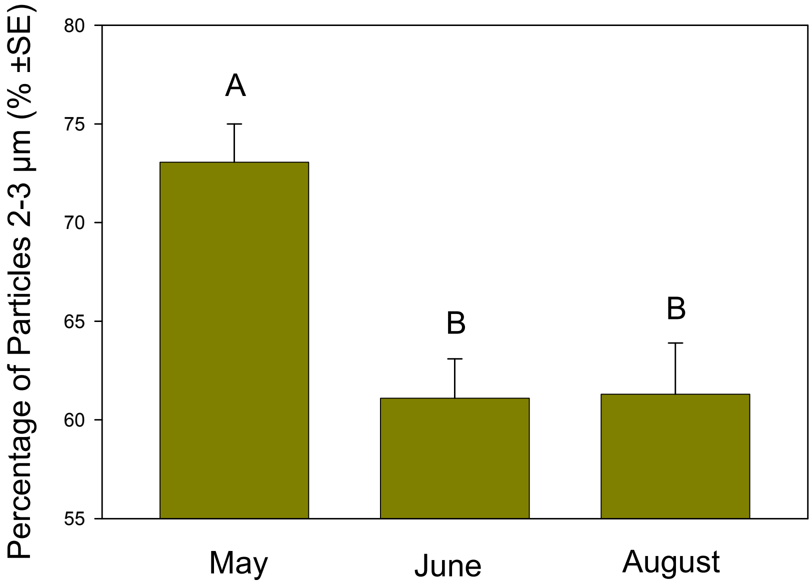

Figure 12. *Percentage of total particles analyzed that were 2-3 µm in diameter (±SE) in water sampled from three rivers in eastern Oregon during summer, 2005. For each month, different letters above bars denote statistical differences as determined by a LSD multiple range analysis from the two-way ANOVA (α=0.05).*

It is important to note that these findings regarding temporal and spatial shifts in the fine scale size distribution of seston particles are limited to just a three basins and only three warm months during one sampling year. Furthermore, river water was collected mainly during low flow conditions. Particle sizes are certain to vary more widely with flow, being larger and more numerous during periods of greater runoff. Little is known about seasonal shifts in seston sizes and their importance for suspension-feeding animals; however for the purposes of this project we focused on the warm months when the quantitative nutritional demands of aquatic consumers are highest and when flows are generally much lower.

Although the focus of this project was to assess physiological rates of freshwater mussels rather than their impacts to stream ecology, we observed an interesting phenomenon in the North Fork John Day River that demonstrates the interplay between seston particle sizes and the possible feeding activities of suspension-feeders. Seston was collected on the North Fork John Day River just above and below an extensive bed of the *Margaratifera falcatus*. These upstream and downstream sampling locations are named Forest Road 3963 and Mussel Bed, respectively, in Table 5. The relative concentrations of seston particles in each of six size ranges were contrasted in water collected in May and June from the upstream and downstream sampling locations (only one site was sampled in August). As shown in Figure 12, the largest sized particles were less numerous below the mussel bed and smaller particles were more numerous there. This effect was apparent in both months, with a more pronounced depression of large particles during June.

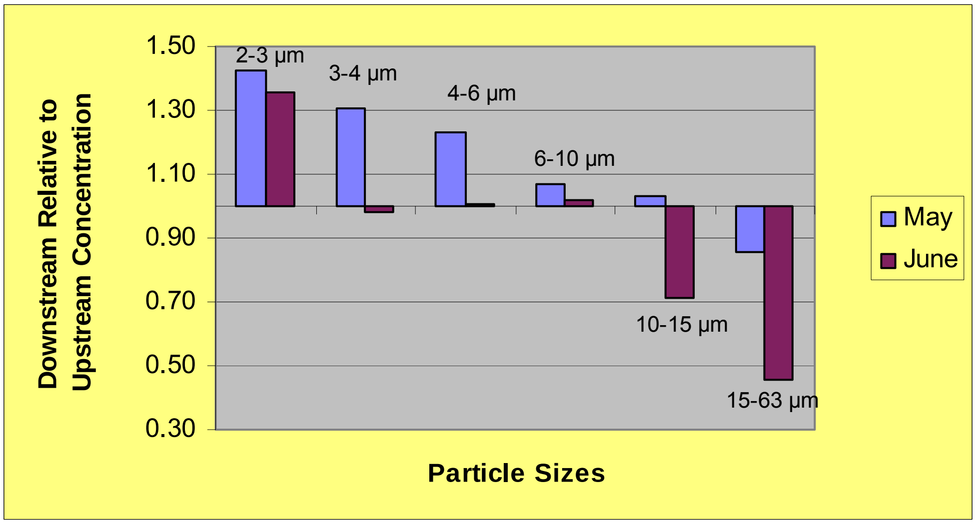

Figure 12. *Concentration of seston particles in six different size ranges expressed is a relative proportion quantified from water sampled above and below a mussel bed on the North Fork John Day River, Oregon, during May and June, 2005.*

While we cannot unequivocally attribute this pattern to mussel feeding activity per se, the magnitude of these shifts in size distributions was much greater than any of the seasonal or inter-basin effect differences summarized above and it is certainly plausible that the suspension-feeders were responsible. The effects were not likely to have resulted from microenvironmental differences associated with the two sampling locations (e.g. back eddies) since seston was consistently collected from similar flow and substrate environments. In any case, the data in Figure 12 clearly demonstrate that particle size distributions can vary over reach scales within a relatively small stretch of the same river, perhaps as a result of grazing by benthic suspension-feeders such as mussels, where they are abundant. Further study and analysis of additional archived samples may be warranted to learn more.

1.2 Seston Weight Concentration

The weight concentration of particulate material (PM) comprising seston was determined from water sampled from nine river locations at various times during 2005 (n=139), and a subset of locations were targeted for repeated sampling in 2006 (n=16) to discern where inter-annual variation might be significant. An effort was made to sample throughout the year with the following representative months: February (n=20), March (n=21), May (n=23), June (n=28), August (n=24 in 2005 and 16 in 2006), and October (n=23). No significant differences (t-test, $p>0.05$) were detected for the PM concentration between August 2005 and August 2006, and so those data were combined for further analyses. Mean concentrations of PM are summarized in Table 6 by sampling month and location for the 6 principal river sites.

Overall, concentrations of particulate material were <5 mg L^{-1}, which is low to moderate, reflecting typical low to normal flow conditions during summer in North American freshwater streams and rivers. There were significant spatial and temporal differences in PM, however, despite overall low seston concentrations. Spatial differences were generally not statistically supported between different sites within the same river; rather, spatial differences were most apparent among the different river basins. Therefore, spatial data from different sites were pooled by river and analyzed further with one- and two-way ANOVA's. Figures 13-15 summarize monthly mean concentrations of particulate material for each of the three rivers studied.

Table 6. Average concentrations and pooled standard errors (sample sizes are in parentheses) of seston particulate material from different sampling sites in Oregon rivers during different months in 2005 and 2006. For each month, significant differences among sites are denoted as different letters as determined with a LSD multiple range analysis (α=0.05). Statistical tests among sites are in unshaded rows, and lumped data comparisons among rivers are in grey shaded rows.

River	Site	Concentration of Particulate Material (mg/L; ±SE)					
		Feb	*March*	*May*	*June*	*Aug*	*Oct*
John Day Middle Fork	Boulder Creek 10	1.98 ±0.44 (3) b	7.44 ±0.44 (3) a	no data	1.42 ±0.38 (4) b	2.31 ±0.38 (4) b	1.45 ±0.38 (4) b
	Fishing Hole 11	no data	6.19 ±0.36 (4) **a**	4.69 ±0.25 (8) **b**	1.10 ±0.36 (4) **c**	1.64 ±0.36 (4) **c**	0.79 ±0.36 (4) **c**
	Pooled	1.96 ±0.29 (6) *c*	6.72 ±0.27 (7) *a*	4.68 ±0.25 (8) *b*	1.26 ±0.25 (8) *cd*	1.92 ±0.21 (12) *c*	1.12 ±0.25 (8) *d*
John Day North Fork	Forest Service Rd 3963 20	1.28 ±0.21 (4) bc	3.78 ±0.21 (4) a	4.17 ±0.21 (4) a	1.69 ±0.21 (4) b	no data	0.99 ±0.21 (4) c
	Mussel Bed 21	0.89 ±1.26 (2) **b**	6.27 ±0.89 (4) **a**	4.68 ±0.89 (4) **a**	1.86 ±0.89 (4) **b**	1.19 ±0.89 (4) **b**	4.63 ±0.89 (4) **a**
	Pooled	1.41 ±0.50 (9) *b*	5.02 ±0.53 (8) *a*	4.42 ±0.53 (8) *a*	1.77 ±0.53 (8) *b*	1.50 ±0.53 (8) *b*	2.81 ±0.53 (8) *b*
Umatilla	Cayuse Bridge 30	1.88 ±0.25 (4) b	1.60 ±0.25 (4) b	2.14 ±0.25 (4) b	0.37 ±0.25 (4) c	2.09 ±0.25 (4) b	2.88 ±0.25 (4) a
	Emaceus 31	0.83 ±0.22 (4) **cd**	1.18 ±0.32 (2) **cd**	3.78 ±0.26 (3) **a**	0.74 ±0.22 (4) **d**	1.49 ±0.22 (4) **c**	2.43 ±0.26 (3) **b**
	Pooled	1.36 ±0.33 (8) *c*	1.46 ±0.39 (6) *c*	2.84 ±0.36 (7) *a*	1.31 ±0.27 (12) *c*	1.79 ±0.33 (8) *bc*	2.69 ±0.36 (7) *ab*

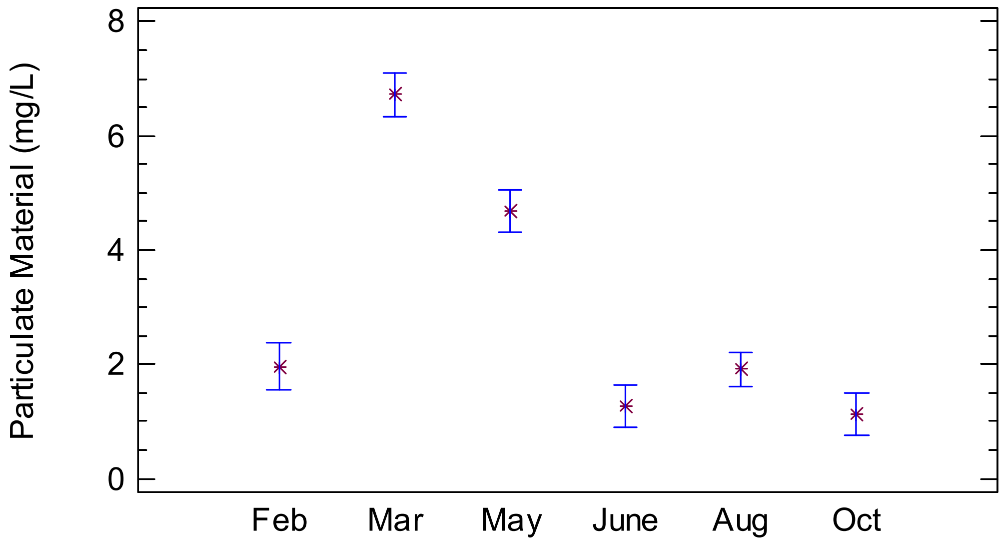

***Figure 13**. Mean (±SE) concentration of seston particulate material in water sampled from two locations on the Middle Fork John Day River, Oregon, during 2005-2006.*

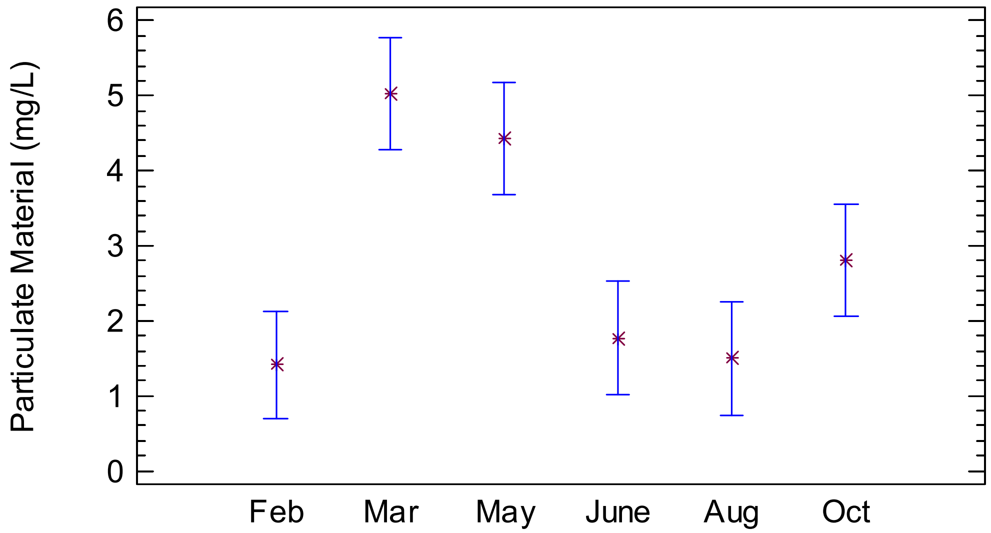

***Figure 14**. Mean (±SE) concentration of seston particulate material in water sampled from two locations on the North Fork John Day River, Oregon, during 2005-2006.*

The monthly patterns were similar in the Middle (Fig. 13) and North (Fig. 14) Forks of the John Day River, being characterized by a peak in seston material in March, with second greatest concentrations in May, followed by mean concentrations of approximately 1-2 mg L^{-1} for the rest of the sampling times. These spring concentrations were slightly higher in the Middle Fork (Fig. 13) compared to the North Fork (Fig. 14), and for both systems the March and May seston concentrations were significantly greater than the rest of the sampling times.

By contrast, mean seston concentrations were lower in the Umatilla River, <3 mg L^{-1} on average in every month (Fig. 15). In addition, the monthly pattern was quite different to that in the John Day drainages. Although there was a slightly higher concentration in May, the March level was low. Mean concentrations trended up later in the year, which was not observed in the John Day system.

Pooled data analysis with a two-way ANOVA indicated that the Middle Fork John Day River had the greatest overall concentration of seston particulate material (mean ±SE = 3.1 ±0.3 mg L^{-1}, n=57), which was not significantly different from that in the North Fork John Day River (mean ±SE = 3.0 ±0.3 mg L^{-1}, n=46). By contrast, the grand mean concentration for the Umatilla River (mean ±SE = 2.5 ±0.3 mg L^{-1}, n=52) was significantly lower (p=0.04) than either John Day drainage.

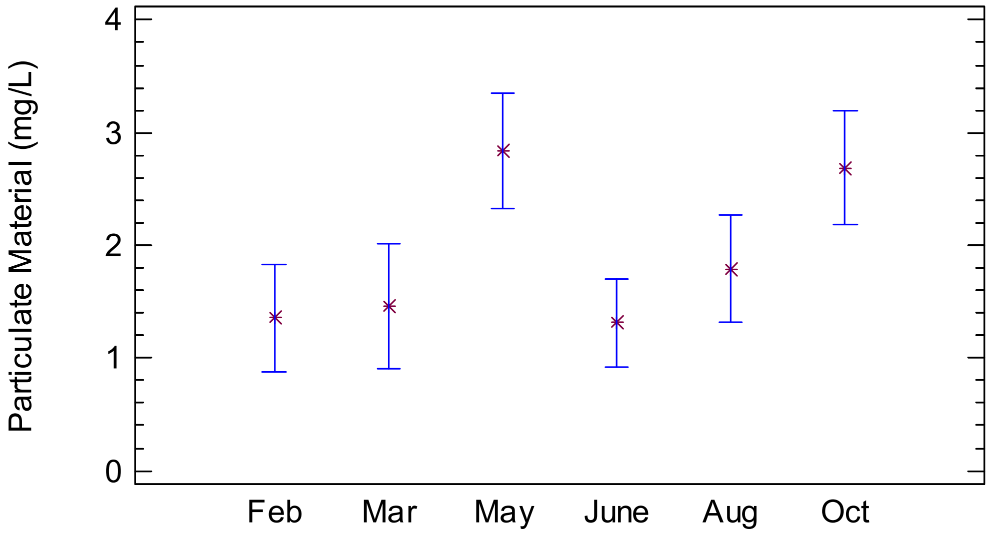

***Figure 15**. Mean (±SE) concentration of seston particulate material in water sampled from two locations on the Umatilla River, Oregon, during 2005-2006.*

1.3 Relationship Between Particle and Weight Concentration

Similar patterns were therefore found between the numerical concentration of particles in the 2-63 µm size range during the summer months (Section 1 above) and the weight concentration of particles captured on a glass fiber filter (effective retention 0.7 µm and water sieved to 53 µm; Section 2 above). Data for both parameters indicated that seston particles were significantly lower in the Umatilla River compared to the Middle Fork John Day and North Fork John Day rivers. Least squares linear regression indicated that the numerical concentration of particles correlated significantly ($p<0.0001$, $R2 = 43.1\%$) with the weight concentration of particulate material (Fig. 16).

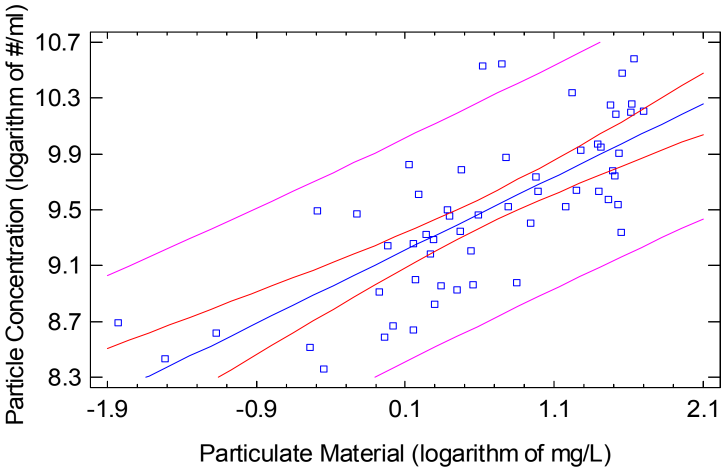

***Figure 16**. The relationship between numerical particle concentration (y-axis) and the weight concentration of particulate material (x-axis) for 56 paired samples of water collected during summer 2005 from three rivers in eastern Oregon.*

1.4 Seston Organic Content

The potential nutritional value of the seston was determined by quantifying its organic content. In general, concentrations of particulate organic material tracked concentrations of total particulate material, and so detailed data are not tabulated or summarized as fully as for the seston metrics reviewed above. For example, pooled data analysis with a two-way ANOVA indicated that the Middle Fork John Day River had the greatest overall concentration of seston particulate organic material (mean ±SE = 1.41 ±0.07 mg L^{-1}, n=43), which was not significantly different from that in the North Fork John Day River (mean ±SE = 1.31 ±0.08 mg L^{-1}, n=33). By contrast, the grand mean concentration for the Umatilla River (mean ±SE = 1.07 ±0.08 mg L^{-1}, n=35) was significantly lower (p=0.006) than either John Day drainage (Fig 17).

In addition to analyzing the weight concentration of particulate organic material, we also calculated the percentage organic content as the proportion of total seston comprised of organics. For statistical analysis, these percentages were transformed by the arcsine square root. A two-way ANOVA comparing seston organic contents by main effects of month and river indicated that no significant differences were found among rivers (p>0.05), but there was a strong temporal effect among months (p<0.0001), as shown in Fig. 18. Averaged across all sites, the organic content significantly increased between May and June, and then started to taper off as the summer and fall ensued.

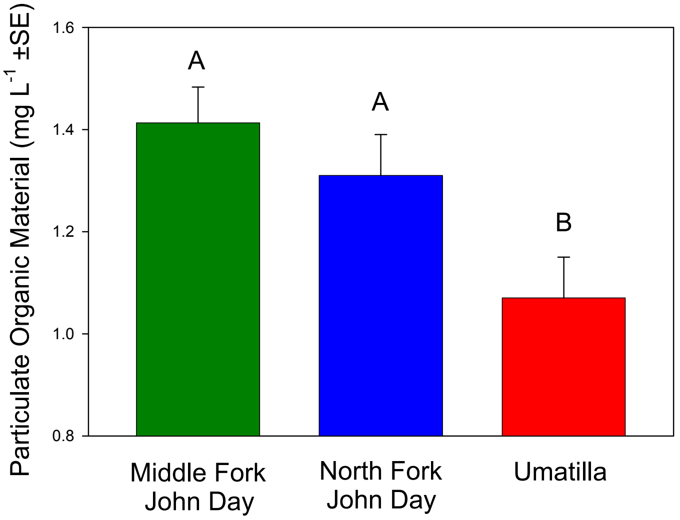

***Figure 17**. Mean (±SE) concentration of particulate organic material in water sampled from the Middle Fork John Day, North Fork John Day, and Umatilla Rivers, Oregon, during 2005-2006.*

Although no significant differences were detected among rivers, in one case we did detect a significant difference in the seston organic content within the same river averaged across all sample times. Seston sampled from the North Fork John Day River from above the mussel bed site was characterized by a mean (±SE) organic content (arcsine square root transformed) of 52.8 (±1.8), which was significantly greater than the organic content of seston sampled from below the mussel bed, 47.2 (±1.7). Although this difference wasn't that marked in absolute terms, this was notable because the statistic (p=0.031) resulted even after averaging across all months which were highly variable (ranging from 38-65 for the North Fork John Day). Taken together with the upstream-downstream differences in particle size distributions, it appears that mussels may have been sufficiently abundant to remove an appreciable portion of the larger sized seston fractions perhaps having higher organic content (e.g. large pennate diatoms).

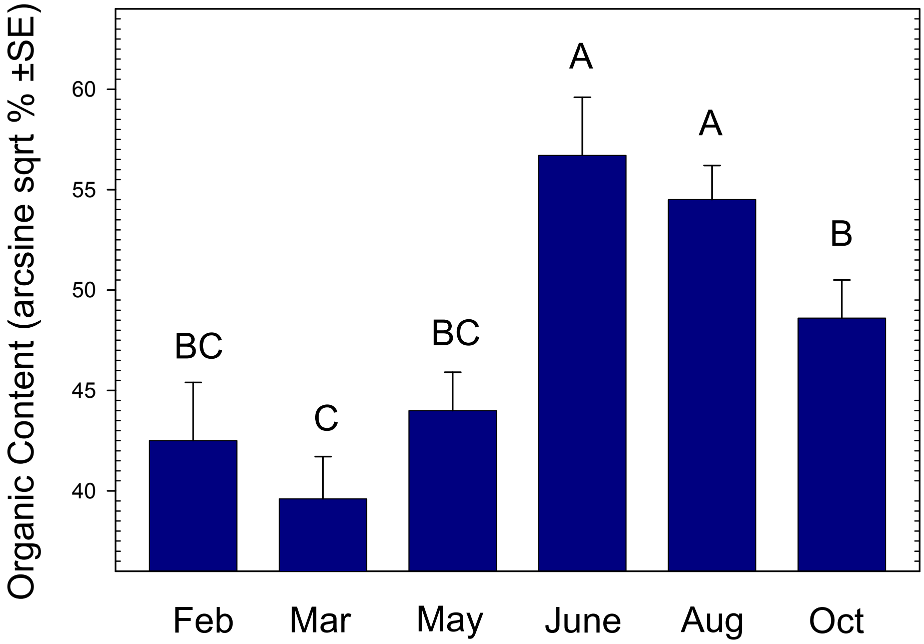

***Figure 18**. Mean (±SE) seston organic content expressed as an arcsine square root transformed percentage of total particulate material concentration of seston particulate material in water sampled from the Middle Fork John Day, North Fork John Day, and Umatilla Rivers, Oregon, during 2005-2006.*

2) Mussel Physiological Status

For each mussel species, an attempt was made to collect and run experiments on as wide a size range as possible. This permitted the most representative characterization of physiological functions across the species populations and total mussel assemblage. Therefore, particular attention was paid to body size metrics (Section 2.1), as well as the condition of mussels that were sampled (Section 2.2).

2.1 Mussel Body Size

Appendix A provides all body size data for the 217 freshwater mussels that were sacrificed for this study. Summary statistics for mussel shell heights and dry tissue weights are provided below for *Margaratifera falcata* (Table 7,) *Gonidea* sp. (Table 8,) and *Anodonta* sp. (Table 9.)

Margaratifera falcata. Comparing mussel sizes that were sacrificed, no significant differences (t-test, $p>0.05$) were detected in the mean shell height or dry tissue weight of *M. falcata* taken from the North Fork and Middle Fork of the John Day Rivers (Table 4) On the North Fork John Day River, mussels were only taken from one location, the Mussel Bed site (Table 1). Averaged across all four sample dates, the mean shell height for *M. falcata* from the North Fork was 68.4 mm and the mean dry tissue weight was 1.21 g (n=40).

The overall mean shell height for *M. falcata* from the Middle Fork John Day River was 62.1 mm and the mean dry tissue weight was 0.97 g (n=73). On the Middle Fork, *M. falcata* were collected from four sites, and of these, sampled *M. falcata* were different-sized from only one location. Mussels taken from the Fishing Hole site had a significantly smaller (ANOVA, p=0.002) mean shell height (55.7 mm, SE=2.3 mm, n=38) compared to the Big Boulder Creek (68.5 mm, SE=2.5 mm, n=32) and Wildcat Point (73.7 mm, SE=8.1 mm, n=3) sites. Similarly, the mean dry tissue weight of mussels sampled from Fishing Hole was 0.75 g (SE=0.49 g, n=38), which was significantly lower (ANOVA, p=0.001) than that for mussels from either Big Boulder Creek (1.20 g, SE=0.58 mm, n=32) and Wildcat Point (1.43 g, SE=0.32 mm, n=3).

There was no significant difference (ANOVA, p>0.05) in the shell heights or dry tissue weights of the different groups of *M. falcata* sampled in each river across all of the different sampling dates (Table 7.)

Relationships between shell height and dry tissue weight are usually highly correlated for bivalve molluscs. These relationships are important for constructing population biomass models based on nondestructive field measurements of shell heights. Therefore, height:weight relationships were developed for each species by performing least squares linear regression comparing the shell height to dry tissue weight for all animals for which we have both those data. Separate regression equations were developed and compared among the different locations that each species were collected, and if they did not differ significantly (p>0.05 for river effect in a multiple regression model) the data were pooled among sites per species.

Table 7. Summary statistics for the shell height and dry tissue weight of *Margaratifera falcata* collected from the North Fork and Middle Fork of the John Day River during 2005-2006.

Collection	Shell Height (mm)					Dry Tissue Weight (g)				
	Mean	SD	n	min	max	Mean	SD	n	min	max
North Fork John Day										
3/22/05	**69.3**	11.4	9	53.3	89.0	**1.20**	0.42	9	0.63	1.93
6/22/05	**64.9**	13.6	18	37.0	83.8	**1.07**	0.64	18	0.23	2.86
10/9/05	**77.7**	12.7	6	61.3	93.9	**1.78**	0.76	6	0.93	3.00
3/20/06	**68.0**	12.3	7	46.0	80.2	**1.10**	0.50	7	0.32	1.67
Middle Fork John Day										
3/22/05	**56.8**	13.4	9	37.1	75.5	**0.74**	0.36	9	0.24	1.26
6/22/05	**64.0**	18.0	20	34.5	99.1	**1.06**	0.65	20	0.16	2.59
10/9/05	**61.7**	16.0	15	24.3	85.3	**1.00**	0.61	15	0.06	2.44
3/20/06	**67.7**	13.3	14	39.8	83.4	**1.14**	0.57	14	0.25	1.97
8/24/06	**57.8**	16.2	15	37.6	95.4	**0.82**	0.54	15	0.30	2.02

No significant differences were detected in the height:weight relationship for *M. falcata* between the Middle Fork and North Fork of the John Day River, and so those data were pooled for development of the following linear regression equation (LSD, n=113):

$$\text{LOG (DTW, g)} = [\ 2.486 \times (\text{ LOG SH, mm })\ ] - 10.407$$

where DTW = grams dry tissue weight, SH = millimeters shell height, and natural logarithms were used to derive a normal distribution. The R^2 for the equation was 88.8% and the correlation coefficient was 0.94. The log-log relationship for this height:weight relationship for *M. falcata* is shown in Fig. 19.

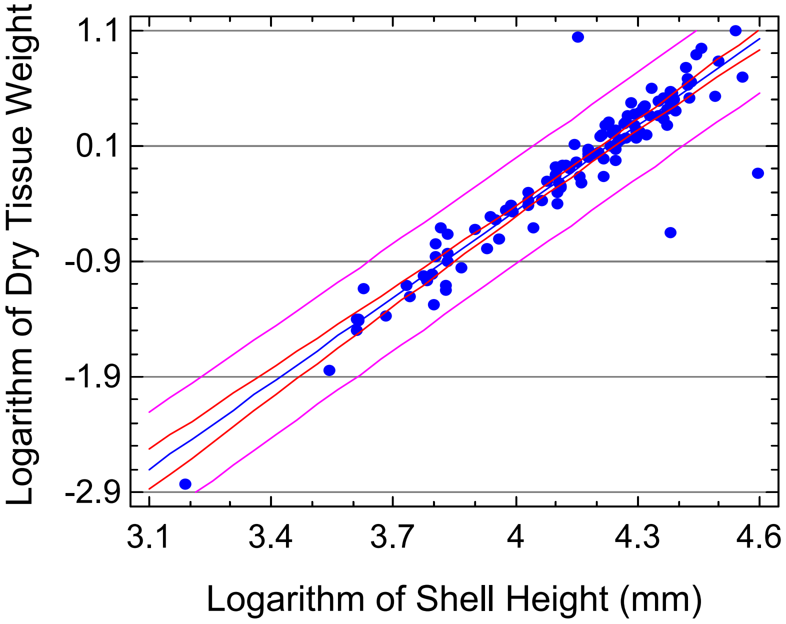

***Figure 19** . Relationship between the dry tissue weight and shell height of* Margaratifera falcata *sampled from the Middle Fork and North Fork of the John Day River during 2005-2006. Red lines depict the 95% confidence intervals for the least squares regression equation*

Gonidea sp. The overall mean shell height for *Gonidea* sp. from the Middle Fork was 64.1 mm (n=33), and this species was only collected from one site, Fishing Hole. The dry tissue weight averaged 1.13 g (SD=0.63, n=33). There was no significant difference (ANOVA, p>0.05) in the shell heights or dry tissue weights of the different groups of *Gonidea* sampled on the five different dates (Table 8.)

Table 8. Summary statistics for the shell height and dry tissue weight of *Gonidea* sp. collected from the Middle Fork of the John Day River during 2005-2006.

Collection	**Shell Height (mm)**					**Dry Tissue Weight (g)**				
	Mean	SD	n	min	max	Mean	SD	n	min	max
Middle Fork John Day										
3/22/05	**72.8**	-	1	-	-	**1.29**	-	1	-	-
6/22/05	**63.1**	9.74	11	47.6	79.3	**1.08**	0.47	11	0.50	2.19
10/9/05	**62.7**	14.0	7	44.7	78.6	**1.37**	0.85	7	0.44	2.66
3/20/06	**59.6**	13.1	7	44.1	77.9	**0.99**	0.68	7	0.33	2.26
8/24/06	**62.4**	12.0	7	43.6	82.4	**1.11**	0.68	7	0.36	2.47

The height:weight relationship for *Gonidea* sp. in the Middle Fork of the John Day River is shown in Fig. 20. The least squares linear regression equation (LSD, n=33) was:

$$\text{LOG (DTW, g)} = [\, 2.838 \times (\text{LOG SH, mm})\,] - 11.707$$

where DTW = grams dry tissue weight, SH = millimeters shell height, and natural logarithms were used to derive a normal distribution. The R^2 for the equation was 92.2% and the correlation coefficient was 0.96.

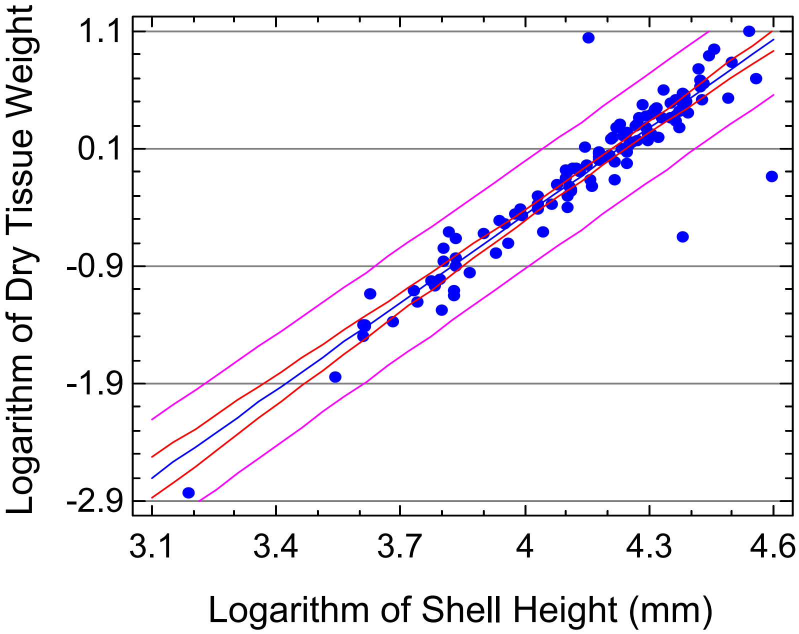

Figure 20. *Relationship between the dry tissue weight and shell height of* Gonidea *sp. sampled from the Middle Fork of the John Day River during 2005-2006. Red lines depict the 95% confidence intervals for the least squares regression equation.*

Anodonta sp. Comparing shell heights of *Anodonta* sp. that were sacrificed, and not discerning between any species or sub-species variants (see Methods section), mussels were significantly larger (t-test, p<0.0001) in the sampled population from the Umatilla River (mean=74.9 mm, SE=1.9 mm, n=17) than the Middle Fork John Day River (mean=44.2 mm, SE=1.1 mm, n=54). Dry tissues weights were also significantly greater (t-test, p<0.0001) in the Umatilla (1.26 g, SE=0.46 g, n=17) than the Middle Fork John Day (0.37 g, SE=0.16 g, n=54). Although the mussels from the Hermiston area of the Umatilla River appeared older, the overall large size of that sample population may simply have been because of the late effort and comparatively smaller sample size which did not yield any young animals.

The *Anodonta* collected from the Middle Fork had statistically similar (ANOVA, p>0.05) mean shell heights: Fishing Hole (43.7 mm, SE=1.2 mm, n=44), Wildcat Point (50.6 mm, SE=4.5 mm, n=3), and Ritter Hot Springs (44.5 mm, SE=3.0 mm, n=7). Dry tissue weights of sampled Anodonta were also comparable among these Middle Fork sites: Fishing Hole (0.37 g, SE=0.15 g, n=44), Wildcat Point (0.46 g, SE=0.12 g, n=3), and Ritter Hot Springs (0.35 g, SE=0.22 g, n=7). There was no significant difference (ANOVA, p>0.05) in the shell heights or dry tissue weights of the different groups of *Anodonta* sampled from the Middle Fork John Day on the five different dates (Table 9.), and similarly, the mean shell heights of Umatilla mussels were not significantly different (t-test, p>0.05) between the two dates they were sampled in 2006.

Table 9. Summary statistics for the shell height and dry tissue weight of *Anodonta* sp. collected from the Middle Fork of the John Day River during 2005-2006 and the Umatilla River during 2006.

Collection	**Shell Height (mm)**					**Dry Tissue Weight (g)**				
	Mean	SD	n	min	max	Mean	SD	n	min	max
Middle Fork John Day										
3/22/05	**44.2**	6.71	11	30.6	56.0	**0.41**	0.15	11	0.07	0.67
6/22/05	**44.7**	7.02	20	33.4	59.9	**0.35**	0.17	20	0.13	0.82
10/9/05	**42.1**	4.88	7	36.2	48.5	**0.36**	0.15	7	0.20	0.57
3/20/06	**43.1**	6.44	7	34.9	50.8	**0.34**	0.20	7	0.14	0.57
8/24/06	**45.1**	6.38	9	33.7	51.2	**0.42**	0.15	9	0.19	0.64
Umatilla										
3/20/06	**75.3**	16.4	4	56.1	92.1	**1.29**	0.64	4	0.70	2.05
8/24/06	**74.8**	10.4	13	51.9	86.7	**1.26**	0.43	13	0.54	1.92

A multiple regression test predicting dry tissue weight (log) from both shell height (log) and river (Middle Fork John Day versus Umatilla) for *Anodonta* sp. indicated that the relationship differed between rivers (LSD model, n=71, p=0.03). Therefore, separate linear regressions were generated for the height:weight relationship for *Anodonta* sp., one for each river (Figs. 21 and 22).

The height:weight relationship for *Anodonta* sp. in the Middle Fork of the John Day River is shown in Fig. 21. The least squares linear regression equation (LSD, n=54) was:

$$\text{LOG (DTW, g)} = [\,3.068 \times (\text{LOG SH, mm})\,] - 12.690$$

where DTW = grams dry tissue weight, SH = millimeters shell height, and natural logarithms were used to derive a normal distribution. The R^2 for the equation was 76.4% and the correlation coefficient was 0.87.

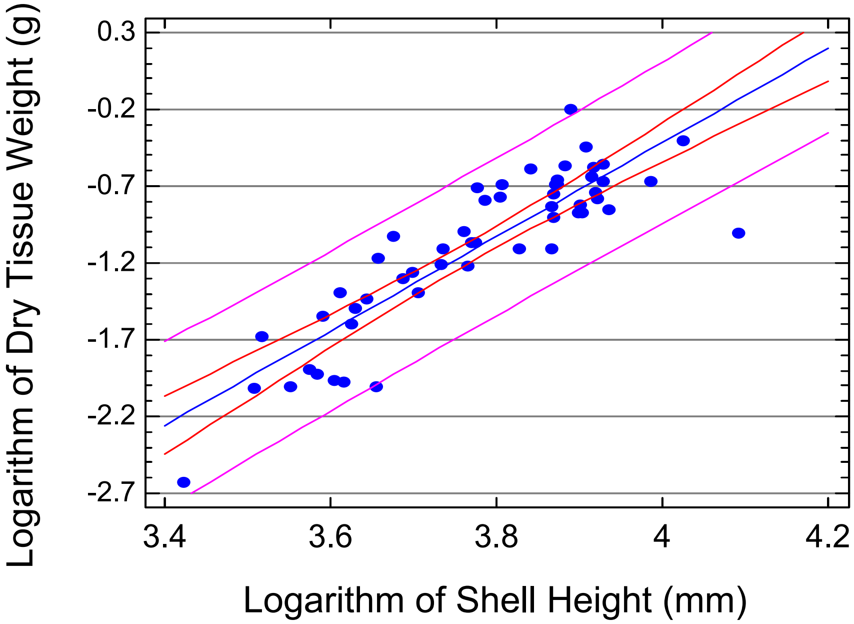

***Figure 21**. Relationship between the dry tissue weight and shell height of* Anodonta *sp. sampled from the Middle Fork of the John Day River during 2005-2006. Red lines depict the 95% confidence intervals for the least squares regression equation.*

All *Anodonta* sp. collected on the Umatilla were compared together since we did not have clear evidence for different species having been included there; however, further analysis may be helpful to contrast the body size metrics for the different individuals collected from the Umatilla River near Mermiston, OR. The height:weight relationship for *Anodonta* sp. in the Umatilla River is shown in Fig. 22. The least squares linear regression equation (LSD, n=17) was:

LOG (DTW, g) = [2.389 x (LOG SH, mm)] – 10.123

where DTW = grams dry tissue weight, SH = millimeters shell height, and natural logarithms were used to derive a normal distribution. The R^2 for the equation was 91.2% and the correlation coefficient was 0.95.

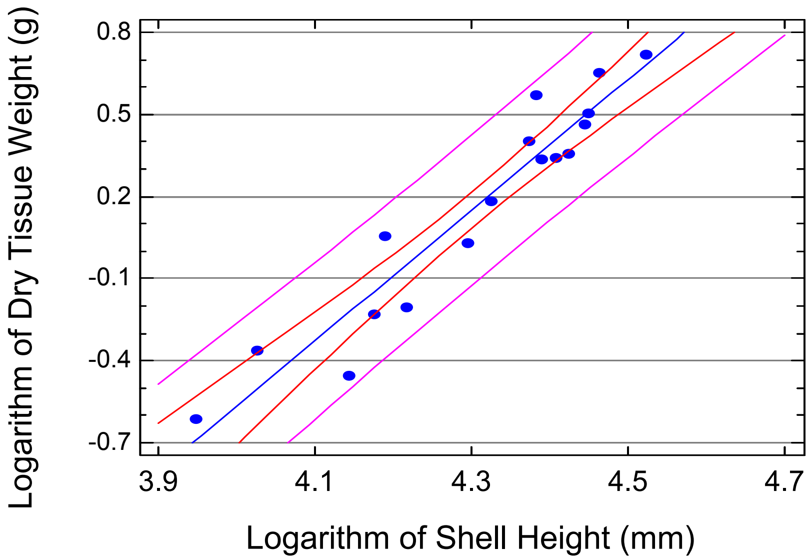

***Figure 22**. Relationship between the dry tissue weight and shell height of* Anodonta *sp. sampled from the Umatilla River during 2006. Red lines depict the 95% confidence intervals for the least squares regression equation*

2.2 ***Mussel Condition***

Appendix A provides data for the condition index for all 217 freshwater mussels that were sacrificed for this study. Appendix A also summarizes the tissue organic contents for most of these mussels (weight-on-ignition analysis for organic content was not completed for all animals).

In addition to these data, tissue organic contents were analyzed for additional mussels provided by Dr. Jeanette Howard from a CTUIR mussel transplant study. Body size metrics and condition indices were not able to be calculated for those animals because no shell data were collected. Organic contents for these additional mussels are reported in Appendix B. As noted in the methods, since shell heights and weights were not recorded for those animals, it was not meaningful to include those samples in the overall analysis for this physiological study. Those freeze-dried samples are archived for potential future analysis (e.g. stable isotope ratios, proximate biochemical composition.)

Summary statistics for mussel condition index and tissue organic content are provided below for *Margaratifera falcata* (Table 10), *Gonidea* sp. (Table 11), and *Anodonta* sp. (Table 12). Spatial variation (i.e., among reaches within a river or among rivers) was examined for each of these species and is discussed in these sections.

2.2.1 Physiological Condition of *Margaratifera falcata*

No significant differences (t-test, p>0.05) were detected between the mean condition index of *M. falcata* taken from the North Fork and Middle Fork of the John Day Rivers (Table 10.) On the North Fork John Day River, mussels were only taken from one location, the Mussel Bed site (Table 1), and condition of mussels from there did not differ significantly among sample months (ANOVA, p>0.05). On the Middle Fork, *M. falcata* were collected from four sites, however no significant differences (ANOVA, p>0.05) were detected among locations when averaged across the sample dates. Averaged across all sample dates, the mean condition index for *M. falcata* from the North Fork was 76.4 (n=73) and the mean condition index for *M. falcata* from the Middle Fork was 80.1 (n=40).

Table 10. Summary statistics for the condition index and percentage organic content of *Margaratifera falcata* collected from the North Fork and Middle Fork of the John Day River during 2005-2006. nd= no data.

Collection	**Condition Index**					**Organic Content (%)**				
	Mean	SD	n	min	max	Mean	SD	n	min	max
North Fork John Day										
3/22/05	**80.7**	13.6	9	55.6	99.9	**87.4**	1.3	6	85.7	89.1
6/22/05	**75.1**	9.4	18	53.6	92.8	**87.3**	0.8	18	86.2	88.2
10/9/05	**80.7**	6.6	6	73.3	88.3	**nd**	nd	0	nd	nd
3/20/06	**70.2**	4.3	7	64.2	75.4	**86.0**	1.2	7	84.2	87.6
Middle Fork John Day										
3/22/05	**83.2**	15.2	9	59.2	105.1	**87.2**	1.7	2	84.8	89.4
6/22/05	**78.8**	10.0	20	61.3	109.2	**90.0**	0.6	18	89.3	90.7
10/9/05	**82.0**	9.8	15	62.8	106.9	**nd**	Nd	0	nd	nd
3/20/06	**77.5**	9.3	14	61.3	96.3	**87.7**	0.7	14	86.8	88.5
8/24/06	**79.1**	12.9	15	48.1	96.9	**88.5**	0.7	14	87.6	89.3

Condition index also did not vary significantly (ANOVA, p>0.05) among sample months when averaged across all sites. The mean condition in March, June and October, 2005, and March and August, 2006, was 81.9, 76.9, 80.9, 74.5, and 77.2, respectively. Data were also pooled seasonally to test whether temporal effects on condition could be discerned, and again, condition index for *M. falcata* did not differ significantly (ANOVA, p>0.05) among early spring (78.3), summer (77.6) or fall (81.7) (Fig. 23).

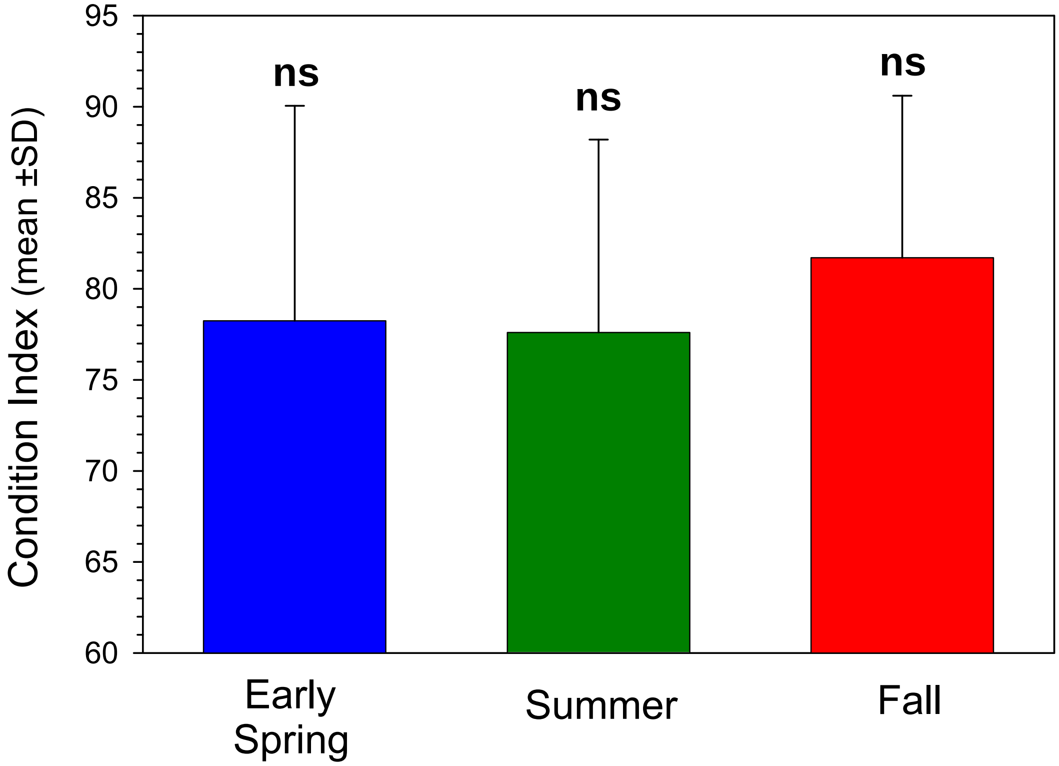

***Figure 23**. Seasonal variation in condition index of* Margaratifera falcata *sampled from the North Fork and Middle Fork John Day River during 2005-2006. ns = not significantly different.*

A 2-way ANOVA comparing condition index of *M. falcata* between the North Fork and Middle Fork and among sample dates was not significant (p>0.05) for either main effect. These results suggest that the condition index of *M. falcata* does not vary much seasonally or spatially within the John Day drainage basin, ranging from 48.1 to 109.2 among 113 mussels sampled from different up to four locations between March and October.

The percentage organic content in the tissues of *M. falcata* was relatively constant among sample dates and between the Middle Fork and North Fork John Day River, varying only between 84.2% and 90.7% for all 79 mussels for which these data were determined. No data were available for October, 2005, and so these findings are limited to sampling from late winter to summer conditions. The mean organic content of mussels collected from the North Fork was not significantly different (ANOVA, p>0.05) among sample dates of March 2005 (87.4%), June 2005 (87.3%) and March 2006 (86.0%). There was a statistically significant difference in the organic content of mussels taken from the Middle Fork where *M. falcata* collected in June 2005 had a tissue organic content of 90.0%, slightly greater than that in March, 2006 (87.7%), and other dates were intermediate. However, the range in organic content was so narrow that these differences were not meaningful physiologically. When analyzed seasonally or comparing rivers, the tissue organic content of *M. falcata* did not vary significantly (ANOVA, p>0.05).

Relationships between condition index and body size can occur in bivalve molluscs, and so it is important to discern whether any seasonal or spatial variation in condition index may be partially attributed to body size effects. Although condition of *M. falcata* was not found to vary with location or sample date, relationships between condition index and body size were nevertheless tested by least squares linear regression.

Since no significant differences were detected in the condition index of *M. falcata* between the Middle Fork and North Fork of the John Day River, those data were pooled for development of the following linear regression equation (LSD, n=113):

$$CI = [-0.272 \times SH] + 96.1$$

where CI = condition index (unit-less) and SH = millimeters shell height. The R^2 for the equation was 14.7% and the correlation coefficient was -0.37. The effect of body size on condition in *M. falcata* is shown in Fig. 24.

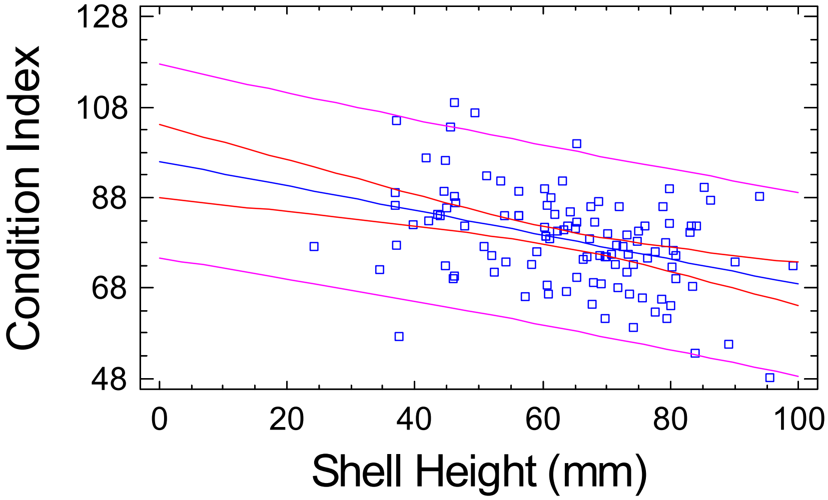

***Figure 24**. Relationship between the condition index and shell height of* Margaratifera falcata *sampled from the Middle Fork and North Fork of the John Day River during 2005-2006. Red lines depict the 95% confidence intervals for the least squares regression equation.*

2.2.2 Physiological Condition of *Gonidea* sp.

The condition index of *Gonidea* sp. taken from the Middle Fork of the John Day River varied significantly (ANOVA, p=0.0001) among sample dates (Table 11.) Condition index ranged from 51.7 to 103.6 (n=33).

Table 11. Summary statistics for the condition index and percentage organic content of *Gonidea* sp. collected from the Middle Fork of the John Day River during 2005-2006

Collection	**Condition Index**					**Organic Content (%)**				
	Mean	SD	n	min	max	Mean	SD	n	min	max
Middle Fork John Day										
3/22/05	**86.1**	-	1	-	-	**nd**	nd	0	nd	nd
6/22/05	**68.7**	6.5	11	60.8	82.2	**90.1**	2.0	11	87.1	92.0
10/9/05	**89.7**	9.5	7	82.0	103.6	**nd**	nd	0	nd	nd
3/20/06	**81.5**	5.5	7	69.9	86.6	**89.0**	3.9	7	82.2	91.8
8/24/06	**73.8**	13.6	7	51.7	86.3	**84.9**	12.7	6	58.9	93.3

The highest condition index was recorded during March, 2006 (89.7, n=7), which was similar to the single value recorded from March, 2005 (86.1). The lowest condition index was recorded in June 2005 (68.7, n=11), which was not significantly different (multiple range analysis, p>0.05) from the second lowest was in August, 2006 (73.8, n=7). These data are shown in Fig. 25, which shows that mussels collected in fall, 2005 had a significantly higher condition than mussels collected in June, 2005.

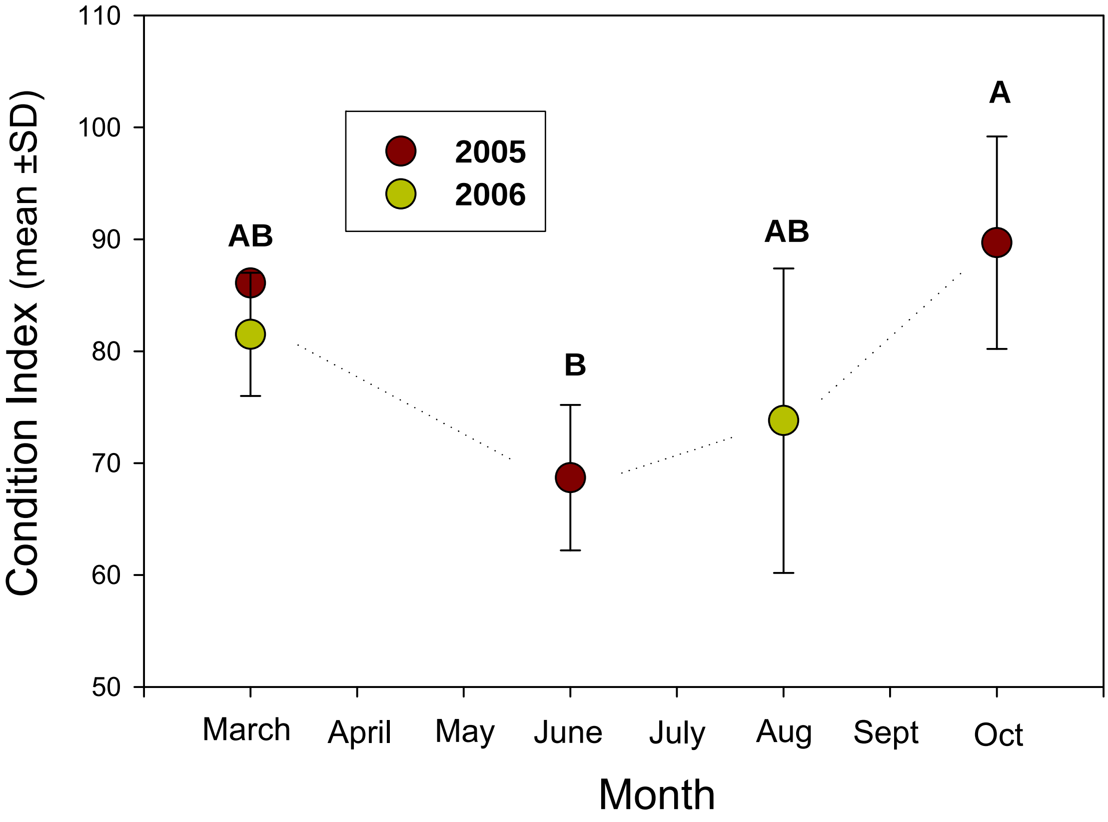

Figure 25. *Monthly variation in condition index of* Gonidea *sp. sampled from the Middle Fork John Day River during 2005-2006. Different letters above symbols denote significant differences as determined by multiple range analyses (ANOVA, α=0.05)*

Since the overlapping early spring and summer data were statistically similar between 2005 and 2006, monthly data were recoded according to seasons for statistical analysis, i.e., as either early spring (March 2005, March 2006), summer (June 2005, August 2006), or fall (October 2005). The seasonal variability in the condition index of Gonidea sp., as tested by ANOVA and multiple range analysis, was characterized by significantly lower (p=0.0006) summer values (70.7, n=18) than either spring (82.1, n=8) or fall (89.7, n=7) (Fig. 26.)

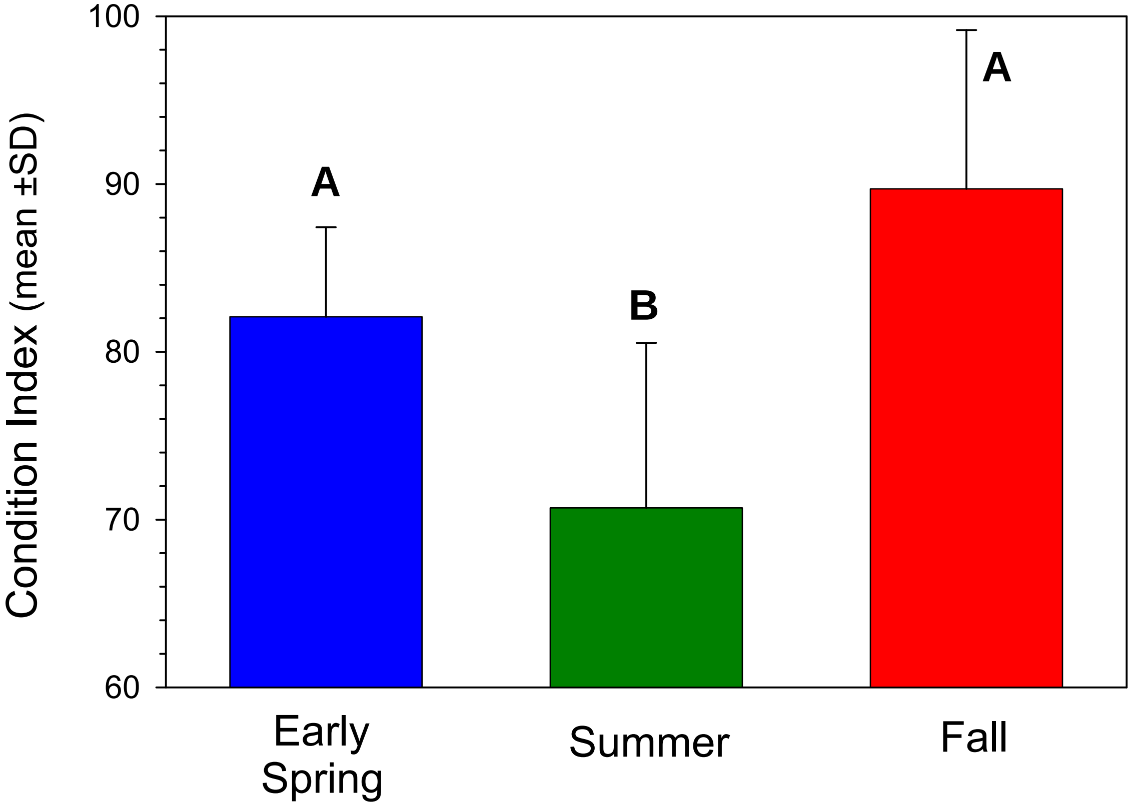

***Figure 26**. Seasonal variation in condition index of* Gonidea *sp. sampled from the Middle Fork John Day River during 2005-2006. Different letters above bars denote significant differences as determined by multiple range analyses (ANOVA, α=0.05)*

No significant relationships were detected between the condition index and shell length of *Gonidea,* which were examined by least squares linear regression (LSD, n=33).

Like *Margaratifera falcata*, the percentage organic content in the tissues of *Gonidea* sp. was relatively constant among sample dates, varying from a mean of 84.9% in June, 2005, to 89.0% in March, 2006, and 90.1% in March, 2005 (not significant, ANOVA, $p>0.05$, $n=24$). No data were available for October, 2005, and so these findings are limited to sampling from late winter to summer conditions. Unlike *M. falcata*, however, there was a greater range in organic content in *Gonidea* sp. among individuals, varying from a minimum of 58.9% in June, 2005, to a maximum of 93.3%, also in June, 2005. A seasonal comparison between early spring (March 2005, March 2006) and summer (June 2005) was not significant (t-test, $p>0.05$) for percentage organic content in *Gonidea* sp.

2.2.3 Physiological Condition of *Anodonta* sp.

The condition index of *Anodonta* sp. taken from the Middle Fork of the John Day River varied significantly (ANOVA, $p<0.0001$) among sample dates (Table 12.); however, the same was not true comparing *Anodonta* condition between the two dates mussels were sampled from the Umatilla. Condition index ranged from 51.7 to 103.6 ($n=33$).

Table 12. Summary statistics for the condition index and percentage organic content of *Anodonta* sp. collected from the Middle Fork of the John Day River during 2005-2006 and the Umatilla River during 2006.

Collection	Condition Index					Organic Content (%)				
	Mean	SD	n	min	max	Mean	SD	n	min	max
Middle Fork John Day										
3/22/05	**65.2**	7.2	11	57.8	75.9	**89.4**	1.3	4	87.7	90.4
6/22/05	**48.2**	6.2	20	36.8	67.3	**86.7**	3.3	20	78.5	91.7
10/9/05	**61.3**	6.3	7	52.5	69.6	**nd**	nd	0	nd	Nd
3/20/06	**56.5**	14.9	7	33.1	77.3	**90.4**	1.9	7	88.6	92.5
8/24/06	**58.6**	8.6	9	46.5	74.9	**90.1**	1.9	9	88.0	93.0
Umatilla										
3/20/06	**56.8**	15.6	4	39.4	77.1	**69.9**	6.8	4	63.0	81.0
8/24/06	**55.4**	13.5	13	40.8	94.7	**84.8**	8.7	9	59.2	91.7

A two-way ANOVA comparing condition index of mussels sampled in different months and from the two rivers suggested that there was no significant difference ($p>0.05$) for the river main effect, but there was a significant temporal effect ($p=0.0003$). This temporal pattern is shown in Fig. 27, suggesting lower early summer condition in *Anodonta* sp. The highest mean condition index was recorded during October, 2005 (61.3, n=7), and the lowest index was recorded in June 2005 (48.2, n=20). A multiple range analysis indicated that these values were significantly different (multiple range analysis, $p>0.05$).

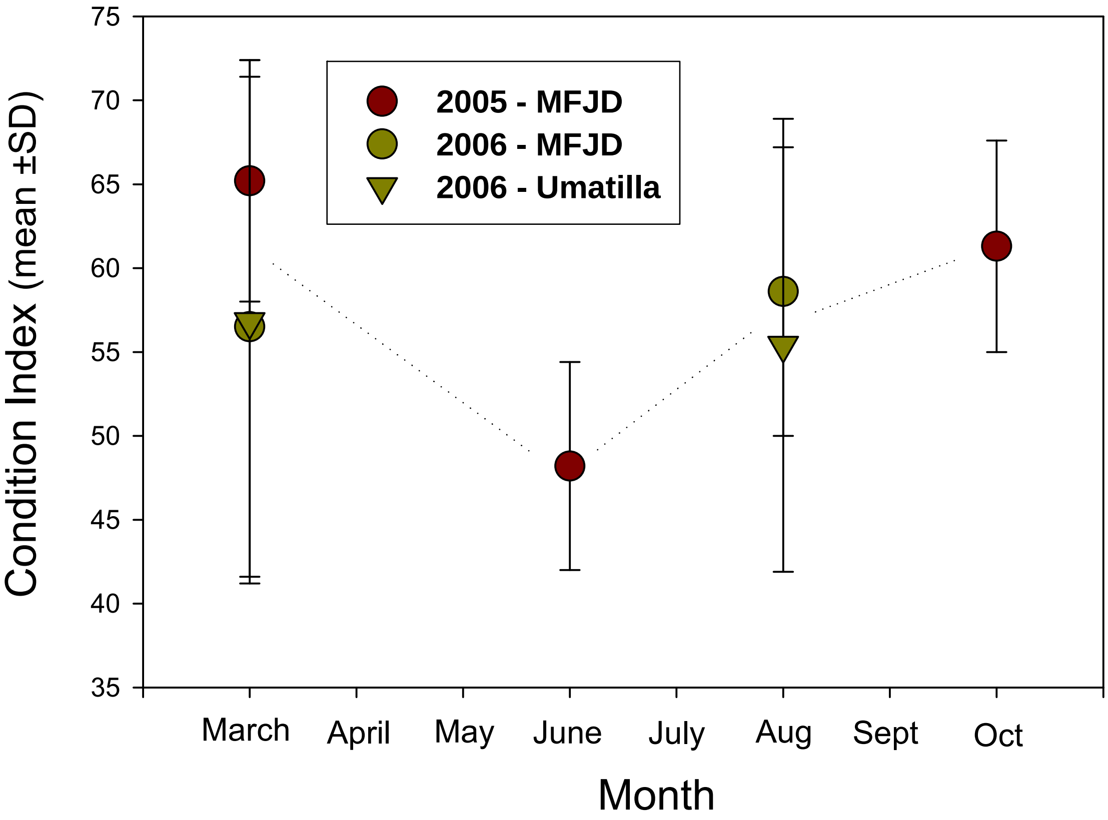

***Figure 27**. Monthly variation in condition index of* Anodonta *sp. sampled from the Middle Fork John Day and Umatilla Rivers during 2005-2006.*

As found for *Gonidea* sp., the overlapping early spring and summer condition indices for *Anodonta* sp. data were statistically similar between 2005 and 2006, and so monthly data were recoded according to seasons for statistical analysis, i.e., as either early spring (March 2005, March 2006), summer (June 2005, August 2006), or fall (October 2005). The seasonal variability in the condition index of *Anodonta* sp., as tested by ANOVA and multiple range analysis, was characterized by significantly lower (p=0.007) summer values (52.6, n=42) than either spring (60.9, n=22) or fall (61.3, n=7) (Fig. 28.)

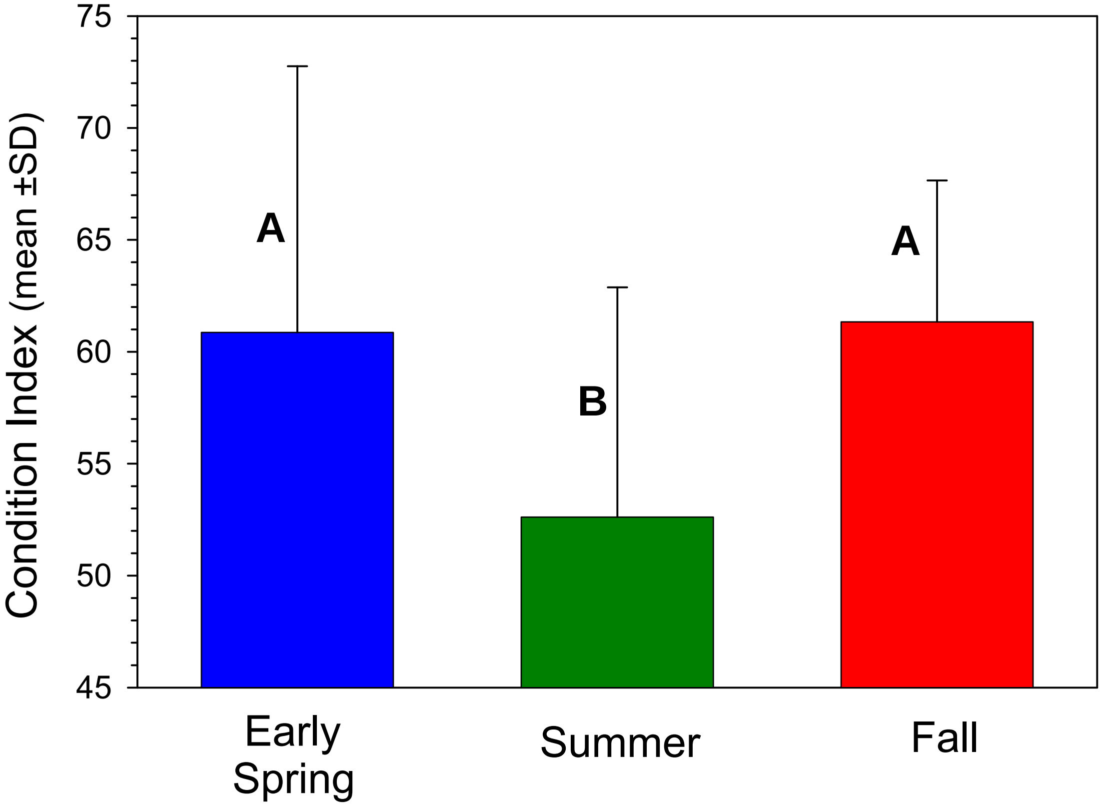

Figure 28. *Seasonal variation in condition index of* Anodonta *sp. sampled from the Middle Fork John Day and Umatilla Rivers during 2005-2006. Different letters above bars denote significant differences as determined by multiple range analyses (ANOVA, α=0.05)*

No significant relationships were detected between the condition index and shell length of *Anodonta* sp., which were examined by least squares linear regression (LSD, n=71).

The percentage organic content in the tissues of *Anodonta* sp. taken from the Middle Fork of the John Day was relatively constant among sample dates, varying only between 78.5% and 93.0% for all 40 mussels for which these data were determined. No data were available for October, 2005, and so these findings are limited to sampling from late winter to summer conditions. The mean organic content of mussels collected from the Umatilla River in 2006, however, did show a significant difference (t-test, p=0.024) between sample dates with mussels taken in March 2006 having lower organic content (69.9%) than those collected in August 2006 (84.8%). The individual range during August 2006 was also high, varying from 59.1% to 91.7% organic content. When data were pooled for the two rivers and analyzed among months or between seasons, this high variability obscured any temporal variation (ANOVA, p>0.05). The greatest effect was found between rivers, whereby the average percentage organic content in *Anodonta* tissues was significantly (t-test, p=0.0001) greater in the Middle Fork John Day, 88.4% (±0.9% SE; n=40) than in the Umatilla River, 80.6% (±1.6% SE; n=13). Further analysis of this difference is warranted, considering that there appeared to be two forms of *Anodonta* sp. present in the mussels collected from the Umatilla River.

2.2.4 Physiological Condition in Two Forms of *Anodonta* sp.

As noted earlier and shown in Fig. 2, based on morphology and color traits, two different *Anodonta* sp. appeared present at the Hermiston site on the Umatilla River, which was included in these analyses in March and August, 2006. The longer, "green-striped" form (perhaps *A. oregonensis*) was discernable from the rounder and flatter dark form (believed to be *A. californianus*). Although replication was limited, a t-test was used to compare the condition index between these forms, with data combined for March and August 2006 since condition was not found to vary seasonally in the Umatilla River. The type presumed to be *A. oregonensis* was significantly (t-test, p=0.021) longer in shell height (mean=77.8 mm, SE=2.6 mm, n=14) and significantly (t-test, p=0.019) heavier in dry tissue weight (mean=1.38 g, SE=0.11 g, n=14) than the form presumed to be *A. californianus (*shell height mean=61.6 mm, SE=5.1 mm, n=3; dry tissue weight mean=0.72 g, SE=0.23 g, n=3).

Despite the size differences between the two forms of *Anodonta* sp. taken from the Umatilla River in 2006, no significant differences (t-test, p>0.05) were detected in the condition index of what was presumed to be *A. oregonensis* (mean=54.0, SE=3.6, n=14) and *A. californianus* (mean=63.6, SE=7.7, n=3). However, significant differences were found between these forms with regard to their tissue organic contents (Fig. 26), and the difference interacted with season. In March 2006, mussels presumed to be *A. oregonensis* collected from the Umatilla River had a significantly (t-test, p=0.0002) lower organic content (mean=65.9%, SE=4.6%, n=3) compared with *A. californianus* that were taken from both rivers at the same time (mean=89.3%, SE=1.1%, n=8). This was also significantly (t-test, p=0.021) lower than the organic content of *A. oregonensis* collected from the Umatilla River in August, 2006 (mean=84.4%, SE=3.0%, n=8). In contrast, *A. californianus* taken from both rivers did not differ significantly (t-test, p>0.05) in organic content between sample times. Contrasting the organic contents for all *Anodonta* sp. taken just in August, 2006, there was no significant difference between types (T-test, p>0.05) (Fig. 29). Averaged across rivers and sample

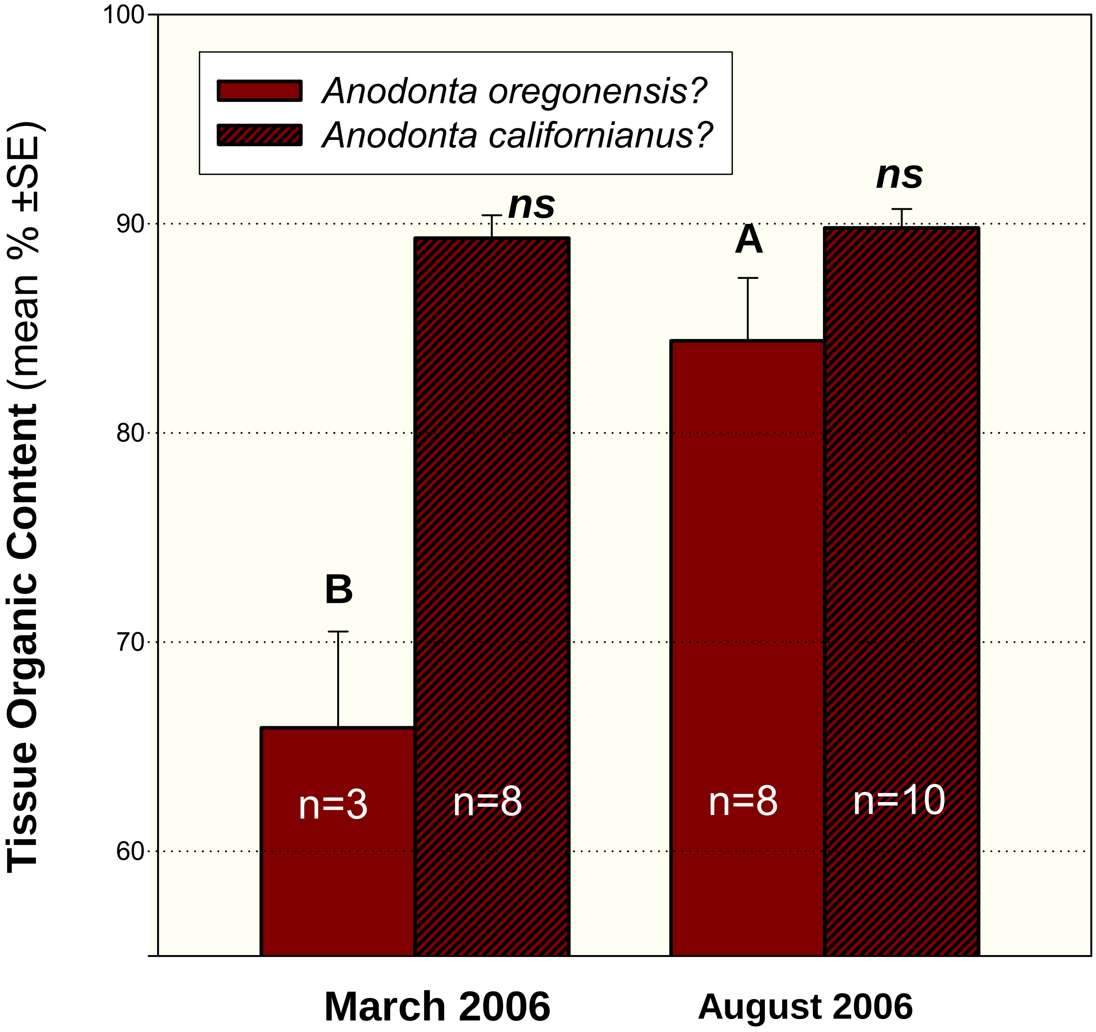

Figure 29. *Percentage organic content in the tissues of two different forms of* Anodonta *sp. sampled from the Middle Fork John Day and Umatilla Rivers during 2006. Different letters above bars denote significant differences between months as determined by multiple range analyses (ANOVA, α=0.05).*

months, the mean organic content of mussels presumed to be *A. oregonensis* was significantly lower (78.5%, SE=2.0%, n=11) than that for *A. californianus* (89.3%, SE=1.5%, n=18).

2.3 Seasonal Variation

A three-way ANOVA comparing condition index among main effects of species, river and season indicated a significant species effect ($p<0.0001$) and a significant season effect (p=0001). As noted above for each species, condition varied significantly among seasons for only two of the three species (*Anodonta* and *Gonidea*), with lower summer condition compared to spring and fall. Although there was no significant seasonal difference in condition of *Margaratifera falcata*, the lowest mean condition was recorded during summer for that species as well.

Taken together, these data indicate that condition index varies significantly in freshwater mussels of the Pacific Northwest, as evidenced by the three genera studied herein. The greatest variability appears to be among species ($p<0.0001$). However, most species also exhibited strong seasonal variation ($p=0.0001$), presumably associated with seasonal changes in physiological and reproductive status. Even though environmental conditions (e.g. river temperature) and food conditions (i.e., seston quantity and quality) can vary widely among rivers (e.g., Umatilla versus Middle Fork John Day versus North Fork John Day), mussel condition did not appear to follow suit. In no case did condition index differ significantly ($p>0.05$) among rivers for the same species sampled in the same month. Hence, mussel condition in rivers of eastern Oregon appears to vary intrinsically, as either interspecific (genetic) differences or seasonal changes in physiological status, but not in response to river conditions per se, and there appears to be good consistency across the region.

Combined for all species, the seasonal effect on condition index is shown in Fig. 30. Condition index was significantly lower in summer for all species (67.9, n=113) than in spring (72.7, n=69) or fall (76.2, n=33).

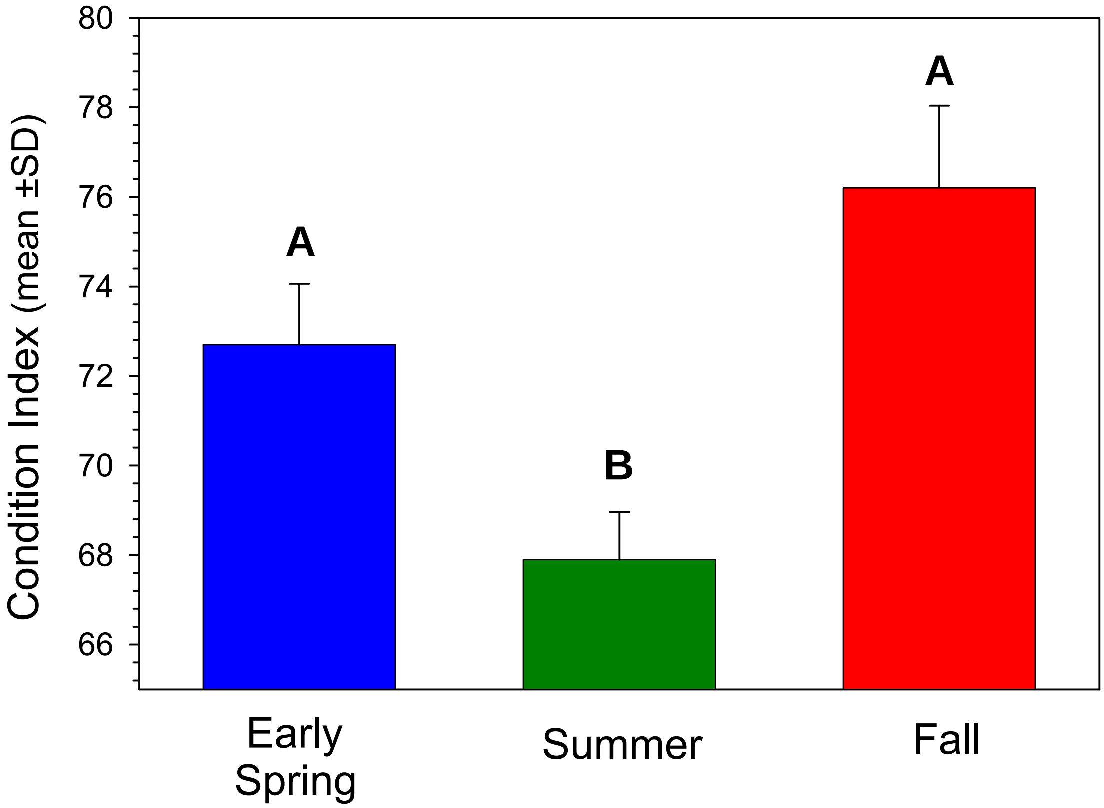

***Figure 30**. Seasonal variation in condition index for all 217 freshwater mussels sampled during 2005-2006 from rivers of eastern Oregon. Different letters above bars denote significant differences as determined by multiple range analyses (ANOVA, $\alpha=0.05$)*

Historically, condition index has been the most common measure used to gauge the physiological status of bivalve mollusks such as oysters (for examples, see Medcof 1946, Menzel and Hopkins 1952, Baird 1958, Haven 1962, Sakuda 1966, Lawrence and Scott 1982), and it continues to be a valuable tool today (e.g., see Austin et al. 1993, Rheault and Rice 1996, Schumacker et al. 1998). When analyzing physiological metrics such as condition index, it is important to clarify the method used and the context in relation to bivalve monitoring programs elsewhere. Condition is a unit-less index that compares the size of the body to either the shell weight or the internal volume of the shell. It can be calculated in various ways based on the morphology, volume and weight of the shell and internal meat. The use of different approaches to calculate condition index has led to problems in comparing values among studies and locations (Crosby and Gale 1990). Nevertheless, the statistical mean condition index reported here for freshwater mussels of the Pacific Northwest (72.3, n=217, range 33-109) is in general agreement with reports of average condition indices for marine species such as oysters which rarely exceed 100 and usually range between 50-80 (Medcof 1946, Menzel and Hopkins 1952, Haven 1962, Sakuda 1966, Barber et al. 1988, Crosby and Gale 1990).

The pattern shown in Fig. 30 is consistent with general seasonal shifts in condition typically seen in marine bivalves from temperate climates. It is well known that marine species such as oysters typically undergo seasonal changes in physiology as a result of alternating cycles of reproduction, growth and quiescence (Thompson et al. 1996). Although exceptions occur, one common pattern is demarcated by springtime or early summer spawning, followed by a period of quiescence and growth of somatic tissue during summer. By fall, many marine species begin to sequester carbohydrate stores in the form of glycogen, and these later serve both as an energy source to help overwinter as well as a fuel for gametogenesis. The fall “conditioning period” can extend into winter in southern latitudes. Following conditioning, gametogenesis can occur when the proliferation of gametes in reproductive tissues demands other nutritional materials such as protein and lipid. Gametogenesis typically gets underway in oysters and mussels by late winter and continues into the spring and early summer spawning season (Thompson et al. 1996, Kreeger et al. 1994).

Therefore, the condition index typically is greatest in the fall and early winter as animals “fatten” up with glycogen, although greatest glycogen concentrations may not occur until gametogenesis is well underway in March (Chipman 1948, Engle 1951). Little has been reported regarding seasonal and interspecific variation in the condition index of freshwater mussels. Presumably, freshwater mussels will optimize their nutrition and maximize production following strategies similar to other bivalves; however, there are marked differences in life history strategy between broadcast spawning marine species and larval brooding freshwater mussels. For example, it is unknown how condition index varies in females that are brooding versus adults that are not brooding, and the timing of brooding (short-term versus long-term brooders) may lead to differences in the annual conditioning pattern of freshwater species compared to marine species. In this study, reproductive status was not assessed directly, and so the possible relationship between seasonal condition patterns and reproductive events is speculative.

2.4 Interspecific Variation

2.4.1 Body size Differences Among Species

As noted in the methods, an attempt was made to collect as wide a size range as possible to ensure physiological measurements were representative of the full size class structure of the population of mussels in the studied streams. Hence, the range of sizes collected per species is roughly indicative of the range of mussels that are common in the streams that were examined, and the height:weight relationships for different sized animals of different species should reflect that for the population at large.

Generally, *M. falcata* and *Gonidea* sp. were larger-sized compared with the bulk of *Anodonta* sp. that were collected from the Middle Fork of the John Day River (Fig. 31). This can be seen by comparing the relative abundance of small versus large animals surveyed in this study in Figure 31. A wide size range was successfully collected for *M. falcata* and *Gonidea* sp.,

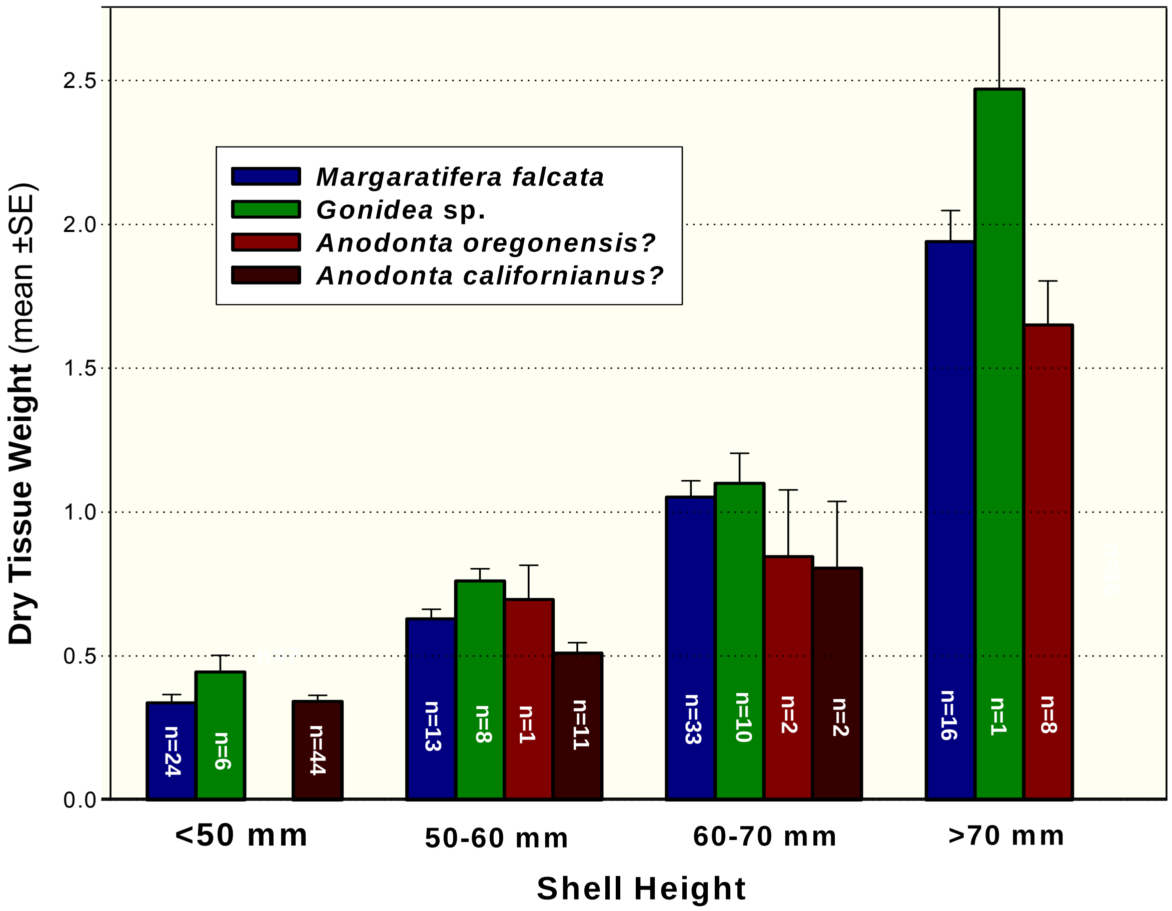

***Figure 31**. Mean dry tissue weight for different shell height size classes of* Margaratifera falcata, Gonidea *sp., and presumptive* A. oregonensis *and* A. californianus *sampled during 2005-2006 from rivers of eastern Oregon.*

characterized by at least 1 animal collected in each of the four main size classes, <50 mm, 50-60 mm, 60-70 mm, and >70 mm. However, no *Anodonta* sp. were found >70 mm in the Middle Fork John Day River, which were all presumed to be *A. californianus*. In contrast, most of the *Anodonta* sp. that were collected on the Umatilla River that were presumably *A. oregonensis* were >70 mm (Fig. 31).

Of particular note, the mean dry tissue weight was reasonably similar among species of freshwater mussels for each of the four size classes, group by shell height (Fig 31.) For example, 74 mussels were collected that were <50 mm shell height, representing 3 species, and their mean dry tissue weight varied between only 0.34-0.44 g (not significant among species, ANOVA, p>0.05). Thirty-three mussels were 50-60 mm, and the mean dry tissue weights varied among species between only 0.51-0.76 g, with *Gonidea* sp. being most "meaty" and *Anodonta californianus* "least meaty" (significantly so, ANOVA, p=0.0011). Forty-seven mussels were 60-70 mm, and the mean dry tissue weights varied among species between 0.80-1.10 g, with *Gonidea* sp. again being most "meaty" and *Anodonta californianus* "least meaty" (but not significantly different, ANOVA, p>0.05). Mussels larger than 70 mm varied between 1.7 and 2.5 g dry tissue weight on average for three species (not significantly different, ANOVA, p>0.05.)

2.4.2 Condition Index Differences Among Species

Interestingly, although the seasonal pattern was reasonably consistent among the three species of freshwater mussels studied here, there was marked differences among species. The condition index of *Anodonta* sp. (58.1, n=71) was significantly lower (ANOVA, p<0.0001) than that for either *Margaratifera falcata* (79.7, n=113) or *Gonidea* sp. (78.9, n=33), which were similar (Fig. 32.)

This difference in condition among species was not due simply to the different body sizes of these species. As mentioned above for *Margaratifera falcata*, condition index can decrease with increasingly body size for some species. However, average sizes of *Anodonta* sp. were smaller (0.78 g dry tissue weight [DTW]) than either *Margaratifera falcata* (1.36 g DTW) or *Gonidea* sp. (1.52 g DTW), and the opposite would be expected if the lower condition indices of *Anodonta* were size-related. To differentiate body size effects on condition index from seasonal or interspecific effects, a series of two-way ANOVA tests (main effects = season, species) were repeated for difference size classes of mussels. For all mussels having shell lengths of <50 mm, the mean condition index for *Anodonta* sp. was 58.5 (SE ±1.7, n=44), which was significantly lower (p<0.05) than that for either *Margaratifera falcata* (mean= 87.4; SE ±2.3, n=24) or *Gonidea* sp. (mean-84.0; SE ±4.4, n=6). Similarly, for all mussels ranging between 55-70 mm, the mean condition index for *Anodonta* sp. was 61.9 (SE ±4.4, n=7), which was significantly lower (p<0.05) than that for either *Margaratifera falcata* (mean= 79.7; SE ±1.9, n=39) or *Gonidea* sp. (mean=75.0; SE ±3.0, n=16).

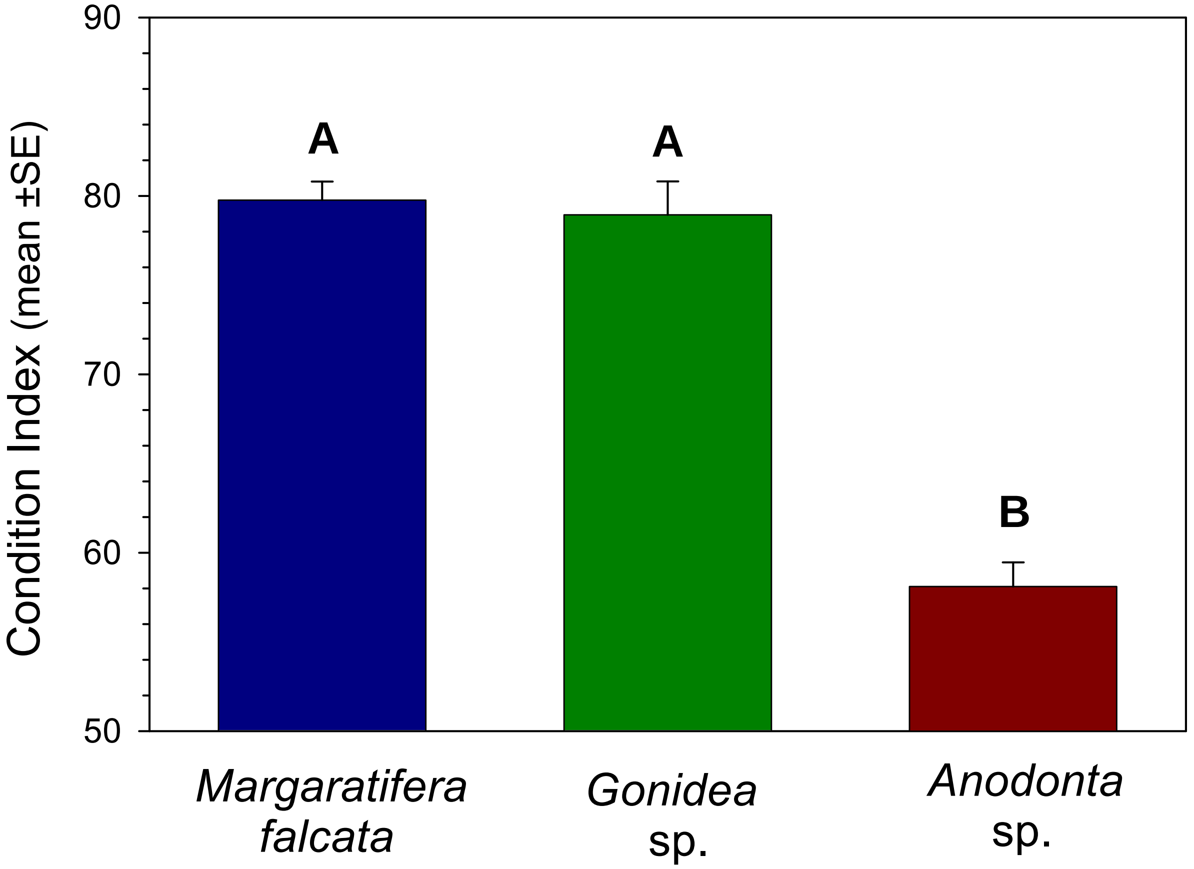

***Figure 32**. Mean condition index for* Margaratifera falcata, Gonidea *sp. and* Anodonta *sp. sampled at various times and from various places in eastern Oregon during 2005-2006. Different letters above bars denote significant differences as determined by multiple range analyses (ANOVA, α=0.05)*

2.4.3 Organic Content Differences Among Species

The percentage organic content was remarkably constant among seasons, rivers, and species, with one exception. This exception was the larger-sized species variant of *Anodonta* sp. that was collected from the Umatilla River near Hermiston, Oregon. These animals, which were assumed to be *A. oregonensis*, had a significantly (ANOVA, $p<0.0001$) lower mean organic content during the early spring (mean=65.9%) than the other form, presumed to be *A. californianus* (89.4%), as well as *M. falcata* (87.2%) or *Gonidea* sp. (89.0%) (Fig. 33). During summer, all species had statistically similar mean organic contents, ranging only from 84.4% to 88.6%.

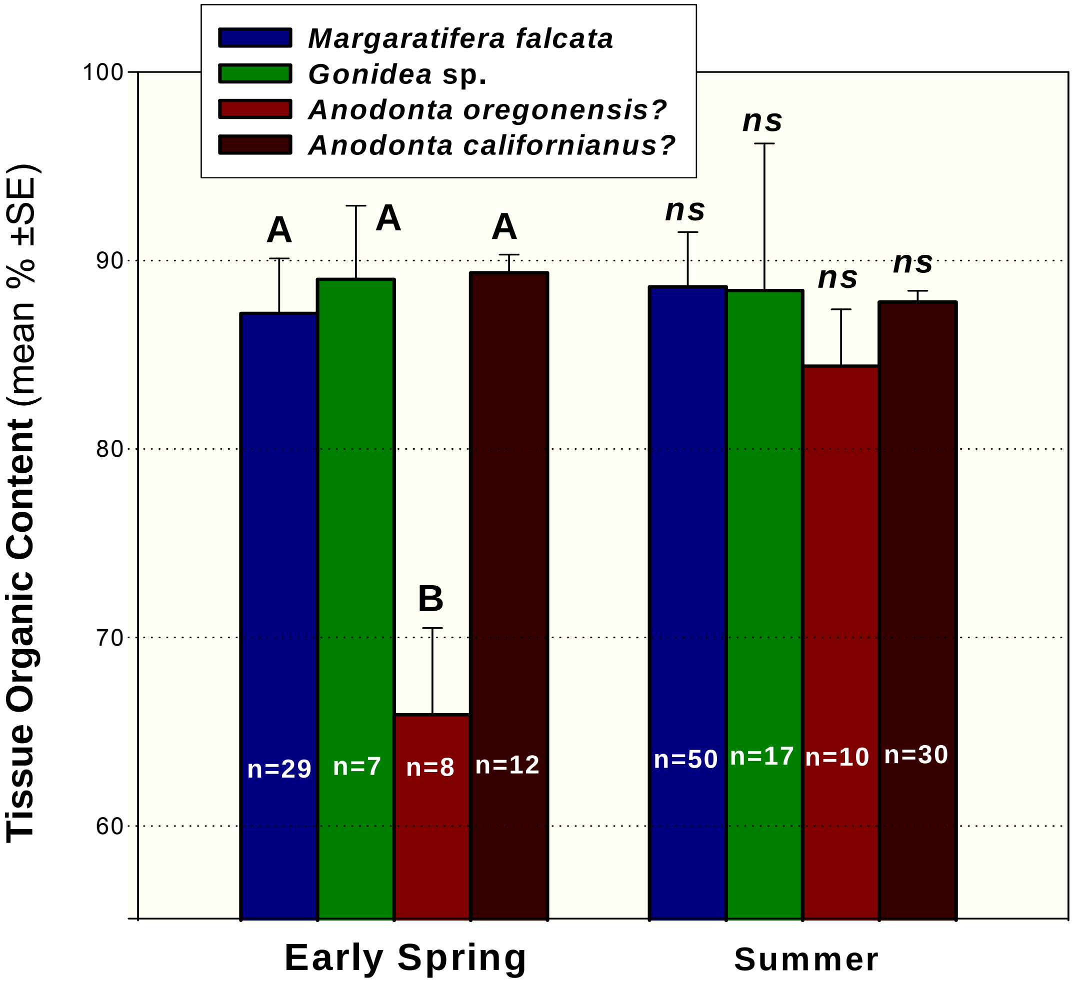

Figure 33. *Percentage organic content in the tissues of* Margaratifera falcata*,* Gonidea *sp. and two morphologically distinct forms of* Anodonta *sp. (with presumptive species names in legend) sampled from rivers of eastern Oregon during early spring (March 2005 and March 2006) or summer (June 2005 and August 2006). Different letters above the bars denote significant differences per season as determined by a multiple range analysis. (ANOVA, α=0.05).*

3) Mussel Feeding

As noted above, physiology experiments were performed in March 2005 (UMP1, UMP2), June 2005 (UMP3, UMP4), October, 2005 (UMP5), March, 2006 (UMP6), and August, 2006 (UMP7.) No significant differences (t-tests, p>0.05) were detected in any species- or site-specific physiological or dietary parameter between UMP experiments conducted during the same month (i.e., UMP1 versus UMP2) and so data were lumped per sample month for all species-site pairings.

3.1 Seasonal and Spatial Variation in Experimental Diet Composition

For all UMP experiments, mussels were fed natural seston collected from the same river reach and at the same time as the mussels, ensuring that the animals saw no significant change in diet quality or quantity between the field and lab. Table 13 summarizes the composition of seston used in the UMP experiments.

Mussel feeding experiments were conducted under base flow conditions, except in March 2005 when snow melt and light precipitation appeared to raise river levels slightly (but not enough to affect visibility for mussel collection.) Under these conditions, typical mean concentrations of particulate material ranged only from 0.8 to 7.4 mg L^{-1} (Table 13) across the three studied rivers, different reaches within these rivers, and also among different seasons.

For all rivers, the mean concentration of particulate matter (PM) was greatest in the early spring (March). For example, in the Middle Fork John Day River at Big Boulder Creek, the PM concentration averaged 7.4 mg L^{-1} in March, 2005, and 4.1 mg L^{-1} in March, 2006, which were both significantly greater than in summer and fall when seasonal means ranged from 1.4 to 2.7 mg L^{-1}. Lower down in the Middle Fork John Day at the Fishing Hole site, the same pattern was evident, although concentrations appeared slightly lower but not significantly different than at Big Boulder Creek. The same pattern was found in seston on the North Fork John Day, although concentrations in March 2006 were not elevated there.

Seston data were not collected from the Umatilla River in 2005 (no mussel experiments), and so there was not adequate information to describe season patterns. However, it was notable that the seston concentrations in the Umatilla River during March and August, 2006, were significantly greater (ANOVA, $p<0.05$) than the PM concentration in either the North or Middle Forks of the John Day, which were sampled concurrently (Fig. 34).

The quality of the seston used in mussel feeding experiments was examined by determining its percentage organic content. The organic content was generally high, ranging from 35 to 89%, across all mussel feeding experiments (Table 13.) Typically, seston organic content does not exceed about 50%, however, under low flow conditions it is possible that detrital and algal organic matter comprised a large portion of microparticulate material. Highest organic contents were found in the Middle and North Forks of the John Day system, except in March 2005. Interestingly, organic contents were significantly lower (ANOVA, $p<0.05$) in the Umatilla River during the dates that seston was sampled there (Fig. 35).

Table 13. Seston concentration and quality fed to mussels in Unionid Mussel Physiology Experiments during 2005-2006. The same water and seston type was fed to mussels from the river locations where they were collected. For each river, seston differences detected via multiple range analysis are denoted with different letters.

Seston Collection	**Particulate Matter (mg L^{-1})**			**Organic Content (%)**		
	Mean	SD	n	Mean	SD	n
Middle Fork John Day Boulder Creek						
UMP 1/2 (3/22/05)	**7.44** ^{a}	0.74	3	**35.3** ^{b}	3.5	3
UMP 3/4 (6/22/05)	**1.43** ^{d}	0.42	4	**47.7** ^{ab}	6.8	1
UMP 5 (10/9/05)	**1.45** $_{d}$	0.18	4	**61.8** ^{a}	3.7	4
UMP 6 (3/20/06)	**4.10** ^{b}	0.51	4	**64.0** ^{a}	3.7	4
UMP 7 (8/24/06)	**2.65** ^{c}	0.56	4	**65.6** ^{a}	3.8	4
Middle Fork John Day Fishing Hole						
UMP 1/2 (3/22/05)	**6.19** ^{a}	0.64	4	**39.1** ^{b}	3.3	4
UMP 3/4 (6/22/05)	**1.10** ^{c}	0.42	4	**78.1** ^{a}	4.1	3
UMP 5 (10/9/05)	**0.79** ^{c}	0.18	4	**81.2** ^{a}	4.1	4
UMP 6 (3/20/06)	**3.60** ^{b}	0.51	4	**67.5** ^{a}	4.6	3
UMP 7 (8/24/06)	**1.90** ^{c}	0.56	4	**nm**	nm	-
North Fork John Day Mussel Bed						
UMP 1/ 2 (3/22/05)	**6.27** ^{b}	0.64	4	**34.7** $^{n.s.}$	4.3	4
UMP 3/4 (6/22/05)	**1.93** ^{b}	0.49	3	**64.4** $^{n.s.}$	7.6	2
UMP 5 (10/9/05)	**1.64** ^{b}	0.25	3	**46.0** $^{n.s.}$	4.8	4
UMP 6 (3/20/06)	**1.96** ^{b}	0.51	4	**89.3** $^{n.s.}$	11.3	1
UMP 7 (8/24/06)	**1.24** ^{b}	0.56	4	**58.2** $^{n.s.}$	10.5	1
Umatilla at Hermiston						
UMP 1/2 (3/22/05)	**n.m.**	-	-	**n.m.**	-	-
UMP 3/4 (6/22/05)	**n.m.**	-	-	**n.m.**	-	-
UMP 5 (10/9/05)	**n.m.**	-	-	**n.m.**	-	-
UMP 6 (3/20/06)	**4.93** $^{n.s.}$	0.51	4	**35.7** $^{n.s.}$	0.7	4
UMP 7 (8/24/06)	**3.73** $^{n.s.}$	0.56	4	**43.4** $^{n.s.}$	1.4	1

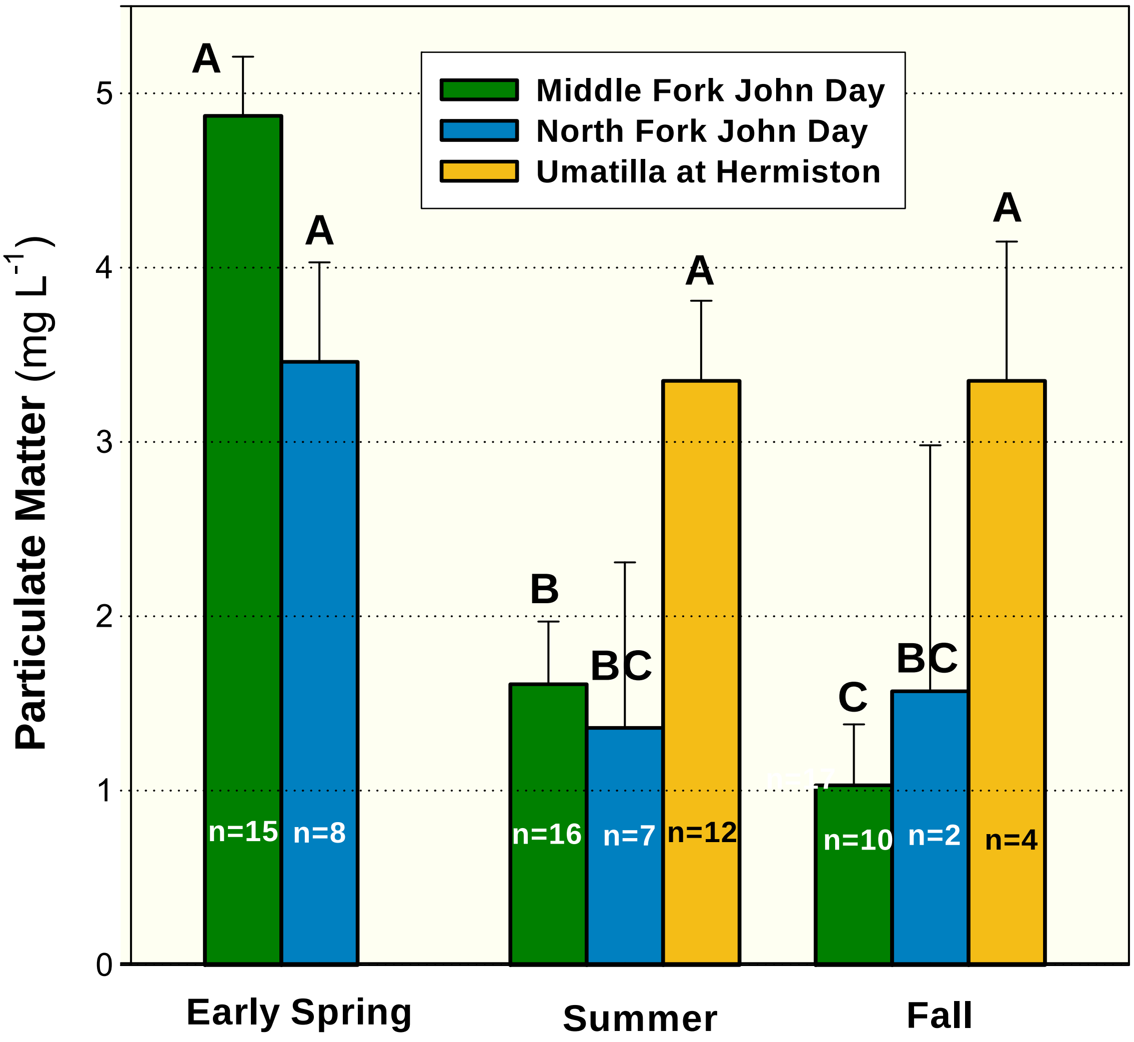

***Figure 34**. Mean (± SD) concentration of particulate matter comprising the seston collected from three Oregon rivers during different seasons for use in mussel physiology experiments. Different letters above bars denote significant differences as indicated by a multiple range analysis of a 1-way ANOVA ($p<0.05$).*

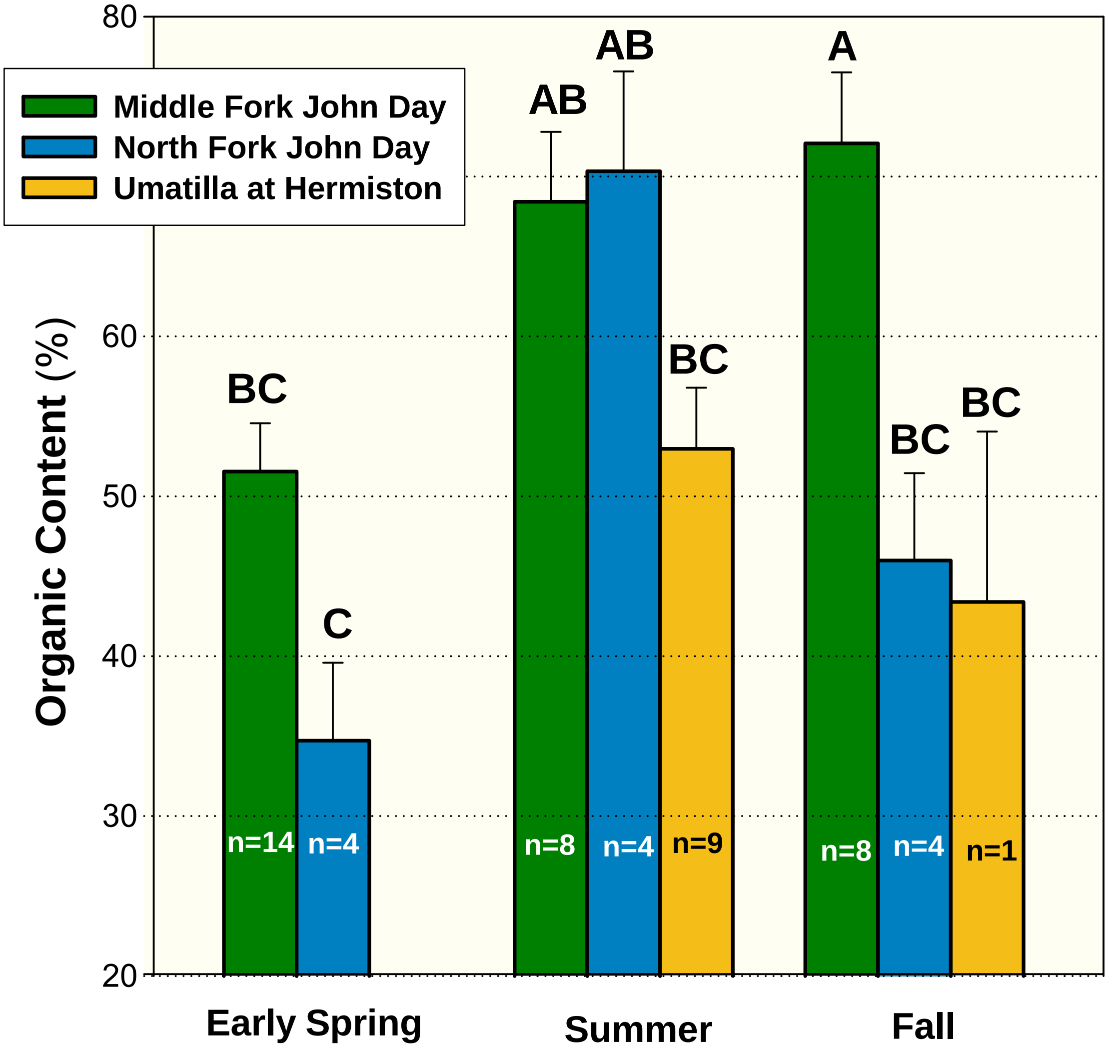

***Figure 35**. Mean (± SD) percentage organic content of seston collected from three Oregon rivers during different seasons for use in mussel physiology experiments. Different letters above bars denote significant differences as indicated by a multiple range analysis of a 1-way ANOVA ($p<0.05$).*

3.2 Clearance Rates

Clearance rates were measured for 157 freshwater mussels in seven Unionid Mussel Physiology (UMP) experiments during 2005-2006, consisting of 85 *Margaratifera falcata*, 25 *Gonidea* sp., and 47 *Anodonta* sp. taken from different river sites and at different times of the year. Appendix C lists both raw clearance rate (L h^{-1}) and weight-specific clearance rates (L h^{-1} g dry tissue $weight^{-1}$) for all of these mussels.

For calculation of weight-specific clearance rates, raw clearance rates were simply divided by the dry tissue weight rather than corrected using allometric scaling relationships because no significant weight exponent was detected; i.e., the slope of the log-log regression of clearance rate versus dry tissue weight was not significantly different from zero in least squares regression ($p>0.05$). This was probably due to having large variation among a small group of mussels for each treatment within each UMP experiment. All statistical analyses and data summaries were calculated using the weight-specific clearance rates to enable direct comparison among species within this project and to other studies.

3.2.1 Intraspecific Variation in Clearance Rates of *Margaratifera falcata*

Mean weight-specific clearance rates for *Margaratifera falcata* collected from various sites and times of year varied from a minimum of 0.18 L h^{-1} g^{-1} (March, 2006 from the Big Boulder Creek site) to a maximum of 1.38 L h^{-1} g^{-1} (October, 2005, from the Fishing Hole site). Considering the range of sample months and associated temperatures among the different experiments, this rather limited range in mean clearance rates suggests that *M. falcata* is active and filtering throughout the period from March-October.

The variation in mean clearance rates was mainly attributed to seasonal differences rather than site-specific differences since clearance rates varied on slightly among sites when contrasted with a one-way ANOVA's ($\alpha=0.05$) for each month (Table 14.) For example, no significant differences were detected among sites in March 2005, June 2005, and August 2006. In both October 2005 and March 2006, *M. falcata* from the Fishing Hole site on the Middle Fork John Day had significantly greater ($p<0.05$) clearance rates than mussels collected upstream at the Big Boulder Creek site on the same river. Mussels taken from the North Fork John Day had intermediate clearance rates in March 2006 and low clearance rates in October 2005. Since the Fishing Hole site is typically warmer than the other two sites, especially at these times of the year, these small differences may have resulted from slower physiological activity by the mussels in the cooler, higher altitude sites.

Table 14. Summary statistics for the clearance rate (L h^{-1} g dry tissue weight^{-1}) of *Margaratifera falcata* collected from the North Fork and two sites on the Middle Fork of the John Day River during 2005-2006. For each date, significant differences ($p<0.05$) among mean clearance rates of mussels from different sites were examined by multiple range analysis and are denoted as different letters.

Date	**Big Boulder Creek Middle Fork John Day**			**Fishing Hole Middle Fork John Day**			**North Fork John Day**		
	Mean	SE	n	Mean	SE	n	Mean	SE	n
UMP 1/ 2 (3/22/05)	**nd**	nd	0	**0.53** ^{ns}	0.15	8	**0.32** ^{ns}	0.16	7
UMP 3/4 (6/22/05)	**0.77** ^{ns}	0.37	5	**1.30** ^{ns}	0.29	8	**0.74** ^{ns}	0.34	6
UMP 5 (10/9/05)	**0.35** ^{B}	0.12	8	**1.38** ^{A}	0.13	7	**0.22** ^{B}	0.06	5
UMP 6 (3/20/06)	**0.18** ^{B}	0.08	6	**0.50** ^{A}	0.08	6	**0.33** ^{AB}	0.10	4
UMP 7 (8/24/06)	**0.44** ^{ns}	0.10	6	**0.65** ^{ns}	0.10	6	**nd**	nd	0

SE – standard error; n = sample size; ns = not significant; nd= no data.

A two-way ANOVA comparing main effects of both site and month suggested that clearance rates of *M. falcata* did differ significantly ($p=0.001$) among the Fishing Hole site and the other two sites, which were statistically similar ($p>0.05$). This test also indicated that the month effect was significant ($p=0.0014$), and a Tukey's multiple range analysis showed that clearance rates of *M. falcata* in June 2005, October 2005 and August 2006 were statistically similar, but greater than those measured in March 2005 and March 2006 (Fig. 36).

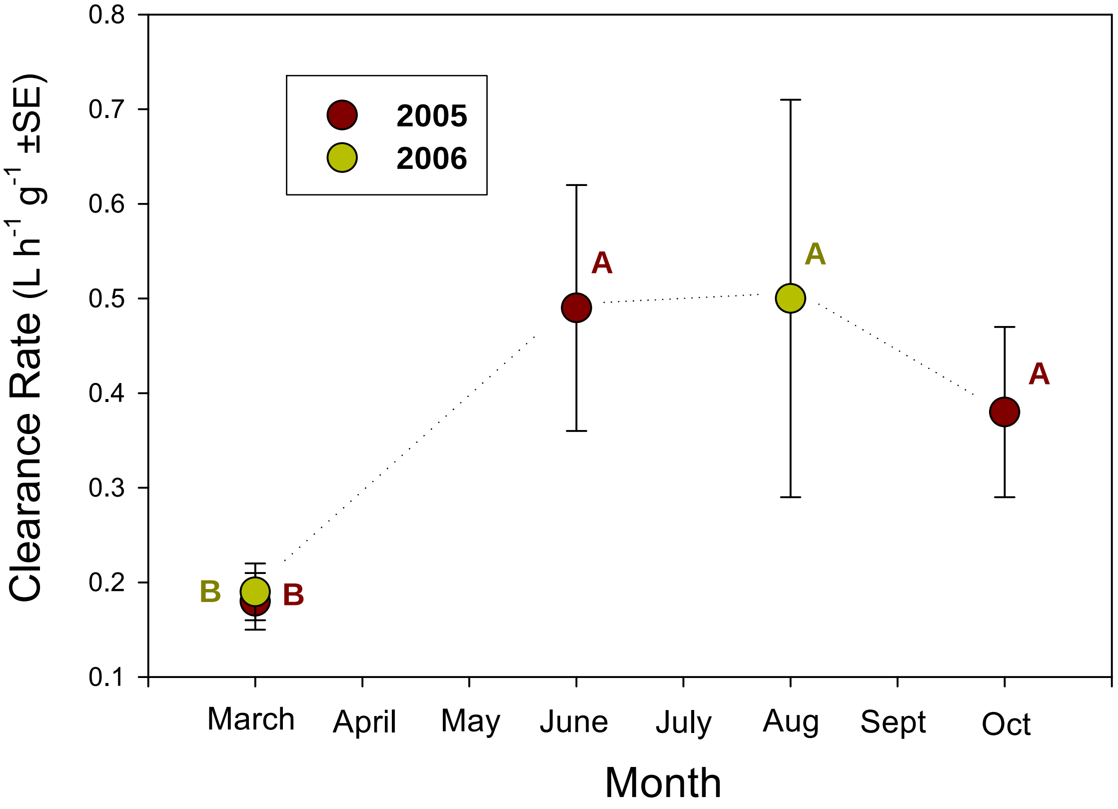

***Figure 36**. Monthly variation in clearance rate of* Margaratifera falcata *sampled from the Middle and North Forks of the John Day River during 2005-2006. Different letters above symbols denote significant differences as determined by multiple range analyses (ANOVA, α=0.05)*

When data for different sites and months are pooled and contrasted among seasons, clearance rates for *M. falcata* were significantly lower (ANOVA, $p<0.05$) in early spring (March 2005 and March 2006) compared with summer (June 2005 and August 2006) and fall (October 2005) (Fig. 37.)

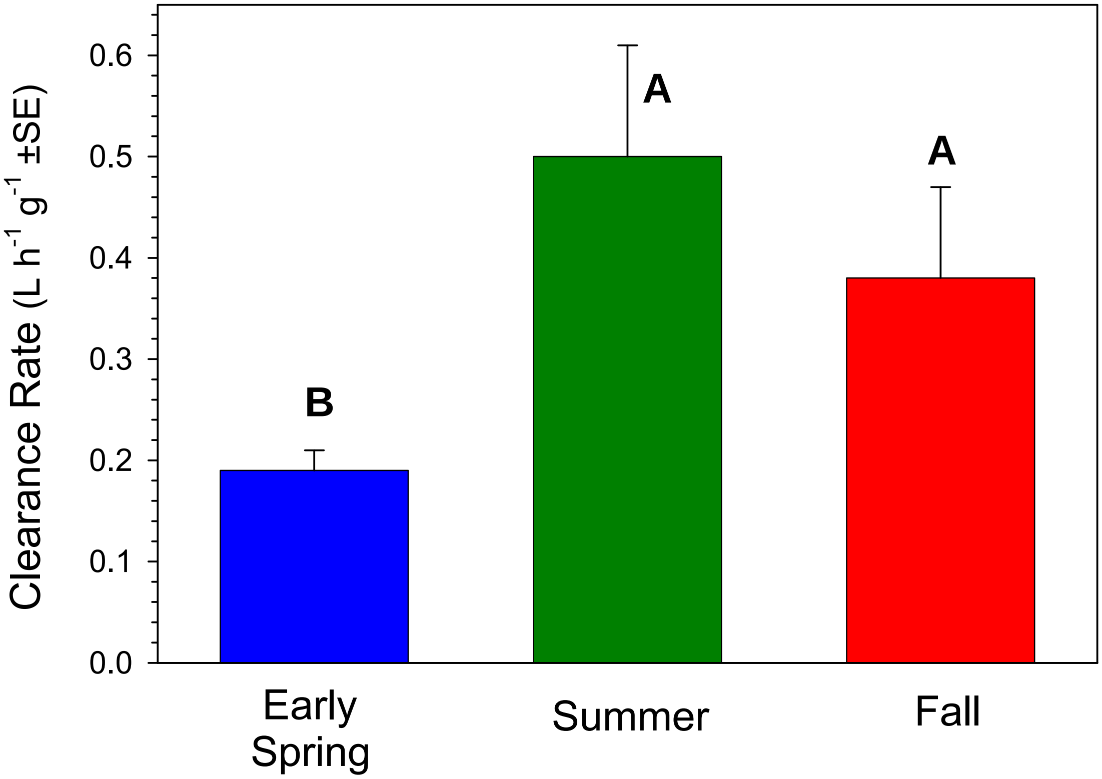

***Figure 37**. Seasonal variation in mean clearance rate of* Margaratifera falcata *sampled from the Middle and North Forks of the John Day River during 2005-2006. Different letters above bars denote significant differences as determined by multiple range analyses (ANOVA, α=0.05)*

3.2.2 Intraspecific Variation in Clearance Rates of *Gonidea* sp.

Mean weight-specific clearance rates for *Gonidea* sp. collected from the Fishing Hole site on the Middle Fork John Day River at four different times varied from a minimum of 0.23 L h^{-1} g^{-1} (March, 2006) to a maximum of 0.55 L h^{-1} g^{-1} (August, 2006) (Table 12.) This is a more narrow range compared with *Margaratifera falcata*, but no data were available for March 2005 which was the time when clearance rates by *M. falcata* were lowest. No significant differences were detected (ANOVA, P>0.05) among either the four different months of UMP experiments (Fig. 38) or among the three seasons when data lumped for summer (Fig. 39.) Like *M. falcata, Gonidea* sp. appeared to be clearing material throughout the March to October period.

Table 15. Summary statistics for the clearance rate (L h^{-1} g dry tissue $weight^{-1}$) of *Gonidea* sp. collected from the Middle Fork of the John Day River during 2005-2006. Only one individual was found for study in March 2005, and so that datum was not included in the statistical analysis although it is shown here.

Date	**Fishing Hole Middle Fork John Day**		
	Mean	SE	N
UMP 1/ 2 (3/22/05)	**0.45**	nd	1
UMP 3/4 (6/22/05)	**0.29**	0.07	6
UMP 5 (10/9/05)	**0.25**	0.05	7
UMP 6 (3/20/06)	**0.23**	0.05	5
UMP 7 (8/24/06)	**0.55**	0.07	6

SE – standard error; n = sample size; nd= no data.

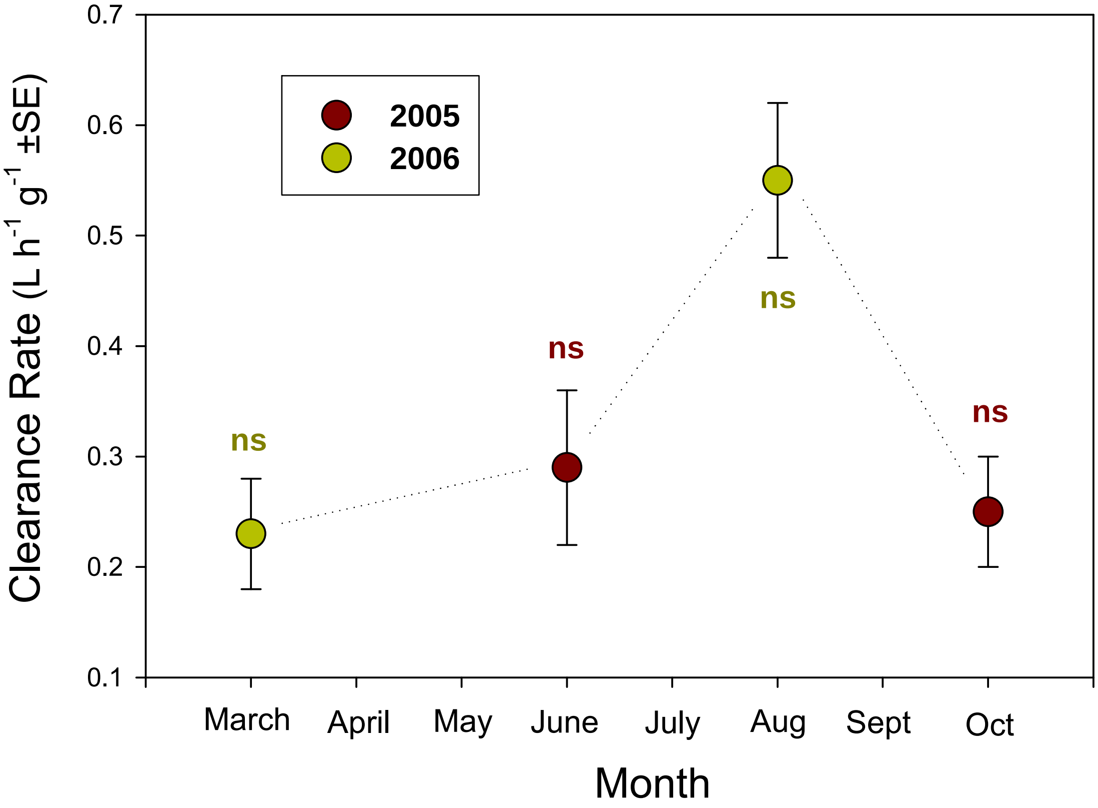

Figure 38*. Mean clearance rate of* Gonidea sp. *sampled from the Middle Fork John Day River during 2005-2006. ns = not significant differences as determined by multiple range analyses (ANOVA, α=0.05)*

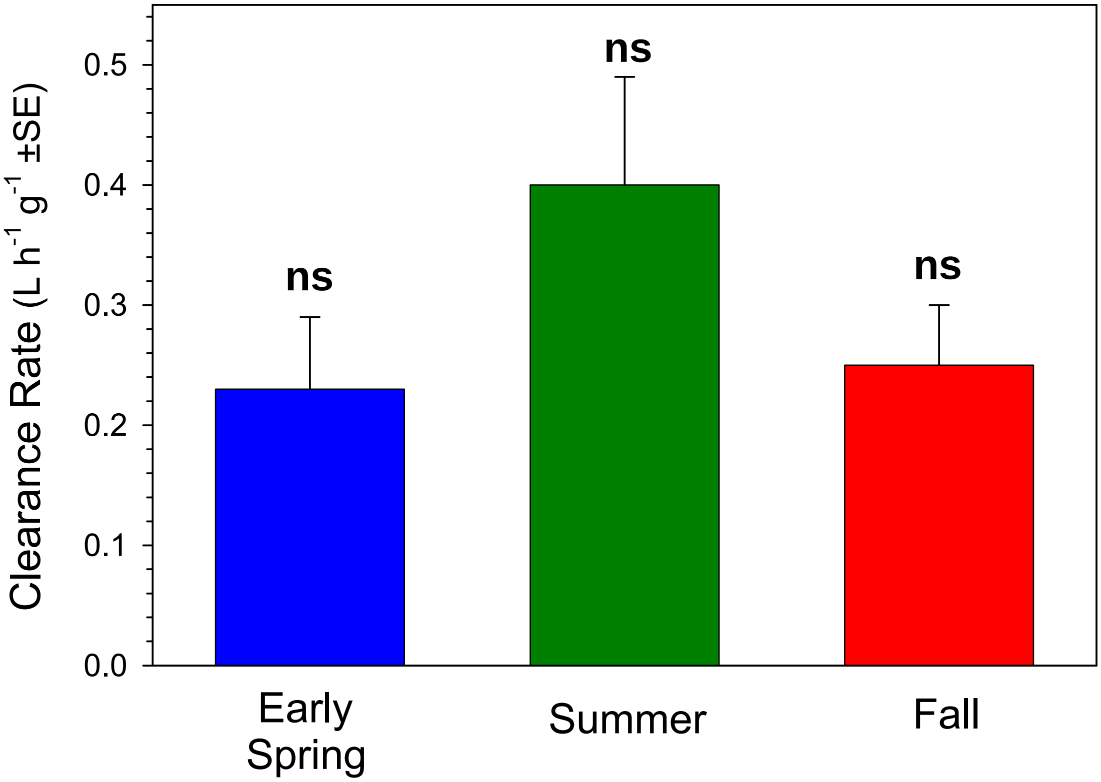

Figure 39. *Seasonal variation in mean clearance rate of* Gonidea sp. *sampled from the Middle Fork John Day River during 2005-2006. ns = not significant differences as determined by multiple range analyses (ANOVA,* α*=0.05)*

3.2.3 Intraspecific Variation in Clearance Rates of *Anodonta* sp.

As noted in Section 2.2.4 above, two different forms of *Anodonta* sp. were collected from the Umatilla River in the 2006 UMP experiments. One form from the Hermiston site on the Umatilla River was longer and "green-striped" (perhaps *A. oregonensis*), which was discernable from the rounder and flatter dark form (perhaps *A. californianus*). For initial statistical tests, clearance data for these two forms were lumped for comparisons among different experiment months and between rivers (Middle Fork John Day versus Umatilla). In addition, clearance data were pooled for *Anodonta* sp. that were collected from different reaches of the Middle Fork John Day (Wildcat Point, Fishing Hole, Ritter) during UMP experiments 3 and 4 in June, 2005, because they did not different significantly (ANOVA, p>0.05.)

Mean weight-specific clearance rates for *Anodonta* sp. collected from the two different rivers and at different times of year varied from a minimum of 0.47 L h^{-1} g^{-1} (March, 2005 from the Middle Fork John Day) to a maximum of 2.16 L h^{-1} g^{-1} (August, 2006, from the Middle Fork John Day) (Table 16.). These findings indicate that *Anodonta* sp. is capable of feeding significantly during the full period from March to October, like the other two mussel species.

Mean weight-specific clearance rates differed both seasonally and between the Umatilla and Middle Fork John Day Rivers. Differences between rivers may have been complicated by the presence of the two forms of *Anodonta* sp. in the Umatilla (examined only during 2006). In March, 2006, clearance data were obtained from only one individual from the Umatilla, but it cleared water at a rate comparable to that for mussels from the Middle Fork John Day (Table 16.) In August, 2006, however, *Anodonta* sp. from the Middle Fork John Day cleared at a faster rate than any other treatment group in this study (2.16 L h^{-1} g^{-1}), which was significantly (t-test, log transformed data, p=0.006) greater than that for mussels from the Umatilla (0.79 L h^{-1} g^{-1}) (Table 16.).

It was unclear whether this result was strictly a river effect, however, because most of the Umatilla River mussels were the form presumed to be *A. oregonensis*, whereas all of the Middle Fork John Day mussels were of the form presumed to be *A. californianus*. When weight-specific clearance rates from August, 2006, were contrasted between the two forms of *Anodonta* rather than the rivers, the form presumed to be *A. oregonensis* cleared at a rate (0.70 ±0.22 L h^{-1} g^{-1} [SE], n=8) significantly lower (t-test, p=0.004) than that for the form presumed to be *A. californianus* (1.90 ±0.22 L h^{-1} g^{-1} [SE], n=8).

Table 16. Summary statistics for the clearance rate (L h^{-1} g dry tissue $weight^{-1}$) of *Anodonta* sp. (all varieties) collected from the Middle Fork of the John Day River during 2005-2006 and the Umatilla River during 2006. For each date, significant differences (p<0.05) among mean clearance rates of mussels from different sites were examined by multiple range analysis and are denoted as different letters.

Date	**Middle Fork John Day**			**Umatilla**		
	Mean	SE	n	Mean	SE	n
UMP 1/ 2 (3/22/05)	**0.47**	0.21	7	**nd**	nd	0
UMP 3/4 (6/22/05)	**1.03**	0.25	11	**nd**	nd	0
UMP 5 (10/9/05)	**0.93**	0.21	7	**nd**	nd	0
UMP 6 (3/20/06)	**0.81**	0.28	5	**0.60**	nd	1
UMP 7 (8/24/06)	**2.16** ^{A}	0.69	6	**0.79** ^{B}	0.16	10

SE – standard error; n = sample size; ns = not significant; nd= no data.

To test whether the river effect or the species form effect was responsible for these differences in August, 2006, clearance rates were compared between the two rivers only for the form presumed to be *A. californianus (*for which there was an ample sample size to perform a t-test.) The test results showed that clearance rates did not differ significantly between the Middle Fork John Day (2.45 ±0.54 L h^{-1} g^{-1}) compared with the Umatilla 1.33 ±0.93 L h^{-1} g^{-1}), seemingly suggesting that the species form effect (or some interaction of effects) was responsible, as shown in Fig. 40 for the August, 2006, data. For these reasons, statistical tests for temporal changes in clearance rates of *Anodonta* sp. were performed with and without pooling the species forms.

Temporal variation in the weight-specific clearance rates of *Anodonta* sp. was significant for the *A. californianus* form (tested five times during 2005-2006), following a similar pattern as that found for *Margaratifera falcata* and *Gonidea* sp. Greatest weight-specific clearance rates were measured in August, with intermediate rates in June and October. When month data were lumped to compare seasons, the same pattern was found for Anodonta sp. taken from the Middle Fork John Day River (Fig. 41). However, no significant temporal difference was detected in the weight-specific clearance rates of the *A. oregonensis* form (only tested in March and August, 2006), which remained low relative to the *A. californianus* form (Fig. 40.)

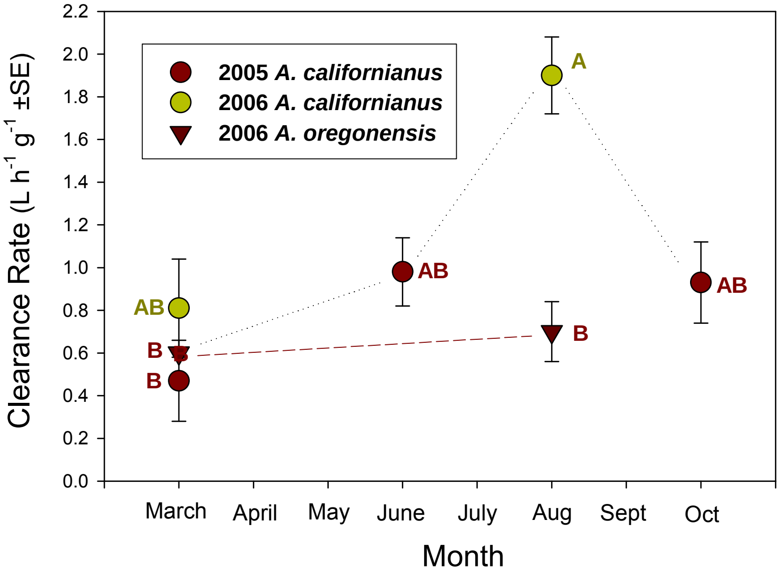

Figure 40. *Monthly variation in clearance rate of* Anodonta *sp*. (presumed species forms are shown in the legend) *sampled from the Middle Fork John Day and Umatilla Rivers during 2005-2006. Different letters above symbols denote significant differences as determined by multiple range analyses (ANOVA, α=0.05)*

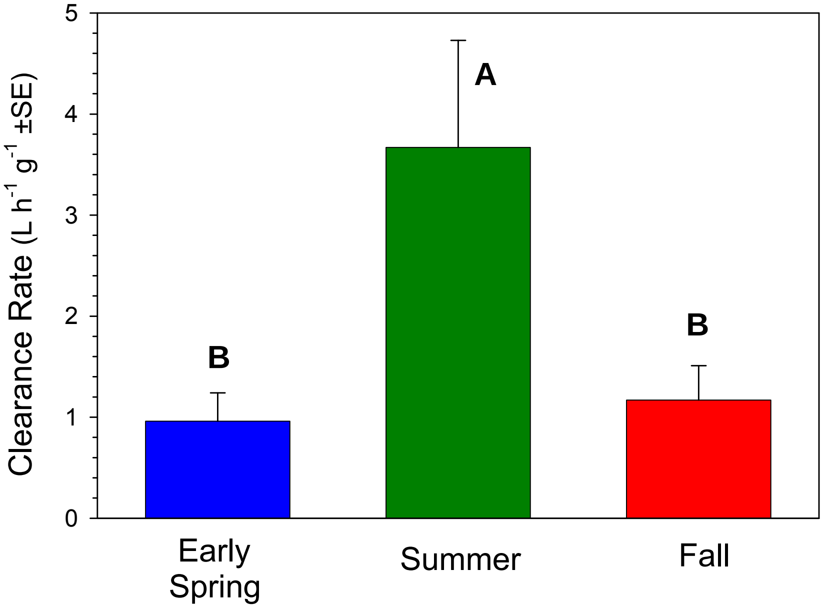

***Figure 41**. Seasonal variation in mean clearance rate of* Anodonta *sp. sampled from the Middle Fork John Day River during 2005-2006 as determined by multiple range analyses (ANOVA, α=0.05)*

The greater clearance rates for the *A. californianus* form taken from the Middle Fork John Day River in summer are consistent with the classic pattern of higher bivalve clearance and metabolic rates at warmer temperatures. However, the comparatively lower clearance rates for mussels from the Umatilla River, which was always warmer than the Middle Fork John Day River, were paradoxical to this typical relationship. Again, since the bulk of mussels tested from the Umatilla appeared to be a different species form, *A. oregonensis,* these results might be attributed either to interspecific differences among these species forms. Alternatively, it cannot be discounted that the Umatilla River may not be as hospitable to mussel feeding. Although not significant (perhaps because of small sample sizes), clearance rates of the *A. californianus* form in the Umatilla River were nearly half those of the *A. californianus* form taken from the Middle Fork John Day (see above). The small sample size of mussels tested from the Umatilla, which was only studied in 2006) makes it difficult to draw firm conclusions, and more study is needed to better discern the reasons for these differences between the two rivers.

A three-way ANOVA comparing main effects of river, season, and species form for *Anodonta* suggested that clearance rates differed significantly ($p=0.023$) only for the main effect of season, with the mean summer clearance rate (3.97 ±0.63 L h^{-1} g^{-1}) being significantly greater than early spring (1.55 ±0.25 L h^{-1} g^{-1}) and fall being intermediate (1.79 ±0.29 L h^{-1} g^{-1}); however, as noted above this comparison of pooled data is not that meaningful because of various interactions.

3.2.4 Interspecific Variation in Clearance Rates

Like most physiological rate functions, clearance rate increases with body size. Interspecific comparisons should therefore be undertaken on data that are normalized for body size (e.g. dry tissue weight.) In this study, all statistical comparisons were performed on weight-specific clearance data to facilitate comparisons among species as well as sites having different population size structures. Even after such normalization, however, smaller sized animals of all species tended to have greater weight-specific clearance rates due presumably to expected allometric scaling. In our experiments, there was insufficient replication of different sized individuals of the same species and treatment type to enable allometric models to be developed. However, to account for allometric body size effects and explore interspecific comparisons irrespective of these body size effects, some statistical tests were performed on like-sized weight classes as well as at the whole sample population in Section 3.2.6 below.

Analysis of variance comparisons of clearance rates of the three species were first performed for each experiment data (Table 17.) For all five times that Unionid Mussel Physiology (UMP) experiments were performed, clearance rates of *Anodonta* sp. were greater than the other two species, and these apparent differences were significant (ANOVA, $P<0.05$) in June, 2005 (UMP 3 and 4) and March 2006 (UMP 6).

Table 17. Mean weight-specific clearance rate (L h^{-1} g dry tissue weight^{-1}) of *Margaratifera falcata, Gonidea* sp. and *Anodonta* sp. collected from eastern Oregon rivers during 2005-2006. For each date, significant differences ($p<0.05$) among mean clearance rates of different species of mussels were examined by multiple range analysis and are denoted as different letters.

Date	***Margaratifera falcata***			***Gonidea* sp.**			***Anodonta* sp.**		
	Mean	SE	n	Mean	SE	n	Mean	SE	n
UMP 1/ 2 (3/22/05)	**0.44** ^{ns}	0.11	15	**0.35**	‘-	1	**0.65** ^{ns}	0.16	7
UMP 3/4 (6/22/05)	**0.60** ^{AB}	0.37	22	**0.29** ^{B}	0.09	6	**1.03** ^{A}	0.53	11
UMP 5 (10/9/05)	**0.51** ^{ns}	0.16	20	**0.25** ^{ns}	0.07	7	**0.93** ^{ns}	0.07	7
UMP 6 (3/20/06)	**0.27** ^{B}	0.04	16	**0.23** ^{B}	0.05	5	**0.77** ^{A}	0.05	6
UMP 7 (8/24/06)	**1.05** ^{ns}	0.29	12	**0.82** ^{ns}	0.41	6	**1.51** ^{ns}	0.25	16

SE – standard error; n = sample size; ns = not significant; nd= no data.

When data were pooled to compare species for each season rather than each experiment, mean seasonal clearance rates for *Anodonta* sp. were consistently greater than at least *Gonidea* sp. during early spring (ANOVA’s, $p=0.05$, Fig. 42), summer, ($p=0.04$, Fig. 43) and fall ($p=0.05$, Fig. 44).

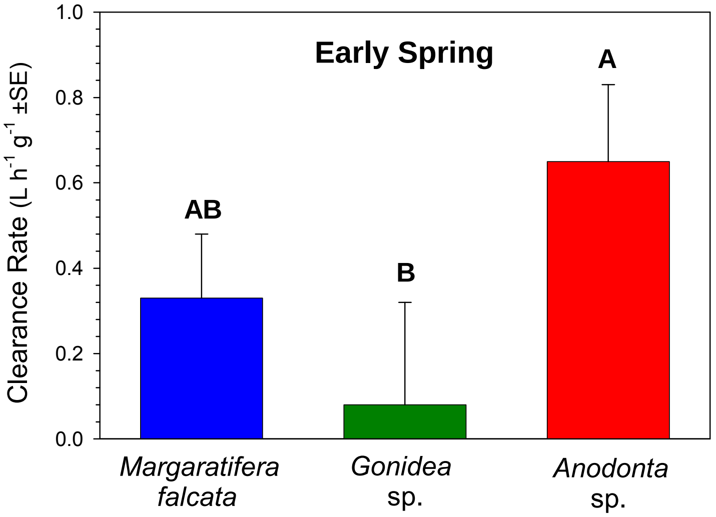

Figure 42. *Interspecific variation in mean clearance rate of freshwater mussels sampled from eastern Oregon rivers in early spring (March 2005, March 2006). Significant differences determined by multiple range analysis (p<0.05) are indicated as different letters above*

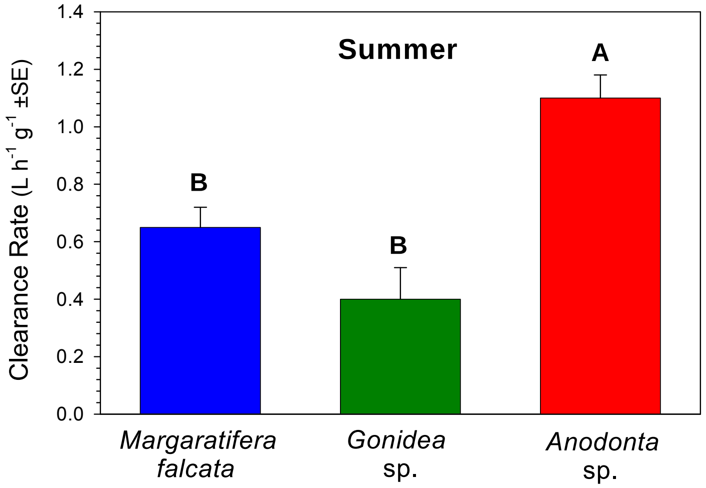

Figure 43. *Interspecific variation in mean clearance rate of freshwater mussels sampled from eastern Oregon rivers in summer (June 2005, August 2006). Significant differences determined by multiple range analysis (p<0.05) are indicated as different letters above bars.*

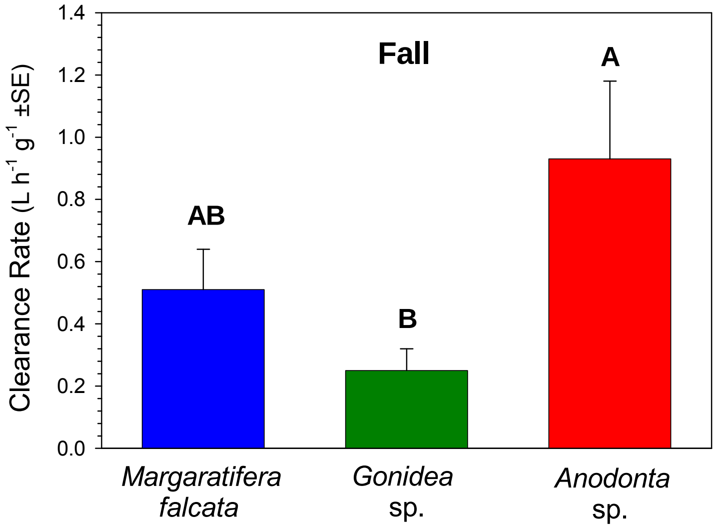

Figure 44. *Interspecific variation in mean clearance rate of freshwater mussels sampled from eastern Oregon rivers in fall (October 2005). Significant differences determined by multiple range analysis ($p<0.05$) are indicated as different letters above bars.*

Pooled data for all experiments indicated that the annual mean clearance rate for *Anodonta* sp. (0.90 L h^{-1} g dry tissue weight^{-1}) was significantly greater than that for either *Margaratifera falcata* (0.45 L h^{-1} g dry tissue weight^{-1}) or *Gonidea* sp. (0.31 L h^{-1} g dry tissue weight^{-1}) (Fig. 45.).

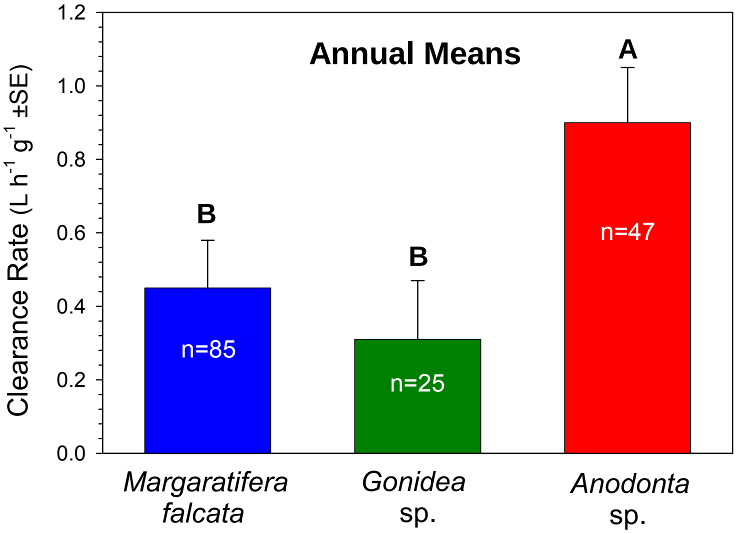

Figure 45. *Interspecific variation in mean clearance rate of freshwater mussels sampled from eastern Oregon rivers in fall (October 2005). Significant differences determined by multiple range analysis ($p<0.05$) are indicated as different letters above bars.*

3.2.5 Variation in Clearance Rates Among Rivers

Weight-specific clearance rates of mussels differed significantly among rivers when 2006 data were examined with a two-way ANOVA comparing river and species effects together. Only 2006 data were examined because this was the only time when mussels from the Umatilla were collected and included in the physiology studies. Although interspecific differences were more important in explaining the variance (p=0.0005), the river effect (p=0.028) suggested that mussels from the Umatilla River have lower overall weight-specific clearance rates (0.11 L h^{-1} g^{-1}) compared with the North Fork John Day (0.67 L h^{-1} g^{-1}) and Middle Fork John Day (1.03 L h^{-1} g^{-1}) Rivers. This difference was most apparent during the summer (August 2006).

3.2.6 Body Size Interactions with River and Species Effects

As noted above, even after raw clearance rates per mussel were converted to weight-specific clearance rates, smaller-sized mussels of all species tended to clear water faster than larger mussels. This body size effect on weight-specific clearance rates was clearly evident from a least squares linear regression of the logarithm of weight-specific clearance rate versus both the logarithm of mussel dry tissue weight and the logarithm of shell height (Fig. 46.)

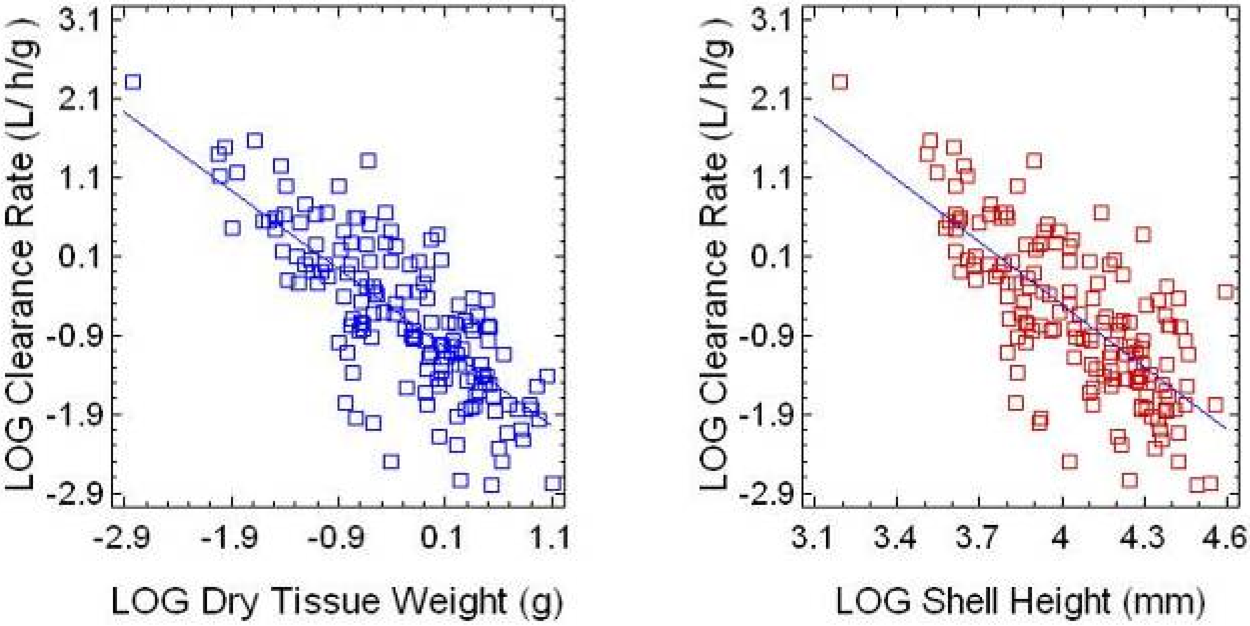

***Figure 46**. Log-log least squares linear regression relationships between the weight-specific clearance rate of all mussels tested in Unionid Mussel Physiology experiments and their dry tissue weight (blue squares in left plot) and shell height (red squares in right plot.)*

For the log-log relationship of weight-specific clearance rate (CR) versus dry tissue weight (DTW) of all mussels, least square linear regression ($p<0.0001$, $R^2 = 61.1\%$) yielded the following equation:

$$\text{LOG CR (L h}^{-1}\text{ g}^{-1}) = \{ -1.05 \times [\text{ LOG DTW (g) }] \} - 0.98$$

For the log-log relationship of weight-specific clearance rate (CR) versus shell height (SH) of all mussels, least square linear regression ($p<0.0001$, $R^2 = 53.2\%$) yielded the following equation:

$$\text{LOG CR (L h}^{-1}\text{ g}^{-1}) = \{ -2.65 \times [\text{ LOG SH (mm) }] \} + 10.08$$

These relationships were significant for all three species as follows:

Margaratifera falcata ($p<0.0001$, $R^2 = 66.2\%$):
$\text{LOG CR (L h}^{-1}\text{ g}^{-1}) = \{ -1.14 \times [\text{ LOG DTW (g) }] \} - 0.98$

Gonidea sp. ($p=0.0003$, $R^2 = 44.7\%$):
$\text{LOG CR (L h}^{-1}\text{ g}^{-1}) = \{ -0.87 \times [\text{ LOG DTW (g) }] \} - 1.14$

Anodonta sp. ($p<0.0001$, $R^2 = 37.1\%$):
$\text{LOG CR (L h}^{-1}\text{ g}^{-1}) = \{ -0.80 \times [\text{ LOG DTW (g) }] \} - 0.73$

Interestingly, the size-specific relationships were similar among species. These data suggest that the variation in clearance rates among rivers (Section 4.2.4) and species (Section 4.2.5) may largely be due to interspecific and riverine differences in mean mussel body size used in the experiments rather than any species-specific physiological strategies per se.

To test whether body size interactions may explain much of the variance discussed above, riverine and interspecific ANOVA comparisons were repeated for like-sized classes. When 2006 clearance rates were compared among rivers for mussels having >50 and >60 mm shell heights, no significant differences (ANOVA, $p>0.05$) were detected among the Umatilla, North Fork John Day, and Middle Fork John Day Rivers.

Comparing species, mean weight-specific clearance rates were not significantly different (ANOVA, $p>0.05$) among species for the <40 mm, 40-49 mm, and 50-59 mm shell height size classes (Fig. 47). The only size class where mussel clearance rates differed interspecifically was the largest class, >60 mm shell height where *Anodonta* sp. cleared at a significantly faster rate (0.73 L h^{-1} g^{-1}) than either *Margaratifera falcata* (0.26 L h^{-1} g^{-1})or *Gonidea* sp. (0.22 L h^{-1} g^{-1}) (Fig. 47.) The greater clearance rates of larger-sized *Anodonta* did not result because of any differences between the presumed variants, *A. oregonensis* and *A. californianus,* which themselves did not different significantly (t-test, $p>0.05$) for the 50-59 and >60 mm size classes.

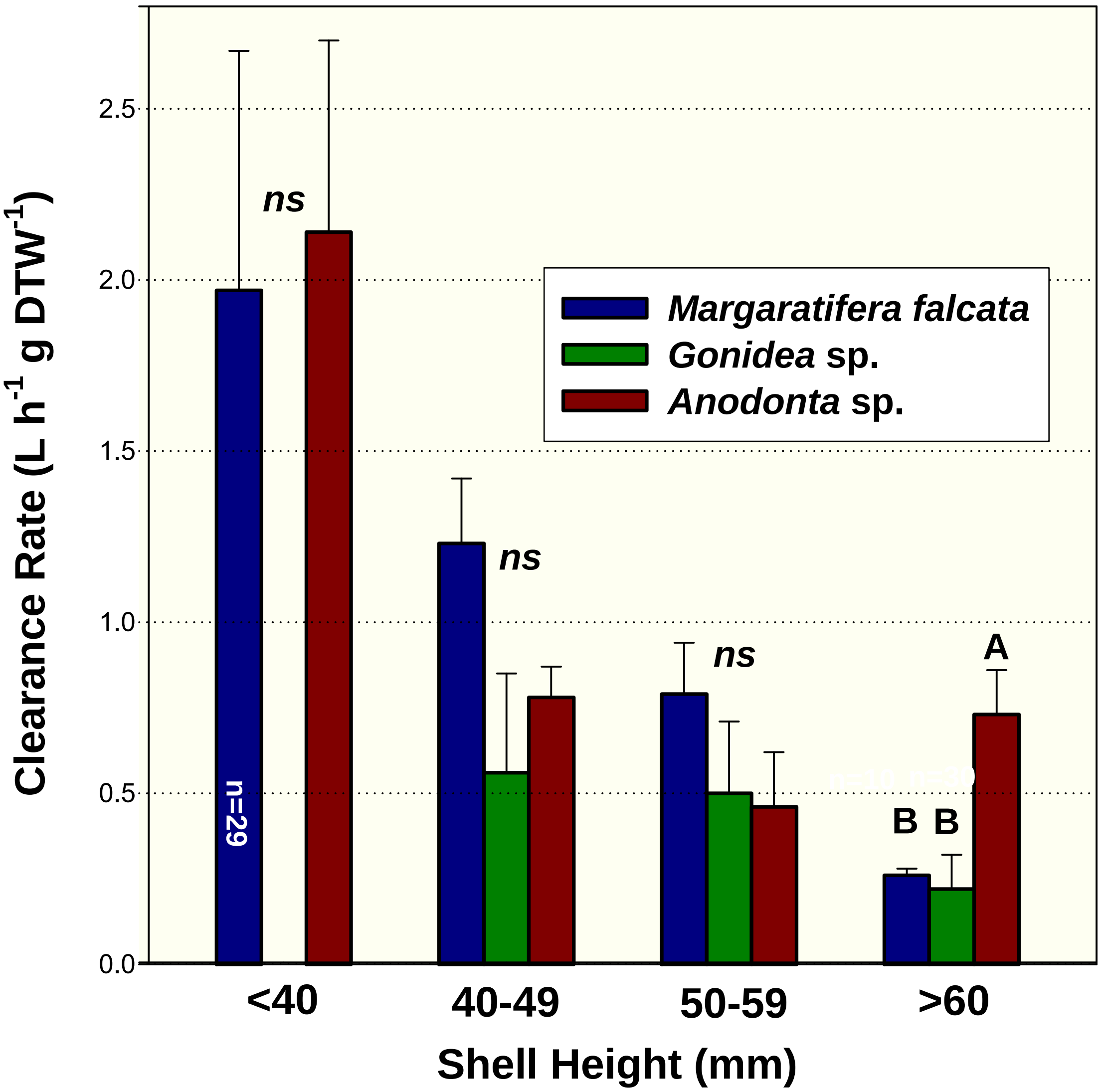

Figure 47. *Mean (±SE) weight-specific clearance rates for different shell height size classes of three species of freshwater mussels from eastern Oregon Rivers. For each size class, significant differences (p<0.05) determined from multiple range analysis are denoted as different letters above bars.*

Taken together, these results suggest that freshwater mussels of eastern Oregon rivers differ little in weight-specific clearance rates when averaged among rivers, seasons, and among species, except for the largest sized adults. Since most of the population biomass is usually associated with the larger, older size classes, the greater weight-specific clearance rate of large *Anodonta* relative to large *Margaratifera* and *Gonidea* may have a bearing on the functional services rendered by populations of these mussels wherever they are mature and abundant. And wherever large numbers of large-sized individuals live, population level clearance rates will be greatest. Hence, studies that seek to quantify clearance rates by mussel populations in eastern Oregon rivers should be most concerned with obtaining an accurate assessment of the population abundance and size class structure of the entire mussel assemblage regardless of species and location (e.g. see mussels living *in situ* in Fig. 48).

Figure 48. Anodonta californianus *were found in high densities below Ritter Hot Springs in the Middle Fork John Day River in June 2006.*

3.3 Filtration Rates

Filtration rates were determined for each mussel which had its clearance rate measured. Filtration rates (mg h^{-1} g dry tissue $weight^{-1}$) were calculated by multiplying the mean concentration of dietary seston particulate material (PM; mg L^{-1}) by the weight-specific clearance rate (L h^{-1} g dry tissue $weight^{-1}$). The organic matter filtration rate was similarly calculated by multiplying the concentration of particulate organic material (POM; mg L^{-1}) in the seston by the mussel's clearance rate. For these calculations, seston concentrations that were used were the mean values for the same river and sample date as where/when mussels were collected (i.e., same as fed to mussels in experiments). The resulting values are therefore an indication of the relative removal rates for particulate matter by mussel filtration per unit body weight.

As shown in Table 18, the seasonal mean filtration rate tended to decline during the year from spring to summer and fall mainly because spring runoff carries more particulate matter; i.e. seston quantity is greater in the spring. This was true for the Middle Fork and North Fork of the John Day River, but in the Umatilla River seston filtration rates were slightly greater in the summer (Table 18). The only significant seasonal difference (ANOVA, p=0.02) was determined for *Anodonta* sp. in the Middle Fork John Day River.

Since higher seston quantities (PM) associated with spring runoff tends to be lower in quality (organic content), these modest seasonal patterns in filtration rate did not hold when they were recalculated for just the organic fraction (Table 18). In fact, the filtration rate for seston particulate organic matter tended to be greatest in the summer or at least equivalent to the spring rates. The only significant (ANOVA, $p=0.015$) seasonal difference for POM filtration was for *Gonidea* sp. in the Middle Fork John Day River (Table 18.)

A three-way ANOVA contrasting the relative importance of season, river and species in determining the mean PM filtration rate (log transformed to achieve normality) for all 157 mussels indicated that river was insignificant ($p>0.05$) whereas both season and species were highly significant ($p<0.0001$) determinants of PM filtration. As suggested from individual species data in Table 18, the overall mean PM filtration rate in the spring was 1.38 mg h^{-1} g dry tissue $weight^{-1}$ (n=50), which was not significantly different from the mean summer rate of 1.07 mg h^{-1} g dry tissue $weight^{-1}$ (n=73). However, the mean PM filtration rate for all species was significantly lower in the fall, 0.51 mg h^{-1} g dry tissue $weight^{-1}$ (n=34) than spring or summer.

Averaged across all seasons, the greatest PM filtration rate per species was measured for *Anodonta* sp., which filtered at a rate of 1.76 mg h^{-1} g dry tissue $weight^{-1}$ (n=47), significantly greater ($p<0.05$) than for *Margaratifera falcata* (0.90 mg h^{-1} g dry tissue $weight^{-1}$, n=85), which was in turn greater ($p<0.05$) than for *Gonidea* sp. (0.48 mg h^{-1} g dry tissue $weight^{-1}$, n=25). As noted above in Section 3.2.6, these interspecific differences may have been partly due to the different mean body sizes for species used in the experimental groups.

Similar statistical results were found for POM filtration rates as for PM filtration rates; i,e, greater spring and summer filtration rates compared with fall ($p=0.0002$), and greater ($p<0.0001$) POM filtration by *Anodonta* sp. than for *Margaratifera falcata* and *Gonidea* sp.

Table 18. Filtration rates (mg h^{-1} g^{-1}) of seston particulate matter and particulate organic matter by three species of freshwater mussels in Unionid Mussel Physiology Experiments during 2005-2006. The same water and seston type was fed to mussels from the river locations where they were collected. For each row, seasonal differences detected via multiple range analysis ($p<0.05$) are denoted with different letters.

Species and River	**Spring**			**Summer**			**Fall**		
	Mean	SE	N	Mean	SE	N	Mean	SE	n
Margaratifera falcata									
Middle Fork John Day River									
Filtration of Particulate Matter (mg h^{-1} g^{-1})	**2.08** ^{ns}	0.39	20	**1.56** ^{ns}	0.33	28	**1.30** ^{ns}	0.45	15
Filtration of Particulate Organic Matter (mg h^{-1} g^{-1})	**0.51** ^{ns}	0.13	20	**0.55** ^{ns}	0.11	28	**0.50** ^{ns}	0.15	15
North Fork John Day River									
Filtration of Particulate Matter (mg h^{-1} g^{-1})	**1.53** ^{ns}	0.53	11	**1.42** ^{ns}	0.72	6	**0.50** ^{ns}	0.78	5
Filtration of Particulate Organic Matter (mg h^{-1} g^{-1})	**0.33** ^{ns}	0.10	11	**0.46** ^{ns}	0.14	6	**0.12** ^{ns}	0.15	5
***Gonidea* sp.**									
Middle Fork John Day River									
Filtration of Particulate Matter (mg h^{-1} g^{-1})	**1.13** ^{ns}	0.34	6	**0.97** ^{ns}	0.24	12	**0.22** ^{ns}	0.32	7
Filtration of Particulate Organic Matter (mg h^{-1} g^{-1})	**0.33** ^{A}	0.11	6	**0.33** ^{A}	0.08	12	**0.09** ^{B}	0.10	7
***Anodonta* sp.**									
Middle Fork John Day River									
Filtration of Particulate Matter (mg h^{-1} g^{-1})	**2.89** ^{A}	0.74	12	**1.79** ^{AB}	0.60	17	**0.73** ^{B}	0.99	7
Filtration of Particulate Organic Matter (mg h^{-1} g^{-1})	**1.02** ^{ns}	0.23	12	**0.97** ^{ns}	0.19	17	**0.33** ^{ns}	0.30	7
Umatilla River									
Filtration of Particulate Matter (mg h^{-1} g^{-1})	**2.97**	na	1	**3.52**	0.68	10	**nd**	nd	0
Filtration of Particulate Organic Matter (mg h^{-1} g^{-1})	**0.53**	na	1	**0.76**	0.15	10	**nd**	nd	0

SE = standard error; n = sample size

4) Mussel Defecation and Absorption Efficiency

All but two mussels used in Unionid Mussel Physiology (UMP) experiments produced feces, and no distinguishable pseudofeces were produced in this study, probably because it was generally conducted under base flow conditions when turbidity was low. Absorption efficiencies were therefore calculated for all but two mussels for which we have clearance and filtration rate data. This represents a substantial contribution of data (n=156) on a rarely measured parameter in freshwater mussels.

In Section 4.1, absorption efficiencies (AE) were statistically analyzed within species, among species, among rivers, among seasons and between years following a similar analysis strategy as used for clearance rates. For statistics, all AE data were transformed by arc sine square root (Sokal and Rohlf, 1980). Body size effects were then examined to determine if they help explain any of the variability in absorption efficiency. Finally, since no measurable pseudofeces were produced, weight-specific filtration rates of seston organic matter (Section 3.3) were assumed equivalent to organic matter ingestion rates and were multiplied by each animal's absorption efficiency to calculate net absorption rate (NAR) for organic matter. These values for NAR are statistically compared in Section 4.2.

4.1 Absorption Efficiencies

Absorption efficiencies (AE) were measured for 156 freshwater mussels in the seven UMP experiments during 2005-2006, consisting of 85 *Margaratifera falcata*, 25 *Gonidea* sp., and 46 *Anodonta* sp. Appendix D provides all absorption efficiency data paired with other physiological measurements on the same individuals. The mean AE for all 156 replicates was 24.1%, which is consistent with the typical range (e.g., 10-50%) of values seen for bivalve molluscs feeding on natural seston in the field.

4.1.1 Intraspecific Variation in Absorption Rates of *Margaratifera falcata*

Mean AE for *Margaratifera falcata* collected from various sites and times of year averaged 31.5% overall but varied widely. The lowest mean AE of mussels from all sites and times was recorded in March, 2005, from the North Fork John Day (NFJD) (3.6%). Interestingly, the highest AE of all mussels (75.8%) was also recorded from this river, in March, 2006. This seems unusual but may reflect the lack of (2005) and abundance of (2006) early spring blooms of algae which are assimilated and digested with much greater efficiency than bulk seston organic material which usually consists of a lot of detritus. Indeed, the exceptionally high AE in March 2006 on the NFJD.

In every month sampled, AE differed significantly among sites as tested with ANOVA ($p<0.05$) (Table 19.) In four of the five months sampled, the mean AE of *M. falcata* taken from the Fishing Hole site on the Middle Fork John Day (MFJD) was significantly greater ($p<0.05$) than that of mussels from other sites. In three of the five months, it was even significantly greater than the mean AE of mussels from upstream on the same river. These data suggest that except for unusual conditions (e.g. a possible bloom of nutritious algae on the NFJD in March 2006), the Fishing Hole site appears to either have more readily assimilated seston or the mussels there have more active digestive processes.

In comparison the comparatively narrow range of clearance rates measured from *M. falcata,* these findings indicate that AE is much more variable throughout the period from March-October, and the seasonal pattern may reverse from one year to the next. Also, unlike clearance rates, there was a high degree of spatial variation in AE even within the same river (Table 19.) Since net food availability for bivalves depends on both ingestion and digestion processes, these data indicate that AE may be a more variable determinant of nutrition in *M. falcata* than clearance rates (see also Conclusions section).

Table 19. Summary statistics for the absorption efficiency (%) of *Margaratifera falcata* collected from the North Fork and two sites on the Middle Fork of the John Day River during 2005-2006. For each date, significant differences ($p<0.05$) among mean absorption efficiencies of mussels from different sites were examined by multiple range analysis and are denoted as different letters.

Date	**Big Boulder Creek Middle Fork John Day**			**Fishing Hole Middle Fork John Day**			**North Fork John Day**		
	Mean	SE	n	Mean	SE	n	Mean	SE	n
UMP 1/ 2 (3/22/05)	**nd**	nd	0	**7.6** ^{A}	0.5	8	**3.6** ^{B}	0.3	7
UMP 3/4 (6/22/05)	**52.3** ^{A}	0.8	5	**54.3** ^{A}	0.5	11	**38.5** ^{B}	0.6	6
UMP 5 (10/9/05)	**30.0** ^{B}	0.3	7	**60.2** ^{A}	0.5	7	**16.2** ^{C}	0.3	6
UMP 6 (3/20/06)	**26.2** ^{C}	1.00	6	**37.6** ^{B}	1.17	6	**75.8** ^{A}	1.80	4
UMP 7 (8/24/06)	**29.1** ^{B}	0.6	6	**52.6** ^{A}	0.80	6	**nd**	Nd	0

SE – standard error; n = sample size; ns = not significant; nd= no data.

A two-way ANOVA comparing main effects of both site and month suggested that AE's of *M. falcata* differed significantly ($p<0.0001$) among the Fishing Hole site (40.9%, n=38) and the other two sites (Boulder Creek, 24.6%, n=24; NFJD, 29.4%, n=23), which were statistically similar ($p>0.05$). This test also indicated that the month effect was highly significant ($p<0.0001$). A Tukey's multiple range analysis showed that AE's of *M. falcata* were greatest in June, 2005 (47.0%, n=22), followed by March 2006 (42.5%, n=16), followed by August, 2006 (39.5%, n=12), then October, 2005 (35.4%, n=20), and the significantly lowest AE's were 3.8% in March, 2005, n=15) (Fig. 49).

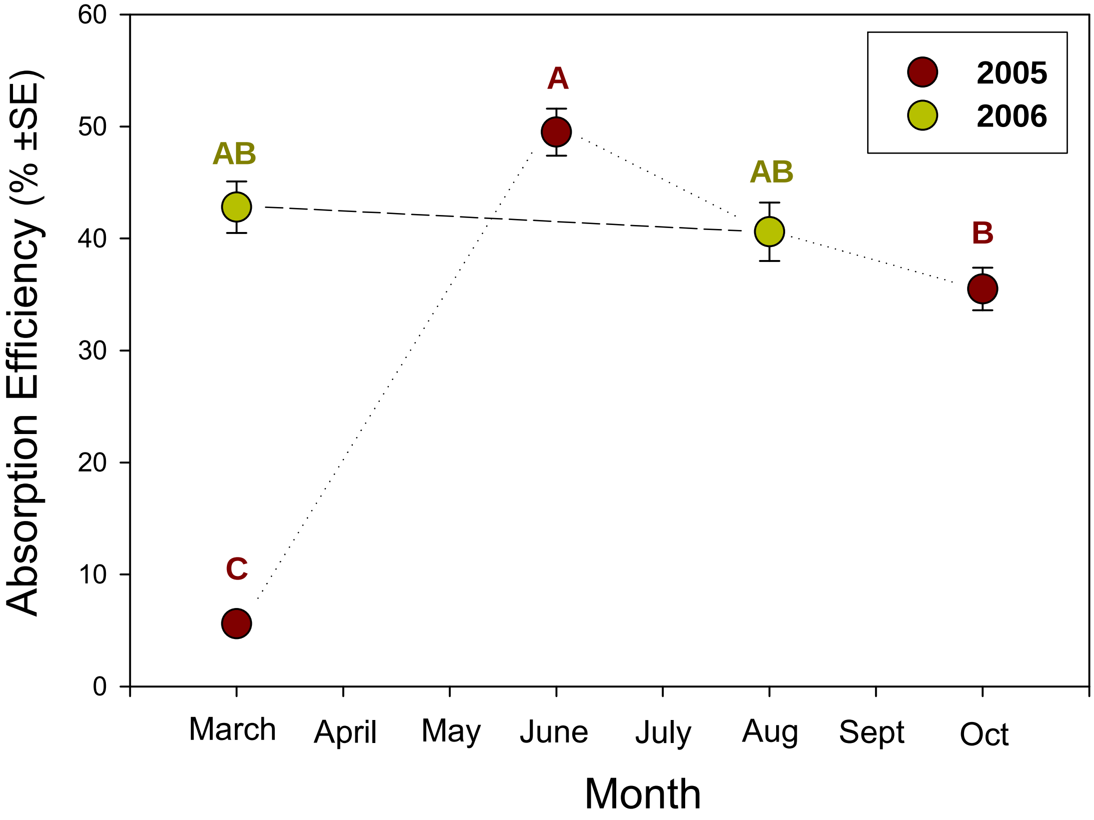

Figure 49. *Monthly variation in absorption efficiency of* Margaratifera falcata *sampled from the Middle and North Forks of the John Day River during 2005-2006. Different letters denote significant differences as determined by multiple range analyses (ANOVA, α=0.05)*

Despite the differences between the AE of mussels taken in March 2005 and March 2006, data were pooled and contrasted among seasons with another ANOVA. Absorption efficiencies for *M. falcata* were significantly lower (ANOVA, p<0.05) in early spring (21.6% ±1.7% SE, n=31; March 2005 and March 2006 combined), compared with summer (46.4% ±2.2% SE, n=34; June 2005 and August 2006) and fall (35.5% ±2.6% SE, n=20; October 2005).

4.1.2 Intraspecific Variation in Absorption Efficiencies of *Gonidea* sp.

Mean AE for *Gonidea* sp. collected from the Fishing Hole site on the Middle Fork John Day River at different times averaged 48.6% overall, varying from a minimum of 29.5% (March, 2006; the one individual studied in March 2005 had only 12.1% AE) to a maximum of 60.1% (October, 2005) (Table 20.) This is a much more narrow range compared with *Margaratifera falcata*, but only one datum was available for March 2005 which was the time when AE by *M. falcata* was lowest.

The absorption efficiency of *Gonidea* sp. varied significantly among months (ANOVA, p<0.0001), being greater in October, 2005, than in either June 2005 or August 2006. In March, 2006, it was significantly lower than all other months (Fig. 50).

Table 20. Summary statistics for the absorption efficiency (%) of *Gonidea* sp. collected from the Middle Fork of the John Day River during 2005-2006. Only one individual was found for study in March 2005, and so that datum was not included in the statistical analysis although it is shown here.

Date	**Fishing Hole Middle Fork John Day**		
	Mean	SE	N
UMP 1/ 2 (3/22/05)	**12.1%**	nd	1
UMP 3/4 (6/22/05)	**54.6%**	0.56	6
UMP 5 (10/9/05)	**60.1%**	0.53	7
UMP 6 (3/20/06)	**29.5%**	0.48	5
UMP 7 (8/24/06)	**52.3%**	0.55	6

SE – standard error; n = sample size; nd= no data.

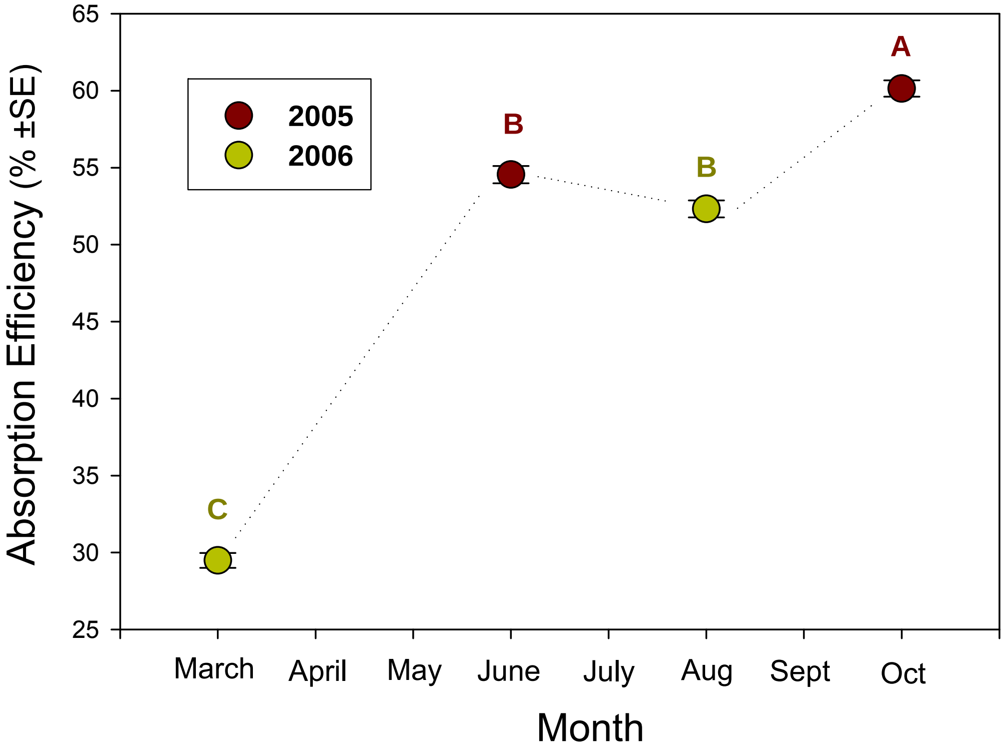

Figure 50*. Mean absorption efficiency of* Gonidea sp. *sampled from the Middle Fork John Day River during 2005-2006. ns = not significant differences as determined by multiple range analyses (ANOVA, α=0.05)*

4.1.3 Intraspecific Variation in Absorption Efficiencies of *Anodonta* sp.

Mean absorption efficiencies for *Anodonta* sp. collected from the Middle Fork John Day (MFJD) and Umatilla Rivers at different times of year varied widely and appeared to be significantly different between rivers (Table 21).. In the MFJD, seasonal trends in AE tended to follow those seen for the other two genera, being lower in early spring (10.5% and 32.2% in March of 2005 and 2006, respectively) and increasing during the growing season (up to 60.5% in October 2005). However, AE for *Anodonta* sp. In the Umatilla (studied only in 2006) never eclipsed 10% even in August. These findings indicate that AE varies widely among months, but *Anodonta* sp. is capable of feeding and assimilating dietary material throughout the full period from March to October, like the other two mussel species. However, the food resources of the Umatilla River were poorly absorbed in comparsion to those in the MFJD.

As noted in Section 2.2.4 above, the Umatilla appeared to contain two different forms of *Anodonta* sp. However, it is not likely that any potential species differences contributed to the substantially lower AE by mussels therein because data shown in Table 21 are for all *Anodonta* combined.

Table 21. Summary statistics for the absorption efficiency (%) of *Anodonta* sp. (all varieties) collected from the Middle Fork of the John Day River during 2005-2006 and the Umatilla River during 2006. For each date, significant differences (p<0.05) among mean clearance rates of mussels from different sites were examined by multiple range analysis and are denoted as different letters.

Date	**Middle Fork John Day**			**Umatilla**		
	Mean	SE	n	Mean	SE	n
UMP 1/ 2 (3/22/05)	**10.5**	1.38	7	**nd**	nd	0
UMP 3/4 (6/22/05)	**54.5**	2.38	10	**nd**	nd	0
UMP 5 (10/9/05)	**60.5**	2.94	7	**nd**	Nd	0
UMP 6 (3/20/06)	**32.2** ^{A}	3.06	4	**7.15** ^{B}	-	1
UMP 7 (8/24/06)	**40.4** ^{A}	2.37	8	**9.52** ^{B}	0.33	8

SE – standard error; n = sample size; ns = not significant; nd= no data.

Like for the other genera, the absorption efficiency of *Anodonta* sp. varied significantly among months (ANOVA, $p<0.0001$), being greater in June and October, 2005, than in March of either year or August 2006 (Fig. 51). Since mussels from the Umatilla consisted partly of the form presumed to be *A. oregonensis* and the MFJD consisted solely of *A. californianus*, it is possible that the effects of river and species form on AE interacted in August 2006; nevertheless, all *Anodonta* sp. from the Umatilla had low AE (Table 21).

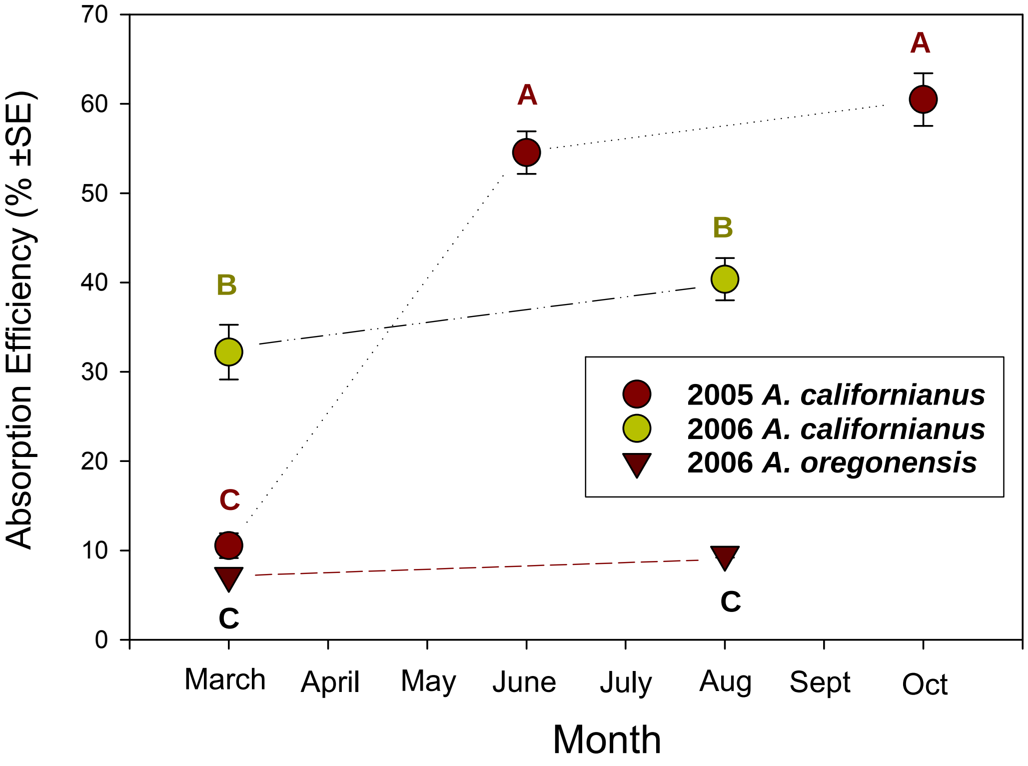

***Figure 51**. Mean absorption efficiency of* Anodonta sp. *sampled from the Middle Fork John Day River during 2005-2006. Significant differences were determined by multiple range analyses (ANOVA, $\alpha=0.05$)*

Since the Umatilla River mussels were larger in body size, which has already been shown to affect feeding rates, it is important to compare absorption efficiencies for similar-sized mussels of the two different *Anodonta* forms. Comparing only the *A. californianus* form between rivers (i.e. the only species common to both rivers and tested in August 2006), the difference between rivers was still highly significant ($p<0.0001$; 53.1% AE from MFJD; 9.0% AE from Umatilla). These findings and additional tests suggest that the mussels in the Umatilla River do in fact have lower seston absorption efficiencies than mussels from the MFJD River, unrelated to species form or body size effects.

A three-way ANOVA comparing main effects of river, season, and species form for *Anodonta* suggested that AE's differed significantly for the main effect of season ($p<0.0001$) and river ($p<0.0001$), but not between the *A. oregonensis* and *A. californianus* forms ($p>0.05$). As noted above, the Umatilla River held mussels that absorbed seston matter with much lower efficiency than the MFJD. Seasonal variation was characterized by low AE in the early spring (5.0% ±0.2%, n=12), high AE in summer (29.9% ±1.0%, n=26) and still higher AE in fall (37.7% ±0.8%, n=7.)

4.1.4 Body Size Effects on Absorption Efficiencies

Whereas measurements of feeding rates of freshwater mussels are becoming more widespread in the literature, absorption efficiencies have not been reported for many species including those examined in this study. Even fewer studies have examined how post-ingestion material processing (e.g., digestion and absorption) differs among species, rivers, or developmental stage (i.e., age.). To deduce whether absorption efficiency varies with age, least squares linear regression was used to test for significant relationships between the species-specific AE's and body size. For all three species, *M. falcata, Gonidea* sp., and *Anodonta* sp. (only MFJD mussels were examined to separate river effects), AE tended to decrease when correlated with both shell height (log-transformed) and dry tissue weight (log transformed.) In all cases, the slope was negative. However, in no case was the slope significant (p>0.05.) Therefore, body size (age) was not as an important factor in determining AE's as it was for clearance rate. The mean AE for major size classes of mussels of each species are shown in Figure 52.

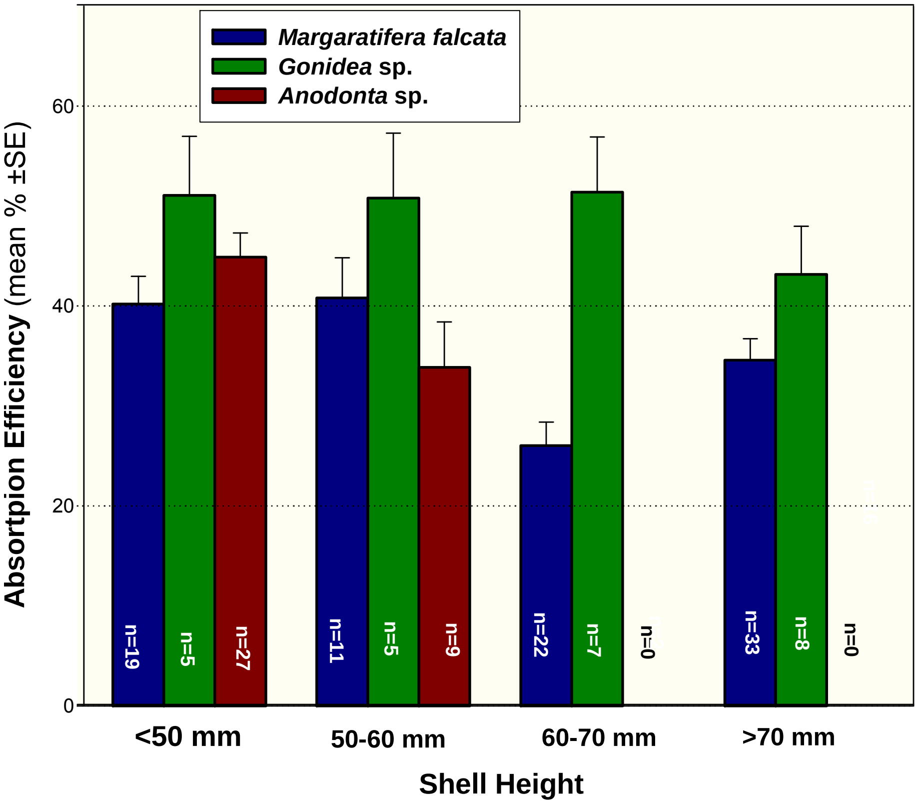

Figure 52. *Mean absorption efficiency of seston by different size classes of* Margaratifera falcate, Gonidea *sp. and* Anodonta *sp. from the Middle Fork And North Fork John Day Rivers during 2005-2006.*

4.1.5 Interspecific Variation in Absorption Efficiency

Differences in AE were compared among species by two-way ANOVA with main effects of species and season (body size was not a significant factor, see Section 4.1.4.) For these interspecific comparisons of AE's, the 2006 data for the Umatilla River was not included because of the major river effect (See Sections 4.1.3 and 4.1.6). The results indicated that both species ($p=0.002$) and season ($p<0.0001$) significantly affected mean AE, and these two main effects also interacted significantly ($p=0.016$). Therefore, interspecific comparisons were undertaken for each season with separate 1-way ANOVA's. In spring, no significant differences in AE were detected among the three species (Fig. 53). However, in both summer ($p=0.0027$) and fall ($p=0.0004$), the mean AE was significantly lower for *Margaratifera falcata* than for *Gonidea* and *Anodonta* sp., which were similar (Fig. 53). On an annual basis, this interspecific difference in AE was significant ($p=0.002$) with *Gonidea* sp. (46.3 ±2.2% SE, n=25) and *Anodonta* sp. (43.0 ±1.9% SE, n=34) being similar ($p>0.05$) and greater than for *Margaratifera falcata* (34.1 ±1.0% SE, n=85).

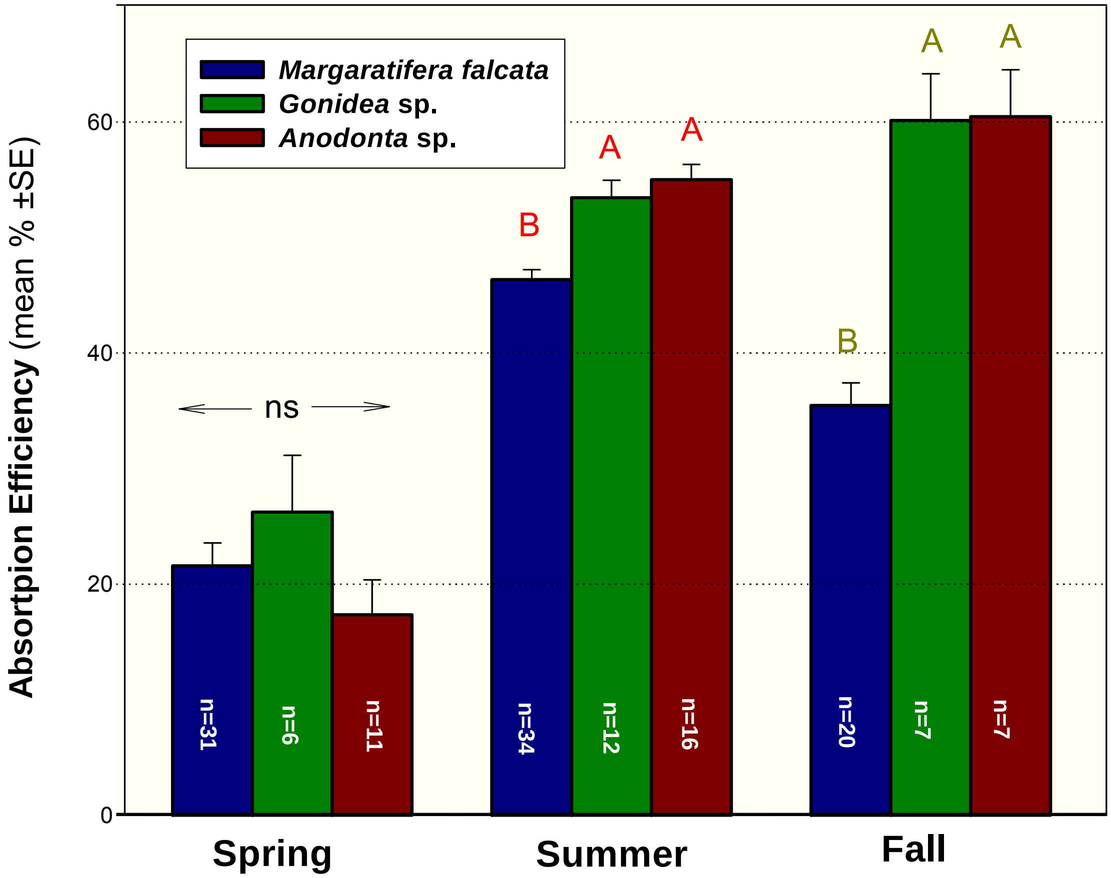

Figure 53. *Mean absorption efficiency of seston by* Margaratifera falcata, Gonidea sp. and Anodonta sp. *from the Middle Fork and North Fork John Day Rivers during different seasons in 2005-2006. For each season, significant differences among species are denoted by different letters above bars as determined by multiple range analysis. ns=not significant (p>0.05.)*

4.1.6 Variation in Absorption Efficiency Among Seasons

Seasonal variation in AE is summarized per species in Section 4.1.5. The two-way ANOVA described in that section showed that seasonal variation was the most significant factor in determining AE ($p<0.0001$). Pooled AE's among all sites and species (except the Umatilla in 2006 which was very different) differed by season as follows: spring (21.6 ±1.4% SE, n=48) was significantly lower ($p<0.05$) than either summer (51.3 ±1.5% SE, n=62) or fall (52.0 ±2.1% SE, n=34), which were similar.

The mean AE of ~50% in summer and fall was moderate to high compared to typical AE's (20-50%) for bivalves feeding on natural seston, which usually contains a large amount of refractory detrital matter. These data suggest that all three species of freshwater mussels in the Middle and North Fork of the John Day Rivers typically receive a nutritious diet that can be captured and digested particularly during the peak of the growing season when the seston organic content is highest (Fig. 53.)

The absorption efficiency also varied with seston composition. A least squares linear regression comparison of mussel absorption efficiency (AE) with the percentage seston organic content (OC) was highly significant (Fig. 54) with the positive relationship summarized as follows:

AE (%) = (1.21 x OC) – 41.7

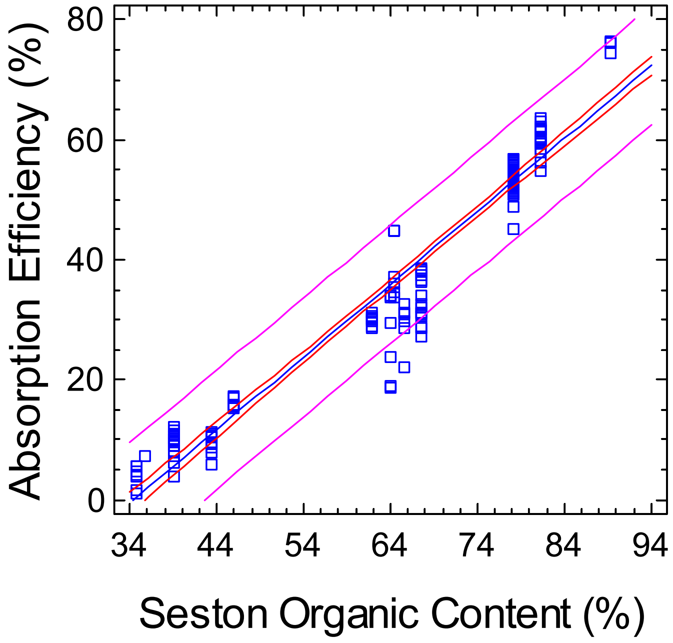

Figure 54. *Regression relationship between the absorption efficiency of seston by 155 freshwater mussels from eastern Oregon rivers and the organic content of seston from their source streams used in physiology experiments (slope* $p<0.0001$*,* R^2 *65.6%).*

Conversely, mussel AE was inversely related to the total concentration of seston particulate material (PM) (Fig. 55) as follows:

AE (%) = (-24.8 x PM) + 56.0

These findings indicate that dietary factors as well as temperature and species are important for predicting how readily dietary material is taken across the gut lumen in eastern Oregon mussels.

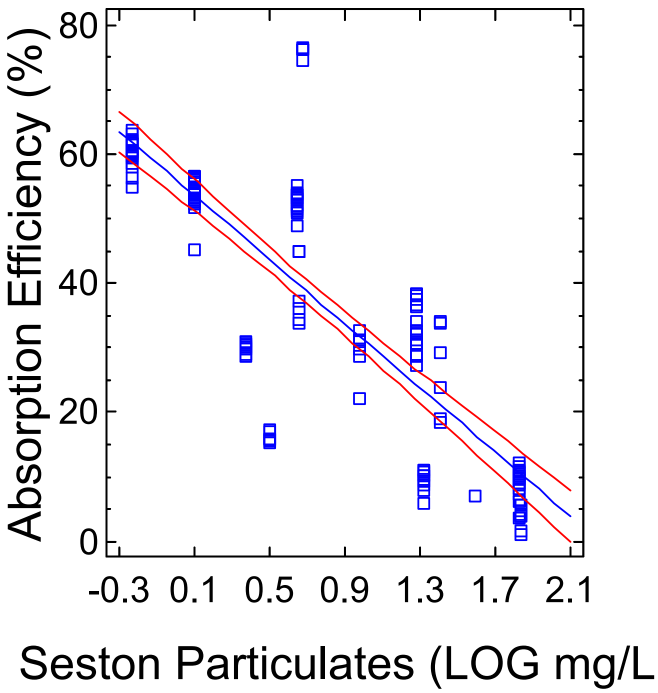

Figure 55. *Regression relationship between the absorption efficiency of seston by 155 freshwater mussels from eastern Oregon rivers and the concentration of particulate seston from their source streams used in physiology experiments (slope p<0.0001, R2 69.6%.)*

4.1.7 Variation in Absorption Efficiency Among Rivers

River effects on mussel absorption efficiency were most evident when comparing the 2006 data from the Umatilla River to the John Day rivers, as already discussed in Section 4.1.3 and summarized in Table 21 for *Anodonta* sp. living in both systems. Floaters from the Umatilla only managed 9.5% AE in August 2006, whereas, floaters from the Middle Fork John Day (MFJD) averaged more than 40% AE at the same time (significantly, p>0.05.)

The only other river effect that was detected was regarding the AE for *Margaratifera falcata* which had a significantly (p=0.015) higher AE by mussels taken from the North Fork John Day (NFJD) River (37.9%, n=62) than the MFJD River (25.1%, n=23.) This difference was strongest in the fall (p=0.0002), moderate but still significant (p=0.039) in the summer, and not significant in the spring (p>0.05). Since temperatures were similar between the MFJD and NFJD rivers in each experiment, these river effects on *M. falcata* AE likely resulted from the differences in seston quality since the seston organic content was much lower in the MFJD (46%) than NFJD in fall (76%,) somewhat lower in the summer (64% vs 77%, respectively) and not significantly different in the spring (55% in both rivers). Similarly, the much lower AE for *Anodonta* sp. living in the Umatilla (<10% in March and August 2006) may also have resulted from the significantly lower seston organic content there (<50%) compared with that in the MFJD (75%) at the same time which was absorbed by *Anodonta* sp. with >40% efficiency.

4.2 ***Net Absorption Rates***

Net absorption rates (NAR's) for dietary carbon are calculated by multiplying carbon filtration rates (mg C h^{-1} g^{-1} dry tissue) by the corresponding absorption efficiency (%) of the same animal. Assuming no pseudofeces were produced, which were not detected in any of these experiments, the calculated NAR represents the organic carbon that was extracted by digestive processes, absorbed across the gut lumen and available for intracellular processing. Absorbed material can be either excreted (typically a nitrogen loss in the form of ammonia and so little carbon is excreted, see Section 4.3), catabolized for energy (typically a carbon loss through respiration, see Section 4.4), or used for growth and reproduction. NAR therefore corresponds to the net carbon from dietary material that is filtered, digested and absorbed, and hence available for catabolic or anabolic processes important for maintenance and growth. Carbon is used as a unit of currency rather than bulk organic matter because the scope for growth calculation is determined from the energy (carbon) budget. In general, the carbon content is approximately equal to 50% of the particulate organic component of seston.

Table 21a summarizes how the net carbon absorption rate (NAR) varied with season, river and mussel species. All three main effects were significant as determined with a 3-way ANOVA. Seasonal variability in NAR (averaged for all species and sites) was characterized by highest values in summer (mean = 0.15 mg C h^{-1} g^{-1} DW; ±0.04; n=72), which were significantly greater (p=0.01) than in spring or fall (<0.05mg C h^{-1} g^{-1} DW). However, it is not appropriate to examine seasonal variation without discerning among rivers because river source elicited the strongest significant variation in NAR (p=0.0009). Indeed, the mean annual NAR for all mussels in the MFJD (0.21 mg C h^{-1} g^{-1} DW; ±0.03; n=121) was nearly double that for the NFJD (0.12 mg C h^{-1} g^{-1} DW; ±0.06; n=23) and the NAR for mussels from the Umatilla (n=11) was not significantly different from zero when averaged annually. This clearly supports the finding that food conditions in the Umatilla were suboptimal for sustaining unionid carbon balance. To further investigate the river effect, interactions from species were removed by contrasting NAR between Anodonta sp. from the MFJD and Umatilla (Fig. 56), showing that these differences transcended the period spring to summer.

Due to the strong river effects and weak season effects, interspecific variation in NAR was best determined by comparing NAR among species in the one river where they were found together, the MFJD (Fig. 57). In summer, *Anodonta* sp. had a significantly greater ($p=0.01$) NAR for carbon than the other two genera, but there were no significant differences among genera in spring and fall.

Table 21a. Net absorption rates (mg C h^{-1} g DTW^{-1}) of seston particulate organic carbon by three species of freshwater mussels in Unionid Mussel Physiology Experiments during 2005-2006. For each row, seasonal differences detected via multiple range analysis ($p<0.05$) are denoted with different letters.

Species and River	Spring			Summer			Fall		
	Mean	SE	N	Mean	SE	N	Mean	SE	n
Margaratifera falcata									
Middle Fork John Day River									
Net Absorption Rate of Organic Matter (mg C h^{-1} g^{-1})	**0.11** ^{ns}	0.07	20	**0.26** ^{ns}	0.06	28	**0.29** ^{ns}	0.08	14
North Fork John Day River									
Net Absorption Rate of Organic Matter (mg C h^{-1} g^{-1})	**0.09** ^{ns}	0.04	11	**0.19** ^{ns}	0.05	6	**0.02** ^{ns}	0.05	6
***Gonidea* sp.**									
Middle Fork John Day River									
Net Absorption Rate of Organic Matter (mg C h^{-1} g^{-1})	**0.09** ^{ns}	0.05	6	**0.17** ^{ns}	0.04	12	**0.06** ^{ns}	0.05	7
***Anodonta* sp.**									
Middle Fork John Day River									
Net Absorption Rate of Organic Matter (mg C h^{-1} g^{-1})	**0.23** ^{ns}	0.11	11	**0.49** ^{ns}	0.09	16	**0.20** ^{ns}	0.13	7
Umatilla River									
Net Absorption Rate of Organic Matter (mg C h^{-1} g^{-1})	**0.04**	na	1	**0.07**	0.02	10	**nd**	nd	0

SE = standard error; n = sample size

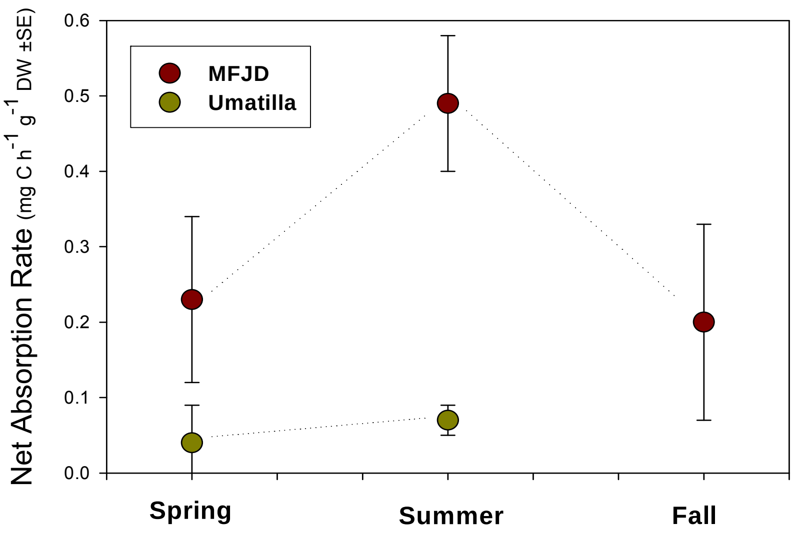

Figure 56*. Net carbon absorption rate of seston by* Anodonta sp. *from the Middle Fork John Day River and the Umatilla River during different seasons, averaged over 2005-2006.*

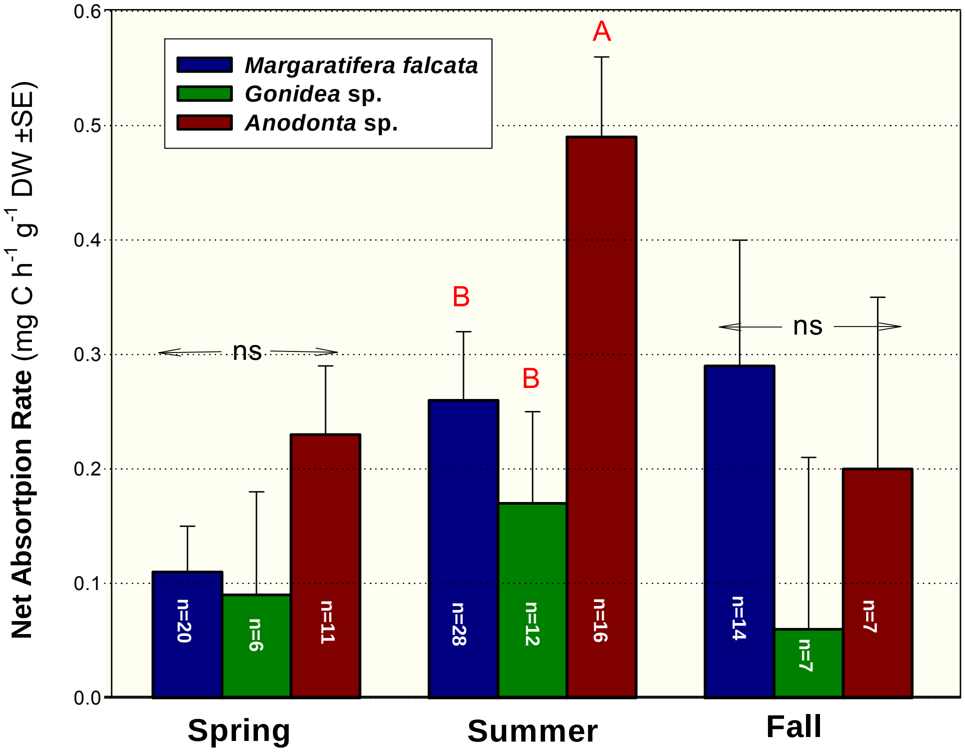

Figure 57*. Average net carbon absorption rate of seston by* Margaratifera falcata, Gonidea sp. and Anodonta sp. *from the Middle Fork John Day River during different seasons in 2005-2006. For each season, significant differences among species are denoted by different letters above bars as determined by multiple range analysis. ns=not significant (p>0.05.)*

5) Mussel Excretion

Excretion rates of ammonia represent energetic losses associated with routine metabolism and are generally higher at times when protein is being used as an energy source in addition to biosynthesis. Table 22 summarizes how ammonia excretion varied with season, river and mussel species. In a 3-way ANOVA comparing main effects of species, season and river, no significant river effect ($p>0.05$) was detected, whereas species ($p=0.012$) and season ($p<0.0001$) were significantly different in ammonia excretion rates.

Table 22. Ammonium-nitrogen excretion rates (μg-at NH_4-N h^{-1} g^{-1}) by three species of freshwater mussels in Unionid Mussel Physiology Experiments during 2005-2006. For each row, seasonal differences detected via multiple range analysis ($p<0.05$) are denoted with different letters.

Species and River	**Spring**			**Summer**			**Fall**		
	Mean	SE	N	Mean	SE	N	Mean	SE	n
Margaratifera falcata									
Middle Fork John Day River									
NH4-N Excretion Rate (μg-at N h^{-1} g^{-1})	**32.5** ^{B}	17.8	22	**86.3** ^{AB}	20.9	16	**108.0** ^{A}	23.2	13
North Fork John Day River									
NH4-N Excretion Rate (μg-at N h^{-1} g^{-1})	**19.8** ^{B}	8.9	15	**85.5** ^{A}	14.0	6	**48.4** ^{AB}	13.0	7
***Gonidea* sp.**									
Middle Fork John Day River									
NH4-N Excretion Rate (μg-at N h^{-1} g^{-1})	**4.9** ^{C}	8.4	3	**80.6** ^{A}	5.5	7	**53.7** ^{B}	5.5	7
***Anodonta* sp.**									
Middle Fork John Day River									
NH4-N Excretion Rate (μg-at N h^{-1} g^{-1})	**54.1** ^{B}	16.7	14	**131.6** ^{A}	17.4	13	**123.1** ^{A}	23.7	7
Umatilla River									
NH4-N Excretion Rate (μg-at N h^{-1} g^{-1})	**74.8**	na	2	**-**	-	-	**-**	-	-

SE = standard error; n = sample size

Seasonal variability in ammonia excretion was characterized by highest values in summer (mean

= 96.6 µg-at NH_4-N h^{-1} g^{-1} DW; ±10.2; n=42), which were not significantly different ($p>0.05$) from fall (mean = 89.5 µg-at NH_4-N h^{-1} g^{-1} DW; ±11.3; n=34). Significantly lower ($p<0.05$) ammonia excretion rates were recorded over all species in spring (mean = 30.4 µg-at NH_4-N h^{-1} g^{-1} DW; ±9.9; n=56).

Interspecific variation in ammonia excretion was less pronounced but significant ($p<0.05$) across all seasons and rivers. Highest average ammonia excretion rates were recorded for *Anodonta* sp. (mean = 103.0 µg-at NH_4-N h^{-1} g^{-1} DW; ±10.7; n=36), which were significantly greater than for both *Margaratifera falcatus* (mean = 67.2 µg-at NH_4-N h^{-1} g^{-1} DW; ±7.3; n=79) and *Gonidea* (mean = 46.3 µg-at NH_4-N h^{-1} g^{-1} DW; ±15.5; n=17), which were not significantly different.

The relative effects of season and species did not significantly interact, following a similar interspecific pattern in every season (Fig. 58). However, when analyzed by one-way ANOVAs per season, the interspecific differences were found not to be significant in the fall (Fig. 58).

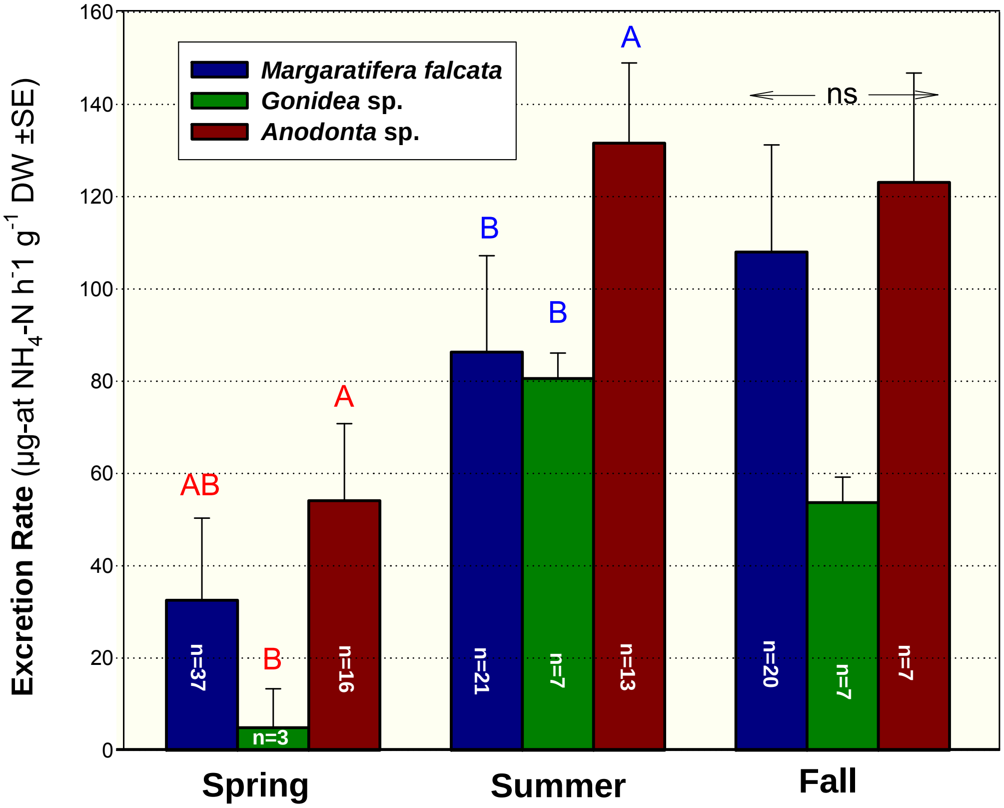

Figure 58*. Average excretion rate of ammonium-nitrogen by* Margaratifera falcata*,* Gonidea sp. and Anodonta sp. *from the Middle Fork John Day River during different seasons in 2005-2006. For each season, significant differences among species are denoted by different letters above bars as determined by multiple range analysis. ns=not significant (p>0.05.)*

6) Mussel Respiration

Respiration was assessed by measuring the oxygen consumption rates of freshwater mussels from the various rivers. Oxygen consumption was only assessed during the three seasons in 2005 and no Umatilla River animals (2006) are therefore included in this analysis. Due to the difficulty of measuring respiration, levels of replication were lower than for other physiological rate functions. Respiration rate measurements also tend to be more variable among individuals than rates for feeding, defecation and ammonia excretion.

Nevertheless, significant seasonal differences ($p<0.05$) were detected when oxygen consumption rates were compared using a 3-way ANOVA with main effects of season, species and river. Mean oxygen consumption rates were significantly lower in early spring (5.2 ml O_2 h^{-1} g^{-1} DW; ±13.4; n=15) than during summer (39.4 ml O_2 h^{-1} g^{-1} DW; ±10.5; n=33) or fall (39.9 ml O_2 h^{-1} g^{-1} DW; ±11.8; n=20).

Table 23. Oxygen consumption rates (ml O_2 h^{-1} g^{-1}) by three species of freshwater mussels in Unionid Mussel Physiology Experiments during 2005. For each row, seasonal differences detected via multiple range analysis ($p<0.05$) are denoted with different letters.

Species and River	**Spring**			**Summer**			**Fall**		
	Mean	SE	N	Mean	SE	N	Mean	SE	n
Margaratifera falcata									
Middle Fork John Day River									
Oxygen Consumption Rate (ml O_2 h^{-1} g^{-1})	**11.3** ^{ns}	23.7	6	**38.7** ^{ns}	16.7	12	**67.9** ^{ns}	21.9	7
North Fork John Day River									
Oxygen Consumption Rate (ml O_2 h^{-1} g^{-1})	**10.5** ^{ns}	22.4	5	**56.4** ^{ns}	25.1	4	**15.0** ^{ns}	22.4	5
***Gonidea* sp.**									
Middle Fork John Day River									
Oxygen Consumption Rate (ml O_2 h^{-1} g^{-1})	**7.1** ^{ns}	-	1	**38.0** ^{ns}	7.9	6	**30.0** ^{ns}	9.7	4
***Anodonta* sp.**									
Middle Fork John Day River									
Oxygen Consumption Rate (ml O_2 h^{-1} g^{-1})	**8.5** ^{ns}	17.2	3	**53.3** ^{ns}	9.0	11	**52.4** ^{ns}	14.9	4

SE = standard error; n = sample size

When examined per species, seasonal variability was not significant (Table 23, 1-way ANOVAs, p>0.05) due to high variability and low replication. There was no significant interspecific difference in oxygen consumption rates analyzed within each season (Fig. 59, 1-way ANOVAs, P>0.05). Oxygen consumption rates therefore appeared to be more uniform per dry tissue mass among species and rivers, but seasonally variable likely because of changing water temperatures.

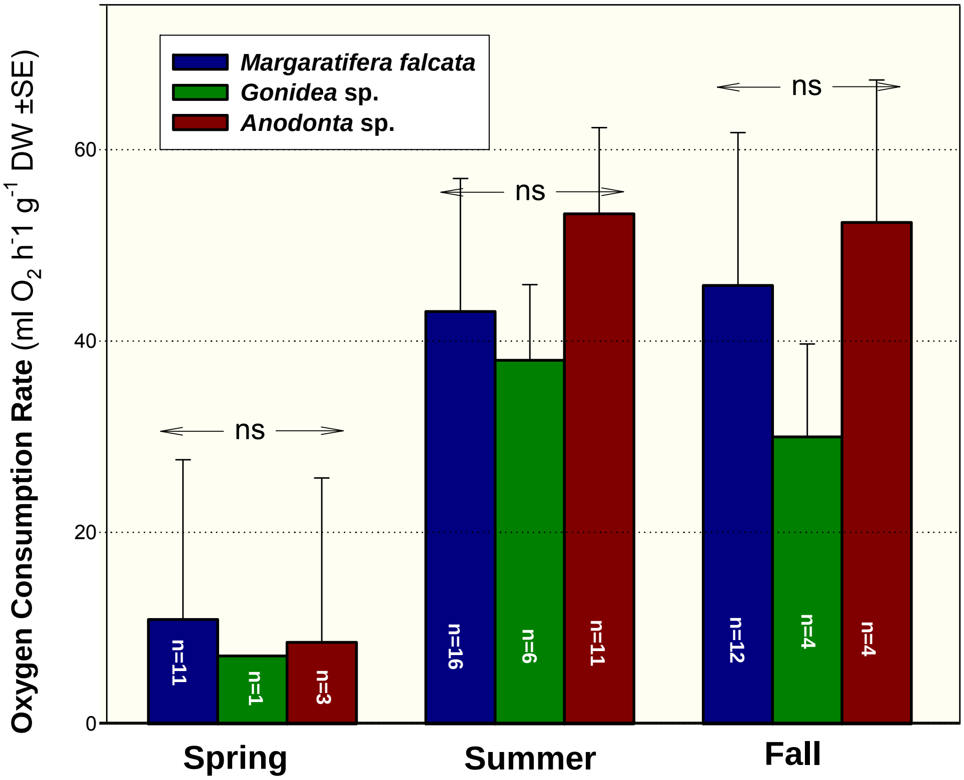

Figure 59*. Average oxygen consumption rate by* Margaratifera falcata*,* Gonidea sp. and Anodonta sp. *from various rivers during different seasons in 2005. For each season, significant differences among species are denoted by different letters above bars as determined by multiple range analysis. ns=not significant (p>0.05.)*

7) O:N Ratios

Ratios of oxygen consumption to ammonia excretion (O:N ratios) are useful indicators of protein balance in suspension-feeding bivalves (Kreeger and Langdon 1994), with low values <15 typically reflecting metabolic use of dietary protein for general catabolic needs and high values >20 typically reflecting protein conservation (“protein sparing”). No published data exist for O:N ratios in freshwater mussels, however data for marine species of bivalves has suggested that O:N ratios can vary seasonally in relation to changing nutritional demands or food conditions associated with reproductive cycling (Kreeger 1993).

Interestingly, O:N ratios measured for the three species of freshwater mussels in this study did not vary significantly (3-way ANOVA, p>0.05) among species, rivers, or seasons. However, all mean values were greater than 30 (Table 24), suggesting that dietary protein was being conserved from catabolism at all times in rivers of eastern Oregon. This could result from reliance on a natural diet consisting of riverine detritus dominated by leaf litter in the Middle

Table 24. Ratios of oxygen consumption rates (µg-at O_2-O h^{-1} g^{-1}) to ammonium-nitrogen excretion rates (µg-at NH_4-N h^{-1} g^{-1}) by three species of freshwater mussels in Unionid Mussel Physiology Experiments during 2005. For each row, seasonal differences detected via multiple range analysis ($p<0.05$) are denoted with different letters.

Species and River	**Spring**			**Summer**			**Fall**		
	Mean	SE	N	Mean	SE	N	Mean	SE	n
Margaratifera falcata									
Middle Fork John Day River									
O:N Ratio (gram atomic)	**40.8** ^{ns}	12.3	6	**37.7** ^{ns}	8.7	12	**37.3** ^{ns}	12.3	6
North Fork John Day River									
O:N Ratio (gram atomic)	**59.8** ^{ns}	26.9	3	**53.6** ^{ns}	20.8	4	**20.8** ^{ns}	20.9	5
***Gonidea* sp.**									
Middle Fork John Day River									
O:N Ratio (gram atomic)	**45.6** ^{ns}	-	1	**30.4** ^{ns}	6.8	6	**38.5** ^{ns}	8.3	4
***Anodonta* sp.**									
Middle Fork John Day River									
O:N Ratio (gram atomic)	**43.8** ^{ns}	13.8	3	**24.5** ^{ns}	7.2	11	**40.7** ^{ns}	12.0	4

SE = standard error; n = sample size

Fork and North Fork John Day Rivers where these measurements were undertaken (no respiration rates were measured in 2006 when the Umatilla treatments were included).

Although not significantly different seasonally for any species (1-way ANOVAs, Table 24), it was notable that spring O:N ratios were always the highest of the seasonal means and always >40. This finding would be consistent with marine mussels which typically have higher O:N ratios during spring when protein demands are higher due to the biosynthesis needs associated with gametogenesis (Kreeger 1993, Kreeger et al. 1995).

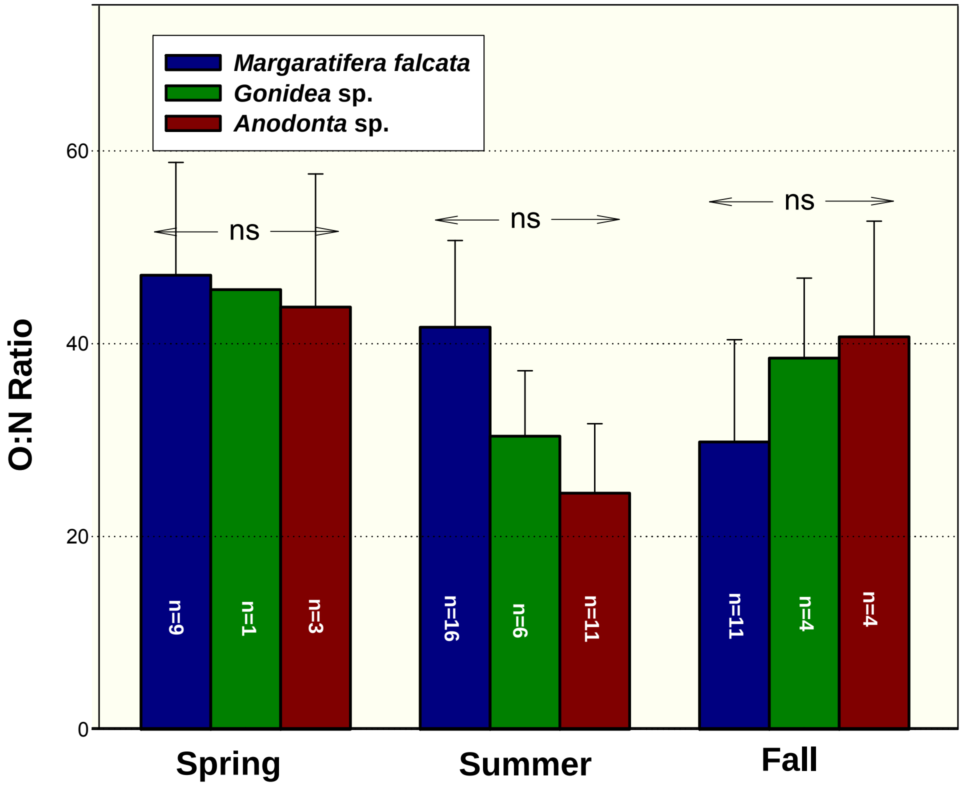

Figure 59*. Average O:N ratio for* Margaratifera falcata*,* Gonidea sp. and Anodonta sp. *during different seasons in 2005. For each season, significant differences among species are denoted by different letters above bars as determined by multiple range analysis. ns=not significant (p>0.05.)*

8) Scope-for-Growth

The energy budget was constructed for each freshwater mussel for which all parameters were measured: consumption rate (C), defecation rate (F), respiration rate (R), and excretion rate (E). Since respiration rates were not recorded in 2006 experiments, the energy budget was therefore examined only during spring (late March), summer (June) and fall (October) in 2005.

As noted in the methods, consumption (C) was assumed equivalent to the ingestion rate since no pseudofeces were observed to be produced. Ingestion of particulate organic matter (POM) was calculated by multiplying the filtration rate (L h^{-1} g^{-1} DW, calculated with allometric scaling for body size) by the concentration of POM in the dietary seston (mg POM L^{-1}), which was obtained from the rivers where the mussels were collected. The standard convention of 50% carbon content in natural particulate organic matter and 19.43 Joules of energy per milligram carbon was then used to calculate consumption rate as Joules h^{-1} g^{-1} dry tissue weight of mussel.

$$C\ (J\ h^{-1}\ g^{-1}\ DW) = FR\ (L\ h^{-1}\ g^{-1}\ DW) \times POM\ (mg\ L^{-1}) \times 0.5\ (mg\ C\ mg^{-1}\ POM) \times 19.43\ J\ mg^{-1}\ C$$

Defecation (F) was determined indirectly as the difference between C and net absorption rate (NAR), which was calculated by multiplying C by the measured absorption efficiency (AE, %) (see above):

$$F\ (J\ h^{-1}\ g^{-1}\ DW) = C\ (J\ h^{-1}\ g^{-1}\ DW) - [\ C\ (J\ h^{-1}\ g^{-1}\ DW) \times AE\ (\%)\ ]$$

Respiration (R) was measured directly as oxygen consumption rate (ml O_2 h^{-1} g^{-1} DW), scaled for allometric body size variability, and then multiplied by a standard oxycaloric conversion factor of 19.43 Joules per ml O_2 consumed (Brett 1985).

$$R\ (J\ h^{-1}\ g^{-1}\ DW) = \text{Oxygen consumption}\ (ml\ O_2\ h^{-1}\ g^{-1}\ DW) \times 19.43\ J\ ml^{-1}\ O_2$$

Similarly, excretion (E) was measured directly as ammonia excretion rate (µg N h^{-1} g^{-1} DW), scaled for allometric body size variability, and then multiplied by a standard oxycaloric conversion factor of 24.87 Joules per mg N excreted (Elliot and Davidson, 1975).

$$E\ (J\ h^{-1}\ g^{-1}\ DW) = \text{Ammonia-N excretion}\ (mg\ NH_4\text{-}N\ h^{-1}\ g^{-1}\ DW) \times 24.87\ J\ mg^{-1}\ N$$

The scope for growth (SFG) was then estimated as the net energy remaining for growth and reproduction after all loss terms were accounted for:

$$SFG\ (J\ h^{-1}\ g^{-1}\ DW) = C - (F + R + E)$$

The energy budgets were able to be fully constructed for 60 freshwater mussels, as summarized in Table 25. Note that for some individuals, the net energy available for growth and reproduction (scope for growth, also called production rate) was negative. This suggests that at the time the experiment was conducted, the maintenance energy demands for those animals exceeded the net energy absorption rate from use of dietary material. Bivalve mollusks have the capability of sequestering energy stores as a seasonal strategy for sustaining maintenance metabolism during times when feeding activity is reduced such as in winter or during disturbance events. In this study, four animals had a negative SFG in March, one in June, and four in October; therefore, this likely reflects the seasonality of energy balance as well as the normal variability associated with energetic studies. It also cannot be ruled out that handling stress could have affected the physiological activity of a few animals despite every attempt to reproduce natural food, water and temperature conditions in the laboratory.

Table 25. Energy budgets for 60 freshwater mussels representing three species from the Middle Fork and North Fork John Day Rivers of eastern Oregon measured during three seasons in 2005. C=consumption rate, NAR = net absorption rate, R = respiration rate, E = excretion rate, F = defecation rate, and SFG = scope for growth (a.k.a. production rate).

Date	Experiment Name[1]	Mussel ID	Mussel Species	River	Shell Length (mm)	Dry Tissue Weight (g)	**Energy Budget Component** (Joules h^{-1} mg^{-1} Dry Tissue Weight)					
							C	NAR	R	E	F	SFG
3/23/05	UMP 1	F-9	*Margaratifera falcata*	John Day, Middle Fork, Fishing Hole	45.48	0.54273	24.11	2.14	0.01	0.02	21.98	**2.11**
3/23/05	UMP 1	N48	*Margaratifera falcata*	John Day, Middle Fork, Fishing Hole	61.8	0.93755	6.16	0.38	0.14	0.02	5.78	**0.22**
3/23/05	UMP 1	ALS-83	*Margaratifera falcata*	John Day, Middle Fork, Fishing Hole	75.47	1.22456	3.38	0.24	0.05	0.01	3.14	**0.19**
3/23/05	UMP 1	F-5	*Anodonta sp.*	John Day, Middle Fork, Fishing Hole	39.5	0.35918	23.23	2.50	0.13	0.02	20.73	**2.35**
3/23/05	UMP 1	N61	*Anodonta sp.*	John Day, Middle Fork, Fishing Hole	48.05	0.4999	19.54	2.11	0.08	0.02	17.42	**2.01**
3/23/05	UMP 1	N72	*Anodonta sp.*	John Day, Middle Fork, Fishing Hole	55.99	0.66466	1.92	0.19	0.28	0.02	1.72	**-0.10**
3/23/05	UMP 1	N37	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	72.84	1.29061	8.11	0.98	0.14	0.01	7.13	**0.83**
3/23/05	UMP 2	N57	*Margaratifera falcata*	John Day, Middle Fork, Fishing Hole	46.26	0.43267	4.06	0.15	0.67	0.03	3.91	**-0.54**
3/23/05	UMP 2	N16	*Margaratifera falcata*	John Day, Middle Fork, Fishing Hole	74.13	1.25969	14.04	1.14	0.11	0.02	12.89	**1.01**
3/23/05	UMP 2	N35	*Margaratifera falcata*	John Day, Middle Fork, Fishing Hole	59.02	0.81548	9.10	0.83	0.34	0.03	8.28	**0.46**
3/23/05	UMP 2	N69	*Margaratifera falcata*	John Day, North Fork	60.35	0.92344	4.13	0.04	0.11	0.01	4.09	**-0.08**
3/23/05	UMP 2	F-4	*Margaratifera falcata*	John Day, North Fork	53.33	0.63278	27.94	1.14	0.43	0.02	26.80	**0.68**
3/23/05	UMP 2	ALS-94	*Margaratifera falcata*	John Day, North Fork	89.02	1.70435	1.27	0.06	0.07	0.01	1.21	**-0.03**
6/22/05	UMP 3	1003	*Margaratifera falcata*	John Day, Middle Fork, Fishing Hole	44.88	0.47205	15.03	8.13	0.83	0.13	6.90	**7.17**
6/22/05	UMP 3	1004	*Margaratifera falcata*	John Day, Middle Fork, Fishing Hole	52.05	0.58172	5.60	3.00	0.21	0.09	2.60	**2.70**
6/22/05	UMP 3	1006	*Margaratifera falcata*	John Day, Middle Fork, Fishing Hole	69.22	1.23568	2.67	1.50	0.58	0.09	1.17	**0.83**
6/22/05	UMP 3	1007	*Margaratifera falcata*	John Day, Middle Fork, Fishing Hole	71.26	1.3446	2.36	1.30	0.63	0.09	1.07	**0.57**
6/22/05	UMP 3	1008	*Anodonta sp.*	John Day, Middle Fork, Fishing Hole	33.41	0.13307	34.20	18.76	0.50	0.27	15.44	**17.99**
6/22/05	UMP 3	1010	*Anodonta sp.*	John Day, Middle Fork, Fishing Hole	37.72	0.22439	14.94	8.36	1.33	0.20	6.58	**6.83**
6/22/05	UMP 3	1012	*Anodonta sp.*	John Day, Middle Fork, Fishing Hole	47.93	0.40515	3.12	1.77	0.92	0.17	1.35	**0.67**
6/22/05	UMP 3	1013	*Anodonta sp.*	John Day, Middle Fork, Fishing Hole	49.39	0.44121	7.45	4.03	1.08	0.14	3.42	**2.81**
6/22/05	UMP 3	1014	*Anodonta sp.*	John Day, Middle Fork, Fishing Hole	49.61	0.41578	10.00	5.65	1.04	0.18	4.35	**4.44**
6/22/05	UMP 3	1015	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	47.62	0.50267	5.22	2.85	1.04	0.11	2.37	**1.70**
6/22/05	UMP 3	1017	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	57.65	0.82887	3.29	1.82	1.10	0.13	1.47	**0.59**
6/22/05	UMP 3	1018	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	65.39	0.9625	2.70	1.44	1.19	0.09	1.27	**0.16**
6/22/05	UMP 3	1019	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	67.73	1.22225	0.85	0.46	0.30	0.12	0.39	**0.04**
6/22/05	UMP 3	1021	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	79.29	2.18877	1.33	0.75	0.10	0.09	0.58	**0.56**
6/22/05	UMP 4	1049	*Margaratifera falcata*	John Day, Middle Fork, Fishing Hole	60.3	0.86587	8.64	4.59	0.65	0.08	4.05	**3.85**
6/22/05	UMP 4	1050	*Margaratifera falcata*	John Day Middle Fork, Wildcat Point	68.87	1.10356	1.96	1.05	0.52	0.08	0.91	**0.45**
6/22/05	UMP 4	1051	*Margaratifera falcata*	John Day Middle Fork, Wildcat Point	71.95	1.43865	1.98	1.06	0.78	0.07	0.92	**0.22**
6/22/05	UMP 4	1052	*Margaratifera falcata*	John Day Middle Fork, Wildcat Point	80.39	1.74088	1.55	0.84	0.56	0.07	0.70	**0.21**
6/22/05	UMP 4	1053	*Anodonta sp.*	John Day Middle Fork, Wildcat Point	47.72	0.32988	10.72	5.87	1.82	0.19	4.85	**3.86**
6/22/05	UMP 4	1054	*Anodonta sp.*	John Day Middle Fork, Wildcat Point	50.27	0.56417	1.12	0.62	0.48	0.17	0.49	**-0.03**
6/22/05	UMP 4	1056	*Margaratifera falcata*	John Day Middle Fork, Big Boulder Crk	37.14	0.24683	15.74	8.23	1.39	0.15	7.51	**6.69**
6/22/05	UMP 4	1057	*Margaratifera falcata*	John Day Middle Fork, Big Boulder Crk	54.18	0.62431	4.53	2.35	1.92	0.06	2.18	**0.36**
6/22/05	UMP 4	1058	*Margaratifera falcata*	John Day Middle Fork, Big Boulder Crk	68.2	1.32746	4.07	2.14	0.36	0.07	1.92	**1.71**
6/22/05	UMP 4	1060	*Margaratifera falcata*	John Day Middle Fork, Big Boulder Crk	99.14	0.86658	5.94	3.13	0.57	0.26	2.81	**2.30**
6/22/05	UMP 4	1061	*Anodonta sp.*	John Day Middle Fork Ritter Hot Springs	35.65	0.15057	13.30	7.30	2.01	0.33	6.01	**4.96**
6/22/05	UMP 4	1062	*Anodonta sp.*	John Day Middle Fork Ritter Hot Springs	48.9	0.81901	3.59	1.62	0.17	0.09	1.97	**1.37**
6/22/05	UMP 4	1064	*Margaratifera falcata*	John Day, North Fork	36.99	0.22541	18.95	8.48	0.11	0.25	10.46	**8.13**
6/22/05	UMP 4	1066	*Margaratifera falcata*	John Day, North Fork	63.65	2.85904	2.93	0.99	0.30	0.03	1.94	**0.66**
6/22/05	UMP 4	1068	*Margaratifera falcata*	John Day, North Fork	80.74	1.65206	5.53	1.91	0.11	0.07	3.63	**1.72**
6/22/05	UMP 4	1069	*Margaratifera falcata*	John Day, North Fork	83.83	1.67677	5.48	1.98	3.87	0.10	3.50	**-1.99**
10/9/05	UMP 5	2985	*Margaratifera falcata*	John Day, Middle Fork, Fishing Hole	53.96	0.65858	9.56	5.53	1.12	0.12	4.03	**4.30**
10/9/05	UMP 5	2989	*Margaratifera falcata*	John Day, Middle Fork, Fishing Hole	85.28	2.44109	1.05	0.64	0.37	0.07	0.40	**0.20**
10/9/05	UMP 5	2990	*Anodonta sp.*	John Day, Middle Fork, Fishing Hole	36.24	0.21233	10.67	6.42	1.15	0.25	4.26	**5.01**
10/9/05	UMP 5	2992	*Anodonta sp.*	John Day, Middle Fork, Fishing Hole	39.92	0.2734	6.92	4.15	0.23	0.13	2.77	**3.79**
10/9/05	UMP 5	2995	*Anodonta sp.*	John Day, Middle Fork, Fishing Hole	47.95	0.50312	2.97	1.77	1.50	0.07	1.20	**0.20**
10/9/05	UMP 5	2996	*Anodonta sp.*	John Day, Middle Fork, Fishing Hole	48.51	0.56753	4.66	2.89	1.19	0.15	1.77	**1.55**
10/9/05	UMP 5	2999	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	57.31	0.94179	1.90	1.14	0.63	0.08	0.76	**0.43**
10/9/05	UMP 5	3000	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	60.89	1.06627	1.76	1.09	0.78	0.09	0.68	**0.22**
10/9/05	UMP 5	693	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	73.03	1.63361	1.51	0.93	0.61	0.06	0.58	**0.26**
10/9/05	UMP 5	694	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	77.39	2.6579	0.87	0.52	0.31	0.05	0.36	**0.16**
10/9/05	UMP 5	697	*Margaratifera falcata*	John Day Middle Fork, Big Boulder Crk	65.34	1.06697	3.20	0.98	0.28	0.04	2.22	**0.66**
10/9/05	UMP 5	700	*Margaratifera falcata*	John Day Middle Fork, Big Boulder Crk	70.05	1.1414	4.22	1.23	0.77	0.06	2.99	**0.40**
10/9/05	UMP 5	702	*Margaratifera falcata*	John Day Middle Fork, Big Boulder Crk	78.7	1.66825	1.89	0.57	0.35	0.04	1.32	**0.18**
10/9/05	UMP 5	703	*Margaratifera falcata*	John Day, North Fork	60.61	0.9109	3.34	0.57	0.20	0.07	2.77	**0.30**
10/9/05	UMP 5	705	*Margaratifera falcata*	John Day, North Fork	67.28	1.20233	3.42	0.54	0.49	0.07	2.88	**-0.02**
10/9/05	UMP 5	706	*Margaratifera falcata*	John Day, North Fork	74.09	1.48121	1.37	0.22	0.41	0.07	1.16	**-0.26**
10/9/05	UMP 5	709	*Margaratifera falcata*	John Day, North Fork	93.87	2.99965	0.45	0.07	0.21	0.06	0.38	**-0.20**

A three-way ANOVA comparing main effects of species, river and season on scope for growth suggested that river (NFJD versus MFJD for *Margaratifera falcatus*) was not a significant factor. However, scope for growth did vary significantly among species and seasons, as evident in Figure 60. Not surprisingly, scope for growth was much greater during summer (2.63 J h^{-1} g^{-1} DW; ±0.53, n=30) than during spring (0.67 J h^{-1} g^{-1} DW; ±0.81, n=13) or fall (1.12 J h^{-1} g^{-1} DW; ±0.68, n=17) ($p<0.05$). This tended to correlate with temperature, 5°C in early spring, 21°C in summer, and 11°C in fall.

Interspecific differences in scope for growth were even more notable ($p=0.0008$) when assessed in a 2-way ANOVA (river effect removed). Indeed, the mean annual scope for growth for ten *Gonidea* sp. was significantly lowest, averaging 0.50 J h^{-1} g^{-1} DW (±0.88, n=10), which was much lower than the mean of 1.33 J h^{-1} g^{-1} DW (±0.48, n=34) for *Margaratifera falcatus*, which was significantly higher ($p<0.05$) than for *Gonidea* sp. The scope for growth for *Anodonta* sp. averaged 3.61 J h^{-1} g^{-1} DW (±0.70, n=16), which was significantly greater ($p<0.05$) than for *M. falcatus*.

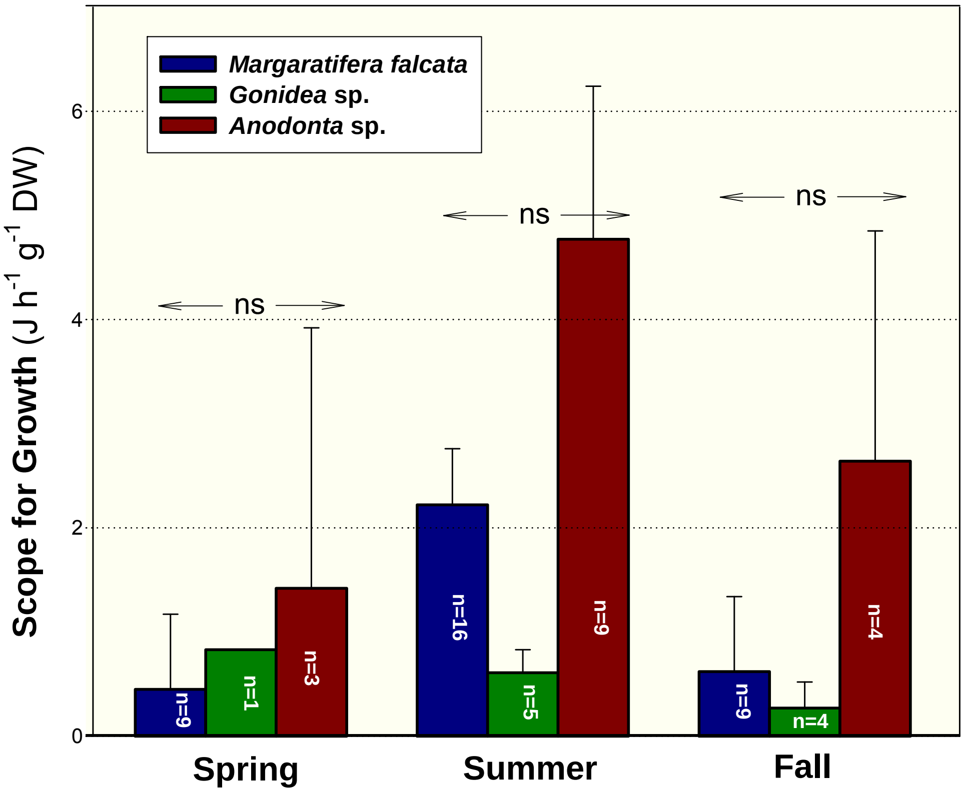

Figure 60*. Scope for Growth for* Margaratifera falcata, Gonidea sp. and Anodonta sp. *during different seasons in 2005. For each season, significant differences among species were tested with multiple range analysis and ns=not significant (p>0.05.)*

The seasonal energy budgets for *Margaratifera falcatus*, *Gonidea* sp. and *Anodonta* sp. are summarized in Figures 61 to 63. These stacked bar plots clearly show that the three species of mussels followed similar seasonal strategies for overall energy balance by taking up more dietary material in the spring with lower consumption in the summer and still lower in the fall. The bulk of consumed material was defecated in all cases, however. The proportion of ingested food that was defecated was far greater in the spring (averaging about 90%), and therefore the net scope for growth was proportionally lower as a result. The spring strategy is best characterized as "quantity over quality" whereby mussels were feeding at higher rates but digesting, absorbing and assimilating lower amounts of the ingested ration. The percentage of consumed energy that was available for growth was only 4, 10 and 10% in the spring for *M. falcatus, Gonidea* sp. *and Anodonta* sp., respectively.

In contrast, in summer and fall all three mussel species absorbed approximately 50% and defecated approximately 50% of the consumed ration, resulting in much greater net scope for growth. The percentage of consumed energy that was available for growth was 34, 23 and 44% in the summer for *M. falcatus, Gonidea* sp. *and Anodonta* sp., respectively. In the fall, it was 19, 18 and 42%, respectively.

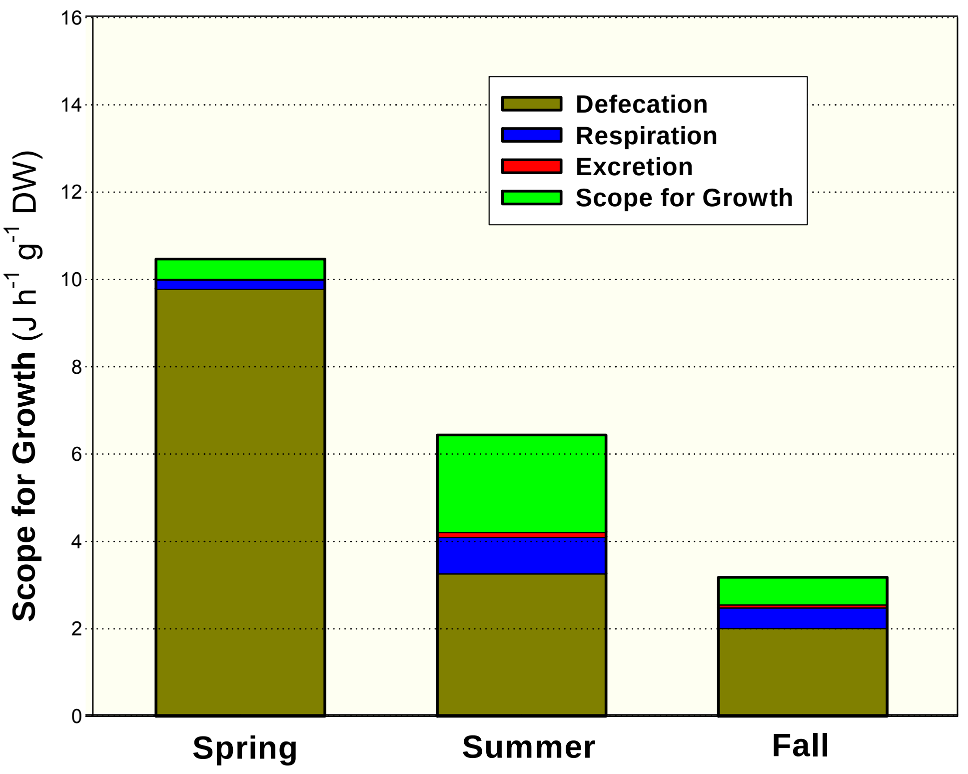

Figure 61. *Energy budget for* Margaratifera falcatus *summarized by season during 2005.*

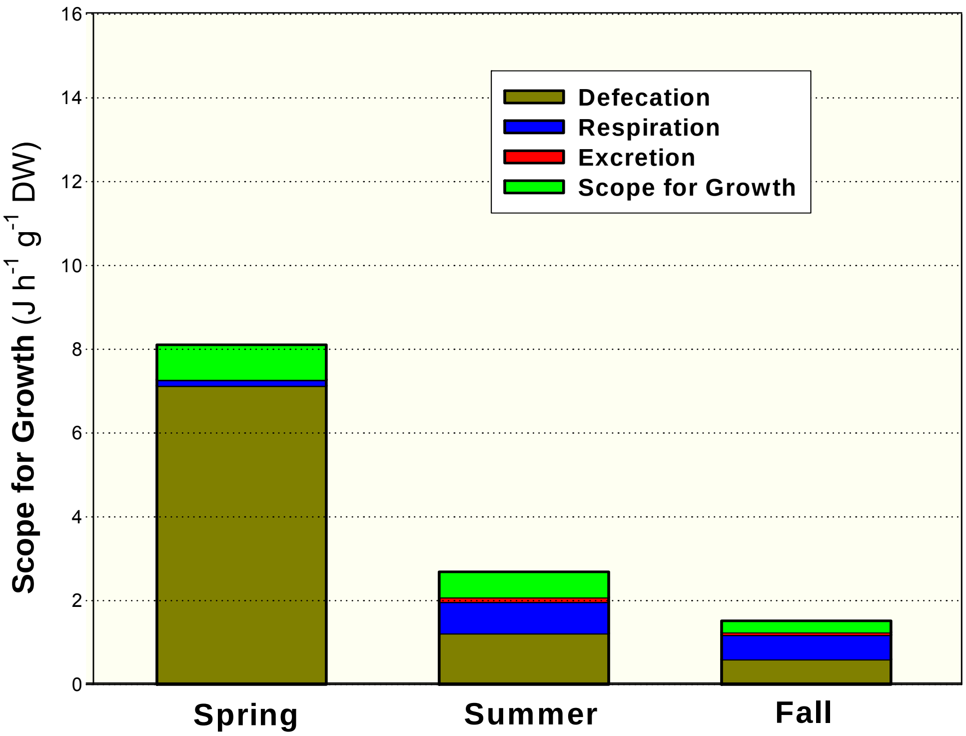

Figure 62. *Energy budget for* Gonidea *sp. summarized by season during 2005.*

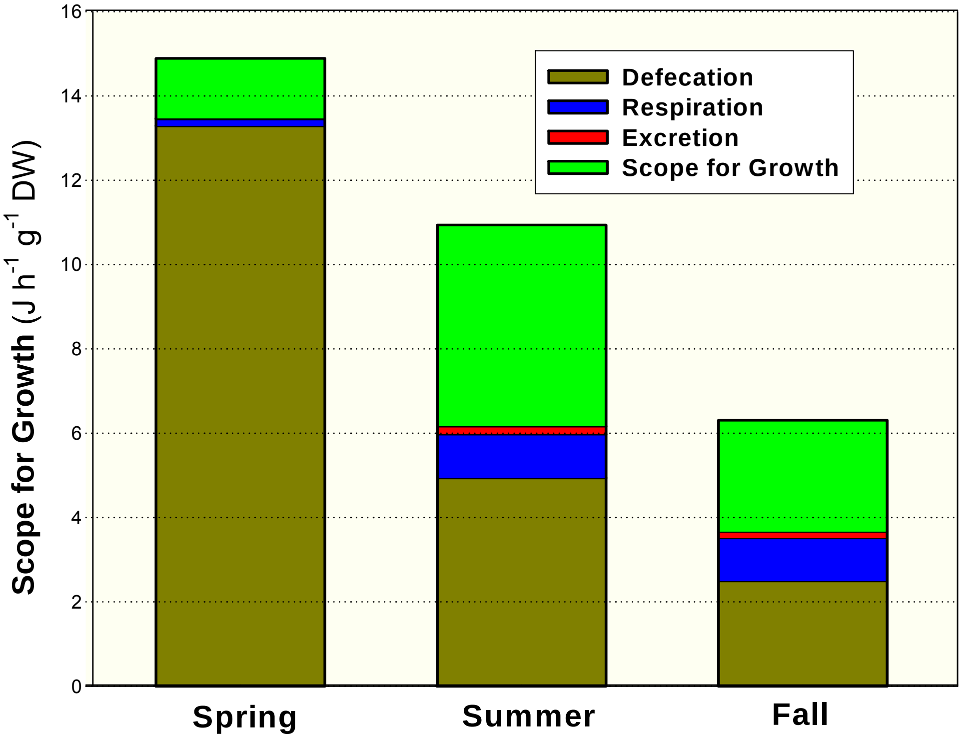

Figure 63. *Energy budget for* Anodonta *sp. summarized by season during 2005.*

Interspecific differences were largely defined by the greater overall rates of energy uptake and utilization by *Anodonta* sp. per unit dry tissue weight (note height of y-axis in Fig. 63 compared to Figs, 61-62). Although physiological rate functions measured in this study were normalized to body size (dry tissue weight) using allometric adjustments for a standard sized mussel, each allometric adjustment was undertaken separately for each species. It is possible that the generally smaller body sizes of *Anodonta* sp. (0.41 g dry tissue weight for 16 mussels with complete energy budgets), moderate sizes of *M. falcatus* (1.19 g DTW for 34 mussels) and slightly larger sizes of *Gonidea* sp. (1.33 g DTW for 10 mussels) contributed to the interspecific variation in overall energy processing per unit weight, as shown in Figs. 61-63.

Multiplication of weight-specific energy consumption rates by the mean dry tissue weights leads to an estimate of energy consumption per mussel. Averaged annually, these “per mussel” consumption rates were 5.4, 3.1 and 3.3 J per hour per mussel for *M. falcatus, Gonidea* sp. and *Anodonta* sp, respectively (not significantly different, ANOVA, $p>0.05$). These values might be useful as a simple proxy for assessing the total energy balance of a natural bed of adult mussels in the field, if the density of mussels per reach is known. However, if the size class distribution can be determined as well, then it would be more scientifically sound to estimate the dry tissue weight of the mussels and compare to weight-specific rate functions reported in this report rather than “per mussel”.

CONCLUSIONS

Physiological rate functions for freshwater mussels (Family Unionidae) have rarely been described in the literature. While several authors have reported clearance rates for mussels, in most instances these data were collected in laboratory settings with unnatural algal diets. In nature, mussels must derive their nutrition from a diverse suite of natural microparticulate material that is likely to rarely be in balance with their nutritional demands for specific biochemicals and nutrients. Since the costs of feeding and digestion account for a major part of the animal’s energy budget, it is important for mussels to optimize their feeding rates, digestive enzyme production, and other maintenance processing to allow for maximal growth and reproduction. To best understand how environmental and dietary factors in nature affect the ability of mussels to meet their nutritional demands, it is therefore important to quantify not only their feeding rates but their physiological processing and net production rates under natural conditions. Since physiological rate functions in nature vary widely with changing conditions and among rivers having different water and food qualities, these physiological rate data are also critical for estimating the ecosystem functions of mussel populations in rivers.

Data collected in this study represent the most complete set of physiological rate functions ever measured for freshwater mussels, and since the measurements were taken under simulated natural conditions (natural seston as food, ambient temperature, etc.) they will be invaluable in estimating the functional role of mussels in the studied rivers. Feeding, absorption, defecation, excretion and respiration rates were measured during spring, summer and fall. Three species of native mussels from different rivers were contrasted, allowing the relative main effects of species, river and season to be discerned. The natural food was also carefully characterized for particle abundance, particle size distribution, and organic content.

Weight-specific clearance rates of *M. falcata, Gonidea* sp. and *Anodonta* sp. varied primarily with season and body size rather than river or species. Most physiological rate functions of bivalve molluscs typically respond to temperature and food conditions, which both vary with season in the Pacific Northwest. It was not surprising therefore that all three species had greater clearance rates in summer (20-22^{o}C) than in early spring (4-9 ^{o}C) or fall (10-15 ^{o}C). Since experiments were performed under mainly base flow conditions, food conditions were characterized generally by low food quantity and moderate to high food quality, which meant that seasonal differences in clearance were likely associated mainly with temperature rather than nutritional challenges.

Upon first analyzing the clearance data, it appeared that weight-specific clearance rates also varied significantly among both rivers and species. However, weight-specific clearance rates decreased for larger-sized mussels which were more prevalent in those rivers and species where clearance rates were lower (and vice versa.) Hence, when the analyses were repeated for similar size classes of freshwater mussels, no differences were found in mean clearance rates among either rivers or species. Therefore, weight-specific clearance rates for *M. falcata, Gonidea* sp. and *Anodonta* sp. can be reasonably predicted simply by knowing the season (i.e. temperature and seston) and body size. “Pound for pound,” the different species did not differ across the study region. This important result will simplify future mass balance estimates of the total clearance by whole mussel populations in rivers of eastern Oregon, suggesting that the most important information will be the size class distribution and abundance of all the mussels present, regardless of species or river.

The seasonal pattern in feeding rate activity was characterized by lower clearance rates in early spring for all three species, compared with summer or fall (Figs. 37, 39, 41). Floaters, *Anodonta* sp., tended to have higher average physiological rates per body size than *Margaratifera falcatus* or *Gonidea* sp., which were similar (Figs. 42-44), and this interspecific difference was significant when averaged across the year (Fig. 45). Despite being normalized to body size, the higher weight-specific rate functions for *Anodonta* sp. might still be a consequence of their smaller overall body sizes for adults (Section 3.2.6 and 8). Despite these differences, all three species filtered water within a general range of 0.2 to 1.0 liter per hour per gram dry tissue weight throughout the spring to fall period. This is typical for bivalves to have a reasonably consistent clearance rate across a range of varying conditions, since the energy costs associated with particle capture are much smaller than the costs associated with digesting and processing ingested (as indicated by the absorption efficiency, Section 4.1.6).

Seston concentrations averaged between 1 and 5 mg per liter, tending to be higher during spring. When clearance rates were compared to seston concentrations, again, mussels performed similarly in the different rivers, seasons, and among species (Table 18). Typically, 1-3 mg of seston were filtered per hour per mussel. Therefore, a small bed of 1000 mussels of mixed species would generally be expected to remove about 2 kg of dry suspended matter per year. These results indicate that the functional importance of freshwater mussels in streams and rivers is not necessarily dependent on which species is present. Pound for pound, they generally filtered water at similar rates. However, much more work is needed to actually quantify filtration in situ due to the complexity of natural systems and the differential selection of different particle sizes by mussels. For example, preliminary comparisons of particle size distributions above and below a mussel bed in the North Fork John Day indicated that larger particles are removed and smaller particles may be enriched downstream as a result of passing over the mussel bed (Fig. 12).

From an organismal perspective, the digestive processing varied widely among seasons and somewhat also among species, suggesting that niche separation may be important in terms of post-ingestion processing of filtered material. In early spring, there was slightly more abundant seston matter but the quality was poor in comparison to summer and fall (Fig. 18). As a consequence, the absorption efficiency of mussels was much lower in spring (Fig. 53). Not surprisingly, absorption efficiency was inversely correlated with food quantity (Fig. 55) and positively correlated with food quality (Fig. 54). When feeding rates, absorption efficiencies and food conditions were integrated, the net carbon absorption rate was found to vary between 0.1 to 0.5 mg per hour per gram dry tissue weight (Fig 57).

In comparison to the limited literature on feeding rates of freshwater mussels, the feeding and absorption rates measured in this study are perhaps a bit lower. This may simply reflect the use of natural diets in this study compared to published studies which typically measure physiological rates of lab cultured algal diets which can be more nutritious. Absorption efficiencies for natural seston are almost always lower than for high quality algal feeds under controlled conditions. In this study, the high O:N ratios (Fig. 59) suggest that diets were highly refractory in relation to the animal’s amino-nitrogen or protein demands. Indeed, the low rates for ammonia excretion suggest that mussels were probably carefully conserving protein and nitrogen balance at all times of the year, perhaps indicating that freshwater mussels in eastern Oregon are nutritionally limited by protein rather than energy per se. In marine species, mussels can be protein-limited leading to high O:N ratios, but that usually only happens during periods of high biosynthesis such as in rapidly growing juvenile life stages (Kreeger and Langdon 1993) or during gametogenesis (Kreeger 1993, Kreeger et al. 1995). It would be interesting to compare O:N ratios of Oregon mussels that are fed on high protein lab algae versus natural seston.

Accounting for energy losses in feces, ammonia excretion and via respiration, the net energy available for growth and reproduction (scope for growth) was assessed, perhaps for the first time ever for freshwater mussels. The scope for growth was highly variable, which is typical because its calculation leads to the additive error from diverse metrics. Nevertheless, significant patterns were statistically evident in this net production term (Fig. 60). Importantly, for all species and seasons, scope for growth was positive, indicating that growing conditions in the North Fork and Middle Fork John Day Rivers was sufficient to lead to positive growth and reproduction (the Umatilla mussels were not assessed for SFG). Floaters, *Anodonta* sp. had significantly greater overall scope for growth than other species, particularly during fall. Summer, the peak of the growing season, clearly supported the best scope for growth overall, despite the fact that much more dietary material was ingested in spring (Figs. 61-63). Again, these data clearly show that feeding rates are less important than absorption efficiencies and the minimization of energy losses post-ingestion. Although animals filtered more material in spring, about 90% of it was defecated, whereas in summer and fall about half was absorbed.

Interestingly, smaller sized Anodonta sp. had a lower overall condition index than the other two mussel species (Fig. 32). Condition, which is a measure of meat fatness within the shell cavity, was generally lower in summer during peak growing season. This is typical for bivalves in temperature climates because they tend to sequester carbohydrate reserves in fall as energy stores for overwintering, and by summer those stores are depleted and growth is being maximized. These findings confirm that mussels in eastern Oregon follow a similar seasonal pattern.

Differences between rivers were contrasted by comparing physiological rates of *M. falcatus* between the North Fork John Day versus the Middle Fork John Day (2005-2006), and also by comparing rates of *Anodonta* sp. between the Middle Fork John Day and Umatilla Rivers (only in 2006). The North Fork John Day tended to be colder, which likely explained some minor differences in clearance rates (Table 14). This was also suggested because clearance rates for mussels taken from a higher elevation, colder portion of the Middle Fork John Day (Big Boulder) were lower than for mussels from the main study bed (Fishing Creek) (Table 14.)

In contrast to the comparison between the North and Middle Forks of the John Day, important differences were found in the apparent fitness and physiological rate functions for mussels living in the Umatilla River. Comparing adult *Anodonta* sp., clearance rates were significantly lower during the one sampling time when a rigorous analysis was completed, August 2006 (Table 16). Seston quantity was significantly higher (Fig. 34) and seston quality was significantly lower (Fig. 17) in the Umatilla compared with the John Day rivers. These two factors (reduced feeding, poorer food quality) led to a very low absorption efficiency (<10%, Table 21, Fig. 51) and net absorption rates (Table 21a, Fig 56) in the Umatilla compared to *Anodonta* sp. in the John Day system. In addition, energetic losses via ammonia excretion appeared to be higher in Umatilla mussels in the one seasonal experiments where they were compared (March 2006, Table 22). These findings, although preliminary because the Umatilla mussels were only discovered and included during 2006 experiments, suggest that the microparticulate food conditions in lower Umatilla River (near Hermiston) are suboptimal for freshwater mussels, resulting in very low absorbable rations. More studies are warranted to measure actual scope for growth in mussels from the Umatilla and to undertake reciprocal transplant studies along the river's course to determine if restoration efforts would be sustainable. In addition, two morphological variants of *Anodonta* sp. exist in the lower Umatilla River (possibly *A. californianus* and *A. oregonensis*), and their physiological rate functions should be further contrasted (sample sizes were too small for statistical differentiation in this study).

Taken together, these findings indicate that in healthy rivers of eastern Oregon (e.g., John Day system) the physiological rate functions are reasonably comparable among *M. falcatus, Gonidea* sp., and *Anodonta* sp. There were some interspecific differences in seasonal strategies for optimizing energy balance with *Anodonta* sp. tending to have more of the energy budget available for growth and later in the year than *M. falcatus* and *Gonidea* sp. However, these interspecific differences were small in comparison to seasonal variation in energy balance for all mussel species. In spring, higher feeding rates were offset by a higher fecal loss term and lower food quality, whereas in summer and fall mussel capitalized on higher food quality by absorbing a higher proportion of ingested matter and turning a larger portion of absorbed matter into positive growth. Although data are preliminary, these patterns appeared to be largely negated in the Umatilla River where high seston quantity and low quality interfered with summer absorption rates in mussels.

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APPENDIX A

Appendix A. Complete set of body size data for freshwater mussels collected from Oregon rivers during 2005-2006.

Date Sampled	Experiment	Sample ID	Mussel Species	River	Site Name	Total Wet Weight (g)	Shell Length (mm)	Dry Shell Weight (mm)	Dry Tissue Weight (g)	Ash-Free Dry Tissue Weight (g)	Height: Weight Ratio	Condition Index	Tissue Organic Content (%)
3/23/05	UMP 1	F-1	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	4.0	37.1	1.69	0.243	-	152.6	105.1	-
3/23/05	UMP 1	F-9	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	8.0	45.5	2.76	0.543	-	83.8	103.6	-
3/23/05	UMP 1	N67	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	8.0	47.7	3.29	0.384	-	124.1	81.6	-
3/23/05	UMP 1	N48	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	20.0	61.8	8.89	0.938	0.827	65.9	84.4	88.23
3/23/05	UMP 1	N62	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	18.0	64.3	8.48	0.807	-	79.7	84.8	-
3/23/05	UMP 1	ALS-83	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	32.0	75.5	13.40	1.225	-	61.6	65.8	-
3/23/05	UMP 1	N44	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	2.0	30.6	0.85	0.072	0.063	423.7	62.8	87.74
3/23/05	UMP 1	N56	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	6.0	38.8	1.78	0.311	0.281	124.5	73.7	90.34
3/23/05	UMP 1	F-5	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	8.0	39.5	2.37	0.359	-	110.0	63.8	-
3/23/05	UMP 1	N60	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	8.0	43.6	2.14	0.345	0.309	126.5	58.8	89.68
3/23/05	UMP 1	F-6	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	10.0	44.1	2.41	0.454	-	97.1	59.8	-
3/23/05	UMP 1	F-3	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	10.0	48.1	3.21	0.515	-	93.5	75.8	-
3/23/05	UMP 1	N61	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	10.0	48.1	3.41	0.500	0.448	96.1	75.9	89.67
3/23/05	UMP 1	F-7	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	12.0	50.4	3.79	0.475	-	106.2	57.8	-
3/23/05	UMP 1	N72	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	16.0	56.0	4.91	0.665	-	84.2	60.0	-
3/23/05	UMP 1	N37	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	22.0	72.8	7.00	1.291	-	56.4	86.1	-
3/23/05	UMP 2	N57	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	8.0	46.3	3.11	0.433	-	106.9	88.4	-
3/23/05	UMP 2	N16	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	38.0	74.1	16.73	1.260	-	58.8	59.2	-
3/23/05	UMP 2	N35	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	18.0	59.0	7.27	0.815	0.701	72.4	76.0	86.02
3/23/05	UMP 2	N68	*Margaratifera falcata*	John Day North Fork	Mussel bed	20.0	65.3	9.30	1.069	0.937	61.0	99.9	87.64
3/23/05	UMP 2	N69	*Margaratifera falcata*	John Day North Fork	Mussel bed	18.0	60.4	7.73	0.923	0.816	65.4	89.9	88.32
3/23/05	UMP 2	N46	*Margaratifera falcata*	John Day North Fork	Mussel bed	24.0	67.4	9.78	1.224	1.072	55.1	86.1	87.56
3/23/05	UMP 2	F-4	*Margaratifera falcata*	John Day North Fork	Mussel bed	12.0	53.3	5.11	0.633	-	84.3	91.8	-
3/23/05	UMP 2	F-8	*Margaratifera falcata*	John Day North Fork	Mussel bed	26.0	69.9	9.05	1.271	-	55.0	75.0	-
3/23/05	UMP 2	ALS-94	*Margaratifera falcata*	John Day North Fork	Mussel bed	56.0	89.0	25.34	1.704	-	52.2	55.6	-
3/23/05	UMP 2	N53	*Margaratifera falcata*	John Day North Fork	Mussel bed	44.0	83.9	20.40	1.927	1.625	43.5	81.7	84.33
3/23/05	UMP 2	N51	*Margaratifera falcata*	John Day North Fork	Mussel bed	32.0	73.1	15.36	1.327	1.170	55.1	79.7	88.16
3/23/05	UMP 2	N71	*Margaratifera falcata*	John Day North Fork	Mussel bed	18.0	61.0	6.40	0.773	0.683	78.9	66.6	88.42
3/23/05	extras	N19	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	10.0	45.0	2.77	0.501	-	89.9	69.3	-
3/23/05	extras	N55	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	8.0	41.9	2.44	0.329	-	127.6	59.1	-
6/22/05	UMP 3	1001	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	3.5	34.5	1.29	0.159	0.144	216.9	72.2	90.73
6/22/05	UMP 3	1002	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	4.4	37.0	1.57	0.248	0.224	149.1	89.0	90.56
6/22/05	UMP 3	1003	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	8.5	44.9	2.98	0.472	0.423	95.1	85.7	89.66
6/22/05	UMP 3	1004	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	12.3	52.1	4.59	0.582	0.525	89.5	75.2	90.19
6/22/05	UMP 3	1005	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	19.7	60.7	8.03	0.803	-	75.6	68.7	-
6/22/05	UMP 3	1006	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	31.6	69.2	13.66	1.236	1.096	56.0	69.0	88.66
6/22/05	UMP 3	1007	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	32.4	71.3	13.98	1.345	1.194	53.0	73.2	88.82
6/22/05	UMP 3	1008	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	3.5	33.4	0.90	0.133	0.116	251.1	52.2	86.91
6/22/05	UMP 3	1009	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	4.0	36.8	1.06	0.140	0.123	261.8	47.1	87.53
6/22/05	UMP 3	1010	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	5.9	37.7	1.55	0.224	0.193	168.1	52.2	86.21
6/22/05	UMP 3	1011	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	9.8	43.4	2.76	0.345	0.307	126.0	48.6	89.16
6/22/05	UMP 3	1012	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	11.4	47.9	2.92	0.405	0.358	118.3	48.0	88.32

Appendix A. Complete set of body size data for freshwater mussels collected from Oregon rivers during 2005-2006.

Date Sampled	Experiment	Sample ID	Mussel Species	River	Site Name	Total Wet Weight (g)	Shell Length (mm)	Dry Shell Weight (mm)	Dry Tissue Weight (g)	Ash-Free Dry Tissue Weight (g)	Height: Weight Ratio	Condition Index	Tissue Organic Content (%)
6/22/05	UMP 3	1013	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	14.0	49.4	3.99	0.441	0.374	111.9	43.9	84.78
6/22/05	UMP 3	1014	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	12.6	49.6	3.42	0.416	0.354	119.3	45.3	85.04
6/22/05	UMP 3	1015	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	9.5	47.6	2.61	0.503	0.453	94.7	73.2	90.16
6/22/05	UMP 3	1016	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	17.6	57.1	5.17	0.753	0.685	75.8	60.8	90.96
6/22/05	UMP 3	1017	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	14.5	57.7	4.39	0.829	0.762	69.6	82.2	91.91
6/22/05	UMP 3	1018	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	22.9	65.4	7.56	0.963	0.883	67.9	62.6	91.71
6/22/05	UMP 3	1019	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	24.5	67.7	7.20	1.222	1.067	55.4	70.5	87.31
6/22/05	UMP 3	1020	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	35.4	76.1	12.29	1.411	1.259	54.0	61.0	89.23
6/22/05	UMP 3	1021	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	49.3	79.3	17.79	2.189	1.921	36.2	69.5	87.74
6/22/05	UMP 4	1049	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	17.6	60.3	7.00	0.866	0.774	69.6	81.5	89.43
6/22/05	UMP 4	1050	*Margaratifera falcata*	John Day Middle Fork	Wildcat Point	27.7	68.9	13.05	1.104	0.978	62.4	75.1	88.60
6/22/05	UMP 4	1051	*Margaratifera falcata*	John Day Middle Fork	Wildcat Point	29.4	72.0	12.65	1.439	1.309	50.0	85.9	90.96
6/22/05	UMP 4	1052	*Margaratifera falcata*	John Day Middle Fork	Wildcat Point	39.2	80.4	16.36	1.741	1.558	46.2	76.3	89.48
6/22/05	UMP 4	1053	*Anodonta sp.*	John Day Middle Fork	Wildcat Point	10.1	47.7	2.44	0.330	0.293	144.7	43.1	88.93
6/22/05	UMP 4	1054	*Anodonta sp.*	John Day Middle Fork	Wildcat Point	14.6	50.3	3.47	0.564	0.460	89.1	50.6	81.58
6/22/05	UMP 4	1055	*Anodonta sp.*	John Day Middle Fork	Wildcat Point	16.4	53.8	4.81	0.511	0.460	105.2	44.0	90.01
6/22/05	UMP 4	1056	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	4.8	37.1	1.59	0.247	0.228	150.5	77.6	92.32
6/22/05	UMP 4	1057	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	14.4	54.2	5.94	0.624	0.555	86.8	73.9	88.86
6/22/05	UMP 4	1058	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	28.3	68.2	12.19	1.327	1.214	51.4	82.5	91.44
6/22/05	UMP 4	1059	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	53.9	86.2	24.24	2.587	2.354	33.3	87.3	91.00
6/22/05	UMP 4	1060	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	20.3	99.1	8.47	0.867	0.786	114.4	73.0	90.71
6/22/05	UMP 4	1061	*Anodonta sp.*	John Day Middle Fork	Ritter Hot Springs	5.1	35.7	1.51	0.151	0.133	236.8	42.3	88.45
6/22/05	UMP 4	1062	*Anodonta sp.*	John Day Middle Fork	Ritter Hot Springs	17.9	48.9	5.68	0.819	0.643	59.7	67.3	78.54
6/22/05	UMP 4	1063	*Anodonta sp.*	John Day Middle Fork	Ritter Hot Springs	12.9	59.9	2.99	0.365	0.320	164.1	36.8	87.64
6/22/05	UMP 4	1064	*Margaratifera falcata*	John Day North Fork	Mussel bed	4.2	37.0	1.60	0.225	0.204	164.1	86.4	90.58
6/22/05	UMP 4	1065	*Margaratifera falcata*	John Day North Fork	Mussel bed	10.0	50.8	4.12	0.452	0.421	112.3	77.2	93.14
6/22/05	UMP 4	1066 +1070	*Margaratifera falcata*	John Day North Fork	Mussel bed	83.0	63.7	40.50	2.859	2.407	22.3	67.3	84.18
6/22/05	UMP 4	1067	*Margaratifera falcata*	John Day North Fork	Mussel bed	32.3	73.5	14.42	1.191	1.042	61.8	66.6	87.56
6/22/05	UMP 4	1068	*Margaratifera falcata*	John Day North Fork	Mussel bed	47.1	80.7	23.52	1.652	1.426	48.9	70.0	86.33
6/22/05	UMP 4	1069	*Margaratifera falcata*	John Day North Fork	Mussel bed	55.6	83.8	24.29	1.677	1.324	50.0	53.6	78.97
6/22/05	extras	1022	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	11.6	49.3	3.23	0.416	0.381	118.4	49.9	91.59
6/22/05	extras	1023	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	4.5	36.0	1.43	0.146	0.133	246.1	48.3	90.55
6/22/05	extras	1024	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	11.7	47.7	3.01	0.435	0.372	109.8	50.0	85.61
6/22/05	extras	1025	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	9.6	50.1	2.87	0.509	0.468	98.4	75.3	91.97
6/22/05	extras	1026	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	24.5	65.6	6.87	1.220	1.077	53.7	69.2	88.28
6/22/05	extras	1027	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	23.2	65.8	6.88	1.087	0.990	60.6	66.4	91.10
6/22/05	extras	1028	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	24.5	62.1	8.31	1.056	0.949	58.7	65.2	89.86
6/22/05	extras	1029	*Anodonta sp.*	John Day Middle Fork	Ritter Hot Springs	11.0	45.9	2.89	0.331	0.275	138.7	41.0	83.03
6/22/05	extras	1030	*Anodonta sp.*	John Day Middle Fork	Ritter Hot Springs	6.3	37.1	1.67	0.248	0.215	149.4	54.0	86.83
6/22/05	extras	1031	*Anodonta sp.*	John Day Middle Fork	Ritter Hot Springs	6.7	40.7	1.59	0.247	0.207	164.9	48.3	83.84
6/22/05	extras	1032	*Anodonta sp.*	John Day Middle Fork	Ritter Hot Springs	8.2	43.2	2.25	0.295	0.258	146.1	50.1	87.19
6/22/05	extras	1033	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	8.9	46.2	4.13	0.517	0.478	89.4	109.2	92.38

Appendix A. Complete set of body size data for freshwater mussels collected from Oregon rivers during 2005-2006.

Date Sampled	Experiment	Sample ID	Mussel Species	River	Site Name	Total Wet Weight (g)	Shell Length (mm)	Dry Shell Weight (mm)	Dry Tissue Weight (g)	Ash-Free Dry Tissue Weight (g)	Height: Weight Ratio	Condition Index	Tissue Organic Content (%)
6/22/05	extras	1034	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	39.2	74.8	19.46	1.545	-	48.4	78.4	-
6/22/05	extras	1035	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	43.6	79.4	21.97	1.323	1.143	60.0	61.3	86.39
6/22/05	extras	1036	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	55.8	83.1	28.72	2.172	1.933	38.2	80.3	89.01
6/22/05	extras	1037	*Margaratifera falcata*	John Day North Fork	Mussel bed	6.8	43.9	2.71	0.344	0.309	127.6	83.9	89.75
6/22/05	extras	1038	*Margaratifera falcata*	John Day North Fork	Mussel bed	13.7	57.2	5.50	0.542	0.455	105.4	66.2	83.81
6/22/05	extras	1039	*Margaratifera falcata*	John Day North Fork	Mussel bed	15.5	60.5	7.04	0.671	0.597	90.2	79.6	89.02
6/22/05	extras	1040	*Margaratifera falcata*	John Day North Fork	Mussel bed	24.5	67.9	10.20	0.993	0.854	69.4	69.3	86.01
6/22/05	extras	1041	*Margaratifera falcata*	John Day North Fork	Mussel bed	17.4	61.2	7.52	0.779	0.678	78.5	79.0	86.97
6/22/05	extras	1042	*Margaratifera falcata*	John Day North Fork	Mussel bed	11.5	51.3	5.06	0.596	0.532	86.0	92.8	89.33
6/22/05	extras	1043	*Margaratifera falcata*	John Day North Fork	Mussel bed	20.0	63.9	9.59	0.847	0.760	75.5	81.7	89.77
6/22/05	extras	1044	*Margaratifera falcata*	John Day North Fork	Mussel bed	16.6	60.5	7.21	0.743	0.667	81.4	79.5	89.70
6/22/05	extras	1045	*Margaratifera falcata*	John Day North Fork	Mussel bed	35.9	78.5	14.49	1.404	1.168	55.9	65.6	83.21
6/22/05	extras	1046	*Margaratifera falcata*	John Day North Fork	Mussel bed	38.4	80.8	18.62	1.491	1.286	54.1	75.3	86.24
6/22/05	extras	1047	*Margaratifera falcata*	John Day North Fork	Mussel bed	37.1	77.6	18.07	1.445	1.233	53.7	76.0	85.32
6/22/05	extras	1048	*Margaratifera falcata*	John Day North Fork	Mussel bed	34.6	76.0	16.98	1.434	1.255	53.0	81.6	87.53
10/9/05	UMP 5	2983	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	1.2	24.3	0.46	0.059	-	410.8	77.1	-
10/9/05	UMP 5	2984	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	7.0	44.5	2.94	0.365	-	121.8	89.5	-
10/9/05	UMP 5	2985	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	12.8	54.0	4.98	0.659	-	81.9	84.1	-
10/9/05	UMP 5	2986	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	9.1	49.4	4.12	0.536	-	92.1	106.9	-
10/9/05	UMP 5	2987	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	20.1	62.4	8.89	0.907	-	68.8	80.6	-
10/9/05	UMP 5	2988	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	43.2	77.6	17.42	1.620	-	47.9	62.8	-
10/9/05	UMP 5	2989	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	50.4	85.3	23.32	2.441	-	34.9	90.2	-
10/9/05	UMP 5	2990	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	5.0	36.2	1.51	0.212	-	170.7	61.0	-
10/9/05	UMP 5	2991	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	5.6	37.5	1.68	0.203	-	184.4	52.5	-
10/9/05	UMP 5	2992	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	6.4	39.9	1.69	0.273	-	146.0	58.4	-
10/9/05	UMP 5	2993	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	7.6	41.8	2.31	0.298	-	140.6	56.0	-
10/9/05	UMP 5	2994	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	9.4	44.9	2.76	0.461	-	97.3	69.6	-
10/9/05	UMP 5	2995	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	10.9	48.0	3.55	0.503	-	95.3	68.6	-
10/9/05	UMP 5	2996	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	12.9	48.5	3.96	0.568	-	85.5	63.2	-
10/9/05	UMP 5	2997	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	7.8	44.7	2.61	0.439	-	101.9	84.4	-
10/9/05	UMP 5	2998	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	8.3	47.1	2.81	0.564	-	83.5	103.6	-
10/9/05	UMP 5	2999	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	15.7	57.3	4.92	0.942	-	60.9	87.5	-
10/9/05	UMP 5	3000	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	20.7	60.9	7.68	1.066	-	57.1	82.0	-
10/9/05	UMP 5	693	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	30.0	73.0	10.47	1.634	-	44.7	83.5	-
10/9/05	UMP 5	694	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	43.5	77.4	17.75	2.658	-	29.1	103.1	-
10/9/05	UMP 5	695	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	46.0	78.6	18.97	2.270	-	34.6	83.9	-
10/9/05	UMP 5	696	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	6.5	44.8	2.63	0.280	-	159.7	73.0	-
10/9/05	UMP 5	697	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	22.4	65.3	9.50	1.067	-	61.2	82.6	-
10/9/05	UMP 5	698	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	28.0	69.7	13.60	1.080	-	64.6	75.0	-
10/9/05	UMP 5	699	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	23.6	65.2	10.80	1.037	-	62.8	81.2	-
10/9/05	UMP 5	700	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	25.9	70.1	11.58	1.141	-	61.4	79.9	-
10/9/05	UMP 5	701	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	30.5	73.4	13.96	1.248	-	58.8	75.4	-

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Date Sampled	Experiment	Sample ID	Mussel Species	River	Site Name	Total Wet Weight (g)	Shell Length (mm)	Dry Shell Weight (mm)	Dry Tissue Weight (g)	Ash-Free Dry Tissue Weight (g)	Height: Weight Ratio	Condition Index	Tissue Organic Content (%)
10/9/05	UMP 5	702	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	37.2	78.7	17.78	1.668	-	47.2	86.0	-
10/9/05	UMP 5	703	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	18.8	60.6	8.19	0.911	-	66.5	86.3	-
10/9/05	UMP 5	704	*Margaratifera falcata*	John Day North Fork	Mussel bed	18.5	61.3	7.91	0.930	-	65.9	88.0	-
10/9/05	UMP 5	705	*Margaratifera falcata*	John Day North Fork	Mussel bed	29.4	67.3	14.12	1.202	-	56.0	78.8	-
10/9/05	UMP 5	706	*Margaratifera falcata*	John Day North Fork	Mussel bed	36.7	74.1	16.52	1.481	-	50.0	73.3	-
10/9/05	UMP 5	707	*Margaratifera falcata*	John Day North Fork	Mussel bed	43.9	79.9	22.47	1.765	-	45.3	82.2	-
10/9/05	UMP 5	708	*Margaratifera falcata*	John Day North Fork	Mussel bed	67.0	90.0	35.55	2.318	-	38.8	73.7	-
10/9/05	UMP 5	709	*Margaratifera falcata*	John Day North Fork	Mussel bed	69.3	93.9	35.36	3.000	-	31.3	88.3	-
3/20/06	UMP 6	997	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	30.2	69.8	14.22	0.980	0.790	71.2	61.3	80.58
3/20/06	UMP 6	955	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	33.0	71.6	15.33	1.368	1.169	52.3	77.6	85.42
3/20/06	UMP 6	956	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	31.8	71.7	14.46	1.180	0.983	60.7	68.2	83.34
3/20/06	UMP 6	957	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	37.5	72.7	16.63	1.610	1.417	45.1	77.2	88.00
3/20/06	UMP 6	958	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	42.9	76.4	18.59	1.813	1.651	42.1	74.6	91.08
3/20/06	UMP 6	959	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	46.4	83.3	22.36	1.971	1.734	42.3	81.8	88.01
3/20/06	UMP 6	960	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	51.5	83.4	23.96	1.884	1.597	44.3	68.5	84.79
3/20/06	UMP 6	962	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	5.1	39.8	2.06	0.252	0.231	157.9	81.9	91.80
3/20/06	UMP 6	963	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	7.3	44.8	2.89	0.424	0.376	105.7	96.3	88.83
3/20/06	UMP 6	964	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	10.4	79.8	4.59	0.524	0.473	152.1	89.9	90.29
3/20/06	UMP 6	965	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	11.8	52.5	4.88	0.492	0.422	106.7	71.6	85.79
3/20/06	UMP 6	967	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	23.6	66.3	9.66	1.037	0.920	63.9	74.3	88.65
3/20/06	UMP 6	968	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	26.1	68.7	10.57	1.356	1.210	50.6	87.2	89.24
3/20/06	UMP 6	969	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	24.9	67.0	10.81	1.051	0.943	63.7	74.8	89.73
3/20/06	UMP 6	970	*Margaratifera falcata*	John Day North Fork	Mussel bed	8.0	46.0	3.55	0.315	0.274	146.3	70.1	86.92
3/20/06	UMP 6	971	*Margaratifera falcata*	John Day North Fork	Mussel bed	15.6	58.2	6.17	0.688	0.622	84.6	73.1	90.34
3/20/06	UMP 6	972	*Margaratifera falcata*	John Day North Fork	Mussel bed	21.7	67.8	8.54	0.845	0.709	80.2	64.4	83.93
3/20/06	UMP 6	973	*Margaratifera falcata*	John Day North Fork	Mussel bed	27.3	70.7	11.73	1.171	1.036	60.3	75.4	88.45
3/20/06	UMP 6	974	*Margaratifera falcata*	John Day North Fork	Mussel bed	38.6	73.1	18.29	1.451	1.225	50.4	71.6	84.43
3/20/06	UMP 6	975	*Margaratifera falcata*	John Day North Fork	Mussel bed	38.0	80.2	15.04	1.669	1.399	48.1	72.6	83.79
3/20/06	UMP 6	976	*Margaratifera falcata*	John Day North Fork	Mussel bed	43.2	80.0	18.93	1.558	1.296	51.3	64.2	83.17
3/20/06	UMP 6	977	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	6.1	44.1	2.09	0.333	0.303	132.5	83.3	90.86
3/20/06	UMP 6	978	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	8.0	46.4	2.38	0.461	0.421	100.6	81.9	91.23
3/20/06	UMP 6	979	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	10.2	53.3	2.98	0.507	0.454	105.1	69.9	89.50
3/20/06	UMP 6	980	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	14.9	56.5	4.82	0.875	0.790	64.5	86.6	90.24
3/20/06	UMP 6	981	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	22.4	65.1	8.72	1.125	1.033	57.8	82.2	91.81
3/20/06	UMP 6	982	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	28.9	74.1	11.74	1.396	1.194	53.1	81.2	85.49
3/20/06	UMP 6	983	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	46.9	77.9	20.49	2.255	1.854	34.5	85.5	82.22
3/20/06	UMP 6	984	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	3.5	34.9	1.01	0.135	0.120	258.5	54.4	88.66
3/20/06	UMP 6	985	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	4.1	37.2	1.04	0.139	0.128	267.3	45.2	91.62
3/20/06	UMP 6	986	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	5.8	38.7	1.73	0.135	0.121	286.5	33.1	89.51
3/20/06	UMP 6	987	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	9.3	43.0	3.07	0.371	0.343	115.9	59.1	92.46
3/20/06	UMP 6	988	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	10.1	46.6	2.91	0.557	0.508	83.6	77.3	91.20
3/20/06	UMP 6	989	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	11.4	50.8	3.40	0.571	0.515	88.9	71.1	90.14

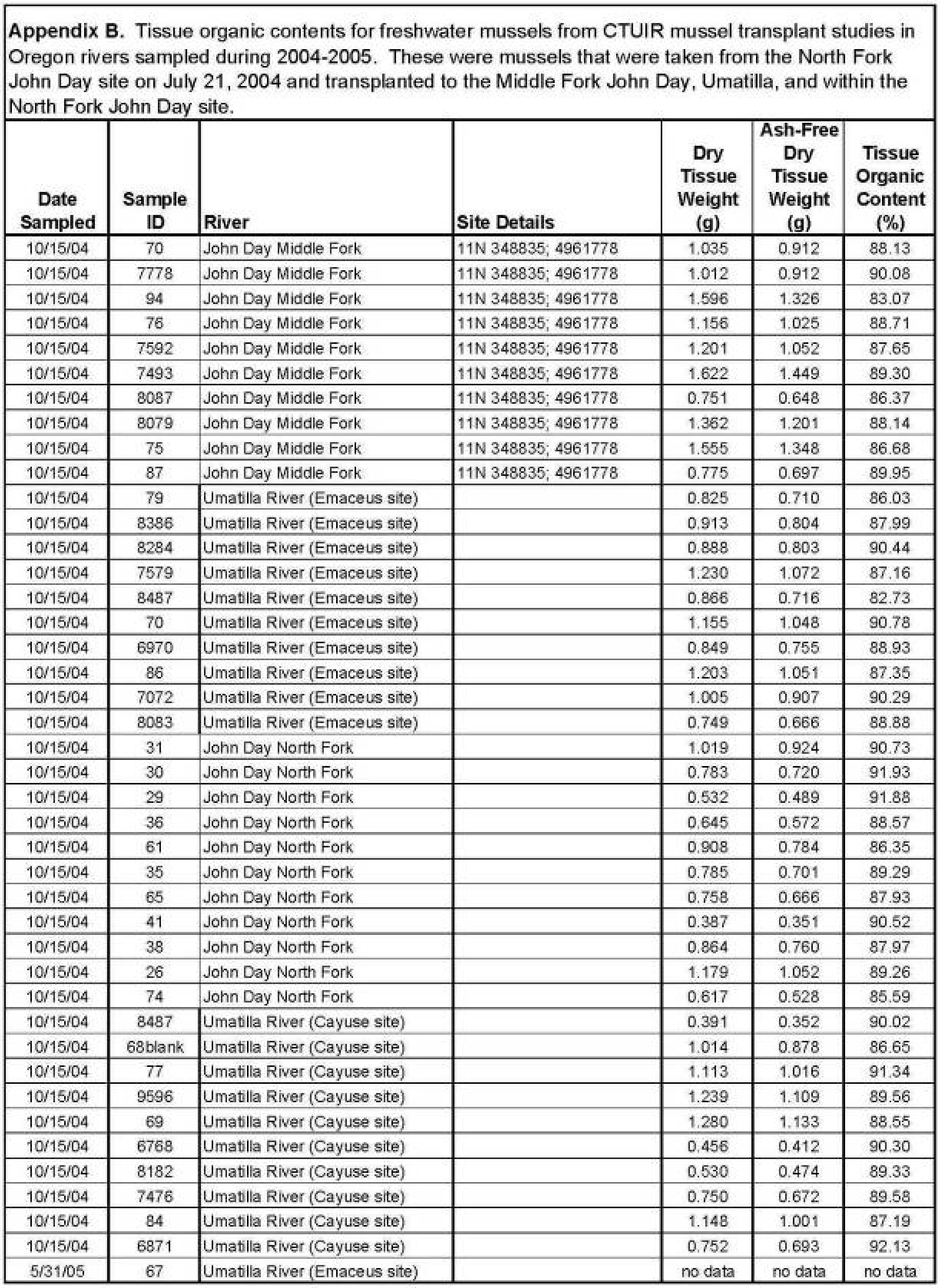
Appendix A. Complete set of body size data for freshwater mussels collected from Oregon rivers during 2005-2006.

Date Sampled	Experiment	Sample ID	Mussel Species	River	Site Name	Total Wet Weight (g)	Shell Length (mm)	Dry Shell Weight (mm)	Dry Tissue Weight (g)	Ash-Free Dry Tissue Weight (g)	Height: Weight Ratio	Condition Index	Tissue Organic Content (%)
3/20/06	UMP 6	992	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	12.3	50.5	3.92	0.459	0.406	110.2	55.0	88.57
3/20/06	UMP 6	993	*Anodonta oregonensis?*	Umatilla	Hermiston	12.5	56.1	3.48	0.696	0.496	80.6	77.1	71.24
3/20/06	UMP 6	994	*Anodonta oregonensis?*	Umatilla	Hermiston	40.7	85.1	12.89	1.590	1.004	53.6	57.1	63.18
3/20/06	UMP 6	995	*Anodonta oregonensis?*	Umatilla	Hermiston	55.3	92.1	16.92	2.051	1.292	44.9	53.4	63.01
3/20/06	UMP 6	996	*Anodonta californianus?*	Umatilla	Hermiston	29.1	67.8	8.41	0.816	0.661	83.1	39.4	81.03
8/24/06	UMP 7	1525	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	6.0	42.1	2.41	0.298	0.266	141.3	83.0	89.33
8/24/06	UMP 7	1526	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	7.8	46.1	3.05	0.332	0.304	138.9	70.5	91.42
8/24/06	UMP 7	1527	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	15.4	56.2	6.58	0.738	0.674	76.2	83.9	91.33
8/24/06	UMP 7	1528	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	20.9	63.3	9.05	0.958	0.840	66.1	80.9	87.72
8/24/06	UMP 7	1529	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	36.5	75.0	17.05	1.568	1.397	47.8	80.5	89.09
8/24/06	UMP 7	1530	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	84.7	95.4	42.74	2.018	-	47.3	48.1	-
8/24/06	UMP 7	1531	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	7.3	37.6	1.72	0.319	0.282	117.8	57.4	88.45
8/24/06	UMP 7	1532	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	5.7	41.7	2.33	0.331	0.290	126.2	96.9	87.71
8/24/06	UMP 7	1533	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	8.0	46.3	3.27	0.408	0.362	113.6	86.9	88.80
8/24/06	UMP 7	1534	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	14.9	56.3	7.18	0.693	0.606	81.1	89.4	87.37
8/24/06	UMP 7	1535	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	14.0	56.2	6.15	0.662	0.586	84.9	84.0	88.40
8/24/06	UMP 7	1536	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	40.5	79.2	20.86	1.528	1.287	51.9	77.9	84.22
8/24/06	UMP 7	1537	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	6.9	43.6	2.26	0.364	0.336	119.9	77.7	92.27
8/24/06	UMP 7	1538	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	16.1	56.7	4.49	0.971	0.724	58.4	83.4	74.56
8/24/06	UMP 7	1539	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	17.4	61.1	5.38	0.930	0.548	65.7	77.4	58.91
8/24/06	UMP 7	1540	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	26.1	66.9	8.85	1.425	-	46.9	82.6	-
8/24/06	UMP 7	1541	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	28.5	68.3	10.35	0.941	0.857	72.7	51.7	91.16
8/24/06	UMP 7	1542	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	48.9	82.4	20.36	2.468	2.219	33.4	86.3	89.91
8/24/06	UMP 7	1543	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	3.9	33.7	1.08	0.187	0.167	180.2	65.2	89.35
8/24/06	UMP 7	1544	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	5.4	38.2	1.46	0.237	0.213	161.1	59.6	89.80
8/24/06	UMP 7	1545	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	7.0	40.4	2.03	0.283	0.252	143.0	57.4	89.16
8/24/06	UMP 7	1546	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	9.0	43.7	2.49	0.490	0.433	89.2	74.9	88.36
8/24/06	UMP 7	1547	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	13.0	51.2	3.89	0.425	0.385	120.4	46.5	90.44
8/24/06	UMP 7	1548	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	13.9	50.2	3.77	0.527	0.481	95.2	52.1	91.35
8/24/06	UMP 7	1549	*Anodonta sp.*	Umatilla	Hermiston	17.6	63.0	4.93	0.635	0.582	99.3	50.1	91.74
8/24/06	UMP 7	1550	*Anodonta sp.*	Umatilla	Hermiston	25.0	66.0	7.52	1.055	0.946	62.6	60.5	89.66
8/24/06	UMP 7	1551	*Anodonta sp.*	Umatilla	Hermiston	29.2	73.4	9.64	1.031	-	71.1	52.9	-
8/24/06	UMP 7	1552	*Anodonta sp.*	Umatilla	Hermiston	38.6	80.7	11.53	1.398	1.230	57.7	51.6	87.97
8/24/06	UMP 7	1553	*Anodonta sp.*	Umatilla	Hermiston	36.2	79.2	11.72	1.492	1.284	53.1	61.0	86.10
8/24/06	UMP 7	1554	*Anodonta sp.*	Umatilla	Hermiston	44.4	83.4	12.55	1.429	0.846	58.4	44.9	59.19
8/24/06	UMP 7	1555	*Anodonta sp.*	Umatilla	Hermiston	49.4	85.6	15.53	1.653	1.320	51.8	48.8	79.85
8/24/06	UMP 7	1556	*Anodonta sp.*	Umatilla	Hermiston	53.6	86.7	6.60	1.921	1.630	45.1	40.8	84.86
8/24/06	UMP 7	1557	*Anodonta sp. (round, thin)*	Umatilla	Hermiston	13.3	51.9	3.77	0.542	0.472	95.8	56.6	87.09
8/24/06	UMP 7	1558	*Anodonta sp. (round, thin)*	Umatilla	Hermiston	25.5	65.2	17.11	0.793	-	82.2	94.7	-
8/24/06	extras	1559	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	13.7	49.7	3.76	0.639	0.562	77.8	64.3	87.96
8/24/06	extras	1560	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	11.4	47.9	2.75	0.472	0.428	101.5	54.4	90.82
8/24/06	extras	1561	*Anodonta sp.*	John Day Middle Fork	Fishing Hole - Site 3742	13.4	50.8	3.67	0.511	0.475	99.4	52.7	92.98

Appendix A. Complete set of body size data for freshwater mussels collected from Oregon rivers during 2005-2006.

Date Sampled	Experiment	Sample ID	Mussel Species	River	Site Name	Total Wet Weight (g)	Shell Length (mm)	Dry Shell Weight (mm)	Dry Tissue Weight (g)	Ash-Free Dry Tissue Weight (g)	Height: Weight Ratio	Condition Index	Tissue Organic Content (%)
8/24/06	extras	1562	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	17.6	57.6	5.40	0.699	0.652	82.3	57.5	93.25
8/24/06	extras	1563	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	6.9	43.5	2.64	0.358	0.315	121.8	84.4	88.06
8/24/06	extras	1564	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	23.1	63.0	10.92	1.120	1.012	56.2	91.7	90.34
8/24/06	extras	1685	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	25.8	65.3	11.57	1.005	0.865	64.9	70.4	86.03
8/24/06	extras	1686	*Anodonta sp. (long, green*	Umatilla	Hermiston	36.5	75.6	11.91	1.199	1.073	63.0	48.8	89.46
8/24/06	extras	1687	*Anodonta sp. (long, green*	Umatilla	Hermiston	45.9	82.1	16.20	1.403	-	58.5	47.2	-
8/24/06	extras	1688	*Anodonta sp. (long, green*	Umatilla	Hermiston	40.1	80.1	11.65	1.770	-	45.2	62.1	-

APPENDIX B



Appendix B. Tissue organic contents for freshwater mussels from CTUIR mussel transplant studies in Oregon rivers sampled during 2004-2005. These were mussels that were taken from the North Fork John Day site on July 21, 2004 and transplanted to the Middle Fork John Day, Umatilla, and within the North Fork John Day site.

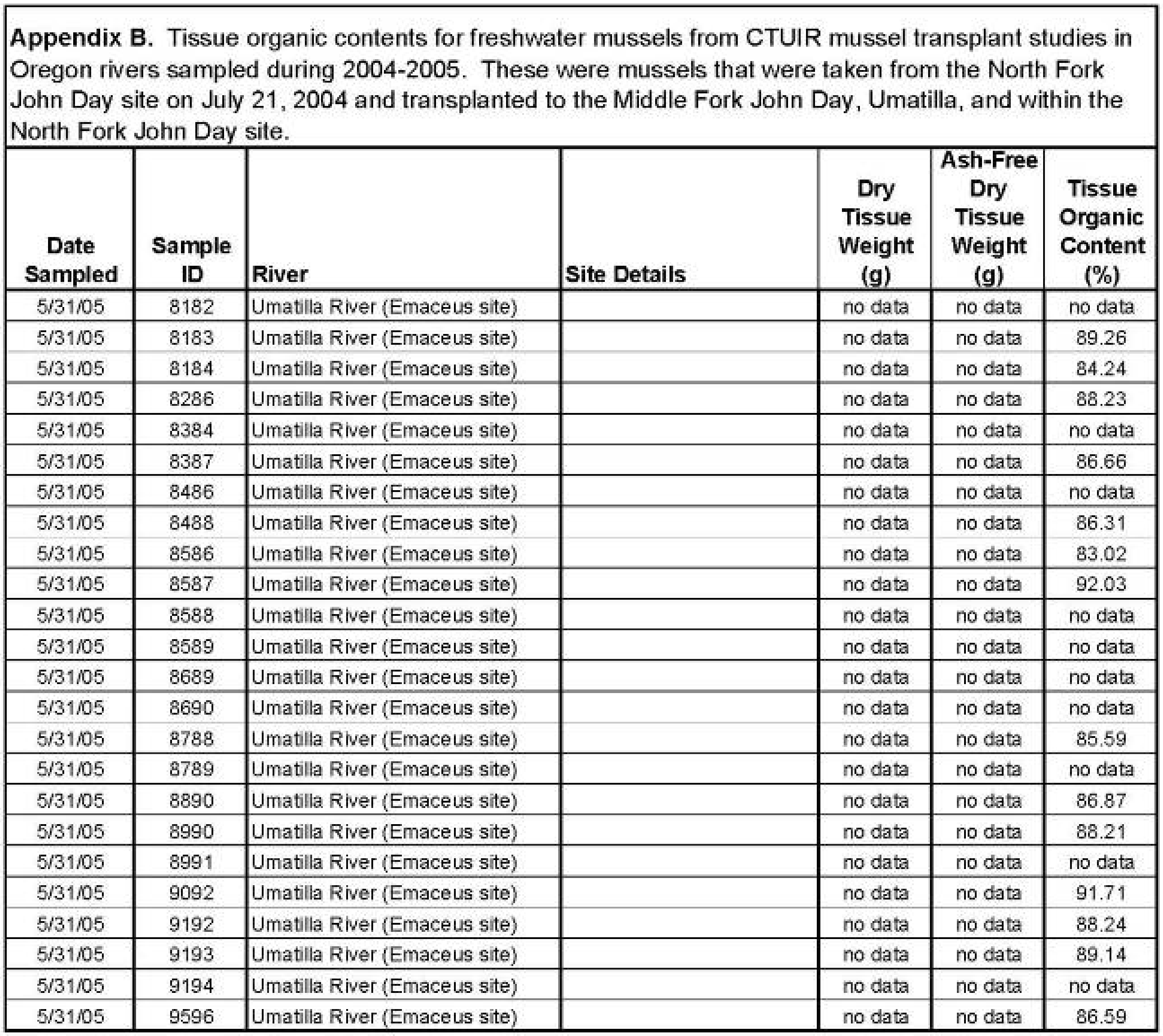
Date Sampled	Sample ID	River	Site Details	Dry Tissue Weight (g)	Ash-Free Dry Tissue Weight (g)	Tissue Organic Content (%)
10/15/04	70	John Day Middle Fork	11N 348835; 4961778	1.035	0.912	88.13
10/15/04	7778	John Day Middle Fork	11N 348835; 4961778	1.012	0.912	90.08
10/15/04	94	John Day Middle Fork	11N 348835; 4961778	1.596	1.326	83.07
10/15/04	76	John Day Middle Fork	11N 348835; 4961778	1.156	1.025	88.71
10/15/04	7592	John Day Middle Fork	11N 348835; 4961778	1.201	1.052	87.65
10/15/04	7493	John Day Middle Fork	11N 348835; 4961778	1.622	1.449	89.30
10/15/04	8087	John Day Middle Fork	11N 348835; 4961778	0.751	0.648	86.37
10/15/04	8079	John Day Middle Fork	11N 348835; 4961778	1.362	1.201	88.14
10/15/04	75	John Day Middle Fork	11N 348835; 4961778	1.555	1.348	86.68
10/15/04	87	John Day Middle Fork	11N 348835; 4961778	0.775	0.697	89.95
10/15/04	79	Umatilla River (Emaceus site)		0.825	0.710	86.03
10/15/04	8386	Umatilla River (Emaceus site)		0.913	0.804	87.99
10/15/04	8284	Umatilla River (Emaceus site)		0.888	0.803	90.44
10/15/04	7579	Umatilla River (Emaceus site)		1.230	1.072	87.16
10/15/04	8487	Umatilla River (Emaceus site)		0.866	0.716	82.73
10/15/04	70	Umatilla River (Emaceus site)		1.155	1.048	90.78
10/15/04	6970	Umatilla River (Emaceus site)		0.849	0.755	88.93
10/15/04	86	Umatilla River (Emaceus site)		1.203	1.051	87.35
10/15/04	7072	Umatilla River (Emaceus site)		1.005	0.907	90.29
10/15/04	8083	Umatilla River (Emaceus site)		0.749	0.666	88.88
10/15/04	31	John Day North Fork		1.019	0.924	90.73
10/15/04	30	John Day North Fork		0.783	0.720	91.93
10/15/04	29	John Day North Fork		0.532	0.489	91.88
10/15/04	36	John Day North Fork		0.645	0.572	88.57
10/15/04	61	John Day North Fork		0.908	0.784	86.35
10/15/04	35	John Day North Fork		0.785	0.701	89.29
10/15/04	65	John Day North Fork		0.758	0.666	87.93
10/15/04	41	John Day North Fork		0.387	0.351	90.52
10/15/04	38	John Day North Fork		0.864	0.760	87.97
10/15/04	26	John Day North Fork		1.179	1.052	89.26
10/15/04	74	John Day North Fork		0.617	0.528	85.59
10/15/04	8487	Umatilla River (Cayuse site)		0.391	0.352	90.02
10/15/04	68blank	Umatilla River (Cayuse site)		1.014	0.878	86.65
10/15/04	77	Umatilla River (Cayuse site)		1.113	1.016	91.34
10/15/04	9596	Umatilla River (Cayuse site)		1.239	1.109	89.56
10/15/04	69	Umatilla River (Cayuse site)		1.280	1.133	88.55
10/15/04	6768	Umatilla River (Cayuse site)		0.456	0.412	90.30
10/15/04	8182	Umatilla River (Cayuse site)		0.530	0.474	89.33
10/15/04	7476	Umatilla River (Cayuse site)		0.750	0.672	89.58
10/15/04	84	Umatilla River (Cayuse site)		1.148	1.001	87.19
10/15/04	6871	Umatilla River (Cayuse site)		0.752	0.693	92.13
5/31/05	67	Umatilla River (Emaceus site)		no data	no data	no data

Appendix B. Tissue organic contents for freshwater mussels from CTUIR mussel transplant studies in Oregon rivers sampled during 2004-2005. These were mussels that were taken from the North Fork John Day site on July 21, 2004 and transplanted to the Middle Fork John Day, Umatilla, and within the North Fork John Day site.

Date Sampled	Sample ID	River	Site Details	Dry Tissue Weight (g)	Ash-Free Dry Tissue Weight (g)	Tissue Organic Content (%)
5/31/05	68	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	69	Umatilla River (Emaceus site)		no data	no data	85.86
5/31/05	72	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	73	Umatilla River (Emaceus site)		no data	no data	87.00
5/31/05	74	Umatilla River (Emaceus site)		no data	no data	89.05
5/31/05	75	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	76	Umatilla River (Emaceus site)		no data	no data	88.62
5/31/05	77	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	78	Umatilla River (Emaceus site)		no data	no data	89.13
5/31/05	80	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	81	Umatilla River (Emaceus site)		no data	no data	86.60
5/31/05	82	Umatilla River (Emaceus site)		no data	no data	87.58
5/31/05	83	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	84	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	88	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	89	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	90	Umatilla River (Emaceus site)		no data	no data	88.73
5/31/05	91	Umatilla River (Emaceus site)		no data	no data	86.65
5/31/05	92	Umatilla River (Emaceus site)		no data	no data	84.21
5/31/05	93	Umatilla River (Emaceus site)		no data	no data	87.91
5/31/05	94	Umatilla River (Emaceus site)		no data	no data	87.63
5/31/05	95	Umatilla River (Emaceus site)		no data	no data	89.38
5/31/05	96	Umatilla River (Emaceus site)		no data	no data	85.50
5/31/05	97	Umatilla River (Emaceus site)		no data	no data	90.01
5/31/05	98	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	99	Umatilla River (Emaceus site)		no data	no data	88.87
5/31/05	100	Umatilla River (Emaceus site)		no data	no data	84.58
5/31/05	101	Umatilla River (Emaceus site)		no data	no data	81.00
5/31/05	102	Umatilla River (Emaceus site)		no data	no data	88.76
5/31/05	103	Umatilla River (Emaceus site)		no data	no data	86.96
5/31/05	104	Umatilla River (Emaceus site)		no data	no data	85.85
5/31/05	105	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	106	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	107	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	108	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	109	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	110	Umatilla River (Emaceus site)		no data	no data	87.50
5/31/05	111	Umatilla River (Emaceus site)		no data	no data	80.18
5/31/05	112	Umatilla River (Emaceus site)		no data	no data	84.37
5/31/05	113	Umatilla River (Emaceus site)		no data	no data	88.02
5/31/05	114	Umatilla River (Emaceus site)		no data	no data	90.12
5/31/05	115	Umatilla River (Emaceus site)		no data	no data	84.62

Appendix B. Tissue organic contents for freshwater mussels from CTUIR mussel transplant studies in Oregon rivers sampled during 2004-2005. These were mussels that were taken from the North Fork John Day site on July 21, 2004 and transplanted to the Middle Fork John Day, Umatilla, and within the North Fork John Day site.

Date Sampled	Sample ID	River	Site Details	Dry Tissue Weight (g)	Ash-Free Dry Tissue Weight (g)	Tissue Organic Content (%)
5/31/05	116	Umatilla River (Emaceus site)		no data	no data	89.90
5/31/05	117	Umatilla River (Emaceus site)		no data	no data	86.57
5/31/05	118	Umatilla River (Emaceus site)		no data	no data	88.56
5/31/05	119	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	120	Umatilla River (Emaceus site)		no data	no data	91.81
5/31/05	121	Umatilla River (Emaceus site)		no data	no data	89.25
5/31/05	6768	Umatilla River (Emaceus site)		no data	no data	85.29
5/31/05	6769	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	6770	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	6872	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	6971	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	6972	Umatilla River (Emaceus site)		no data	no data	87.87
5/31/05	7073	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	7074	Umatilla River (Emaceus site)		no data	no data	88.24
5/31/05	7172	Umatilla River (Emaceus site)		no data	no data	86.79
5/31/05	7173	Umatilla River (Emaceus site)		no data	no data	87.23
5/31/05	7174	Umatilla River (Emaceus site)		no data	no data	92.31
5/31/05	7175	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	7276	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	7374	Umatilla River (Emaceus site)		no data	no data	84.99
5/31/05	7375	Umatilla River (Emaceus site)		no data	no data	88.28
5/31/05	7377	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	7476	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	7477	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	7478	Umatilla River (Emaceus site)		no data	no data	88.66
5/31/05	7576	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	7577	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	7578	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	7678	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	7679	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	7680	Umatilla River (Emaceus site)		no data	no data	87.73
5/31/05	7778	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	7779	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	7780	Umatilla River (Emaceus site)		no data	no data	86.21
5/31/05	7781	Umatilla River (Emaceus site)		no data	no data	86.53
5/31/05	7881	Umatilla River (Emaceus site)		no data	no data	87.49
5/31/05	7882	Umatilla River (Emaceus site)		no data	no data	86.78
5/31/05	7980	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	7982	Umatilla River (Emaceus site)		no data	no data	86.13
5/31/05	7983	Umatilla River (Emaceus site)		no data	no data	90.81
5/31/05	8082	Umatilla River (Emaceus site)		no data	no data	85.10
5/31/05	8084	Umatilla River (Emaceus site)		no data	no data	no data



Appendix B. Tissue organic contents for freshwater mussels from CTUIR mussel transplant studies in Oregon rivers sampled during 2004-2005. These were mussels that were taken from the North Fork John Day site on July 21, 2004 and transplanted to the Middle Fork John Day, Umatilla, and within the North Fork John Day site.

Date Sampled	Sample ID	River	Site Details	Dry Tissue Weight (g)	Ash-Free Dry Tissue Weight (g)	Tissue Organic Content (%)
5/31/05	8182	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	8183	Umatilla River (Emaceus site)		no data	no data	89.26
5/31/05	8184	Umatilla River (Emaceus site)		no data	no data	84.24
5/31/05	8286	Umatilla River (Emaceus site)		no data	no data	88.23
5/31/05	8384	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	8387	Umatilla River (Emaceus site)		no data	no data	86.66
5/31/05	8486	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	8488	Umatilla River (Emaceus site)		no data	no data	86.31
5/31/05	8586	Umatilla River (Emaceus site)		no data	no data	83.02
5/31/05	8587	Umatilla River (Emaceus site)		no data	no data	92.03
5/31/05	8588	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	8589	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	8689	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	8690	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	8788	Umatilla River (Emaceus site)		no data	no data	85.59
5/31/05	8789	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	8890	Umatilla River (Emaceus site)		no data	no data	86.87
5/31/05	8990	Umatilla River (Emaceus site)		no data	no data	88.21
5/31/05	8991	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	9092	Umatilla River (Emaceus site)		no data	no data	91.71
5/31/05	9192	Umatilla River (Emaceus site)		no data	no data	88.24
5/31/05	9193	Umatilla River (Emaceus site)		no data	no data	89.14
5/31/05	9194	Umatilla River (Emaceus site)		no data	no data	no data
5/31/05	9596	Umatilla River (Emaceus site)		no data	no data	86.59

APPENDIX C

Appendix C. Complete set of clearance rate data for freshwater mussels collected from Oregon rivers during 2005-2006.

Date	Experiment Name[1]	Mussel ID	Mussel Species	River	Site Name	Shell Length (mm)	Dry Tissue Weight (g)	Clearance Rate (L h^{-1})	Weight-Specific Clearance Rate (L h^{-1} g^{-1})
10/9/05	UMP 5	2987	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	62.37	0.90656	0.708	0.781
10/9/05	UMP 5	2988	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	77.6	1.62004	1.024	0.632
10/9/05	UMP 5	2989	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	85.28	2.44109	0.410	0.168
10/9/05	UMP 5	2990	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	36.24	0.21233	0.364	1.713
10/9/05	UMP 5	2991	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	37.51	0.20339	0.351	1.723
10/9/05	UMP 5	2992	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	39.92	0.2734	0.304	1.111
10/9/05	UMP 5	2993	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	41.84	0.29755	0.296	0.996
10/9/05	UMP 5	2994	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	44.9	0.46129	0.231	0.501
10/9/05	UMP 5	2995	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	47.95	0.50312	0.240	0.476
10/9/05	UMP 5	2996	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	48.51	0.56753	0.424	0.748
10/9/05	UMP 5	2997	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	44.74	0.43909	0.144	0.328
10/9/05	UMP 5	2998	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	47.09	0.56417	0.302	0.535
10/9/05	UMP 5	2999	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	57.31	0.94179	0.288	0.306
10/9/05	UMP 5	3000	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	60.89	1.06627	0.302	0.283
10/9/05	UMP 5	693	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	73.03	1.63361	0.397	0.243
10/9/05	UMP 5	694	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	77.39	2.6579	0.372	0.140
10/9/05	UMP 5	695	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	78.58	2.26955	0.247	0.109
10/9/05	UMP 5	696	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	44.76	0.28026	0.220	0.784
10/9/05	UMP 5	697	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	65.34	1.06697	0.393	0.368
10/9/05	UMP 5	698	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	69.73	1.07991	0.382	0.353
10/9/05	UMP 5	699	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	65.19	1.03736	0.220	0.212
10/9/05	UMP 5	700	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	70.05	1.1414	0.553	0.485
10/9/05	UMP 5	701	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	73.4	1.24833	0.353	0.283
10/9/05	UMP 5	702	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	78.7	1.66825	0.362	0.217
10/9/05	UMP 5	703	*Margaratifera falcata*	John Day North Fork	Mussel bed	60.61	0.9109	0.349	0.383
10/9/05	UMP 5	704	*Margaratifera falcata*	John Day North Fork	Mussel bed	61.28	0.92951	0.607	0.653
10/9/05	UMP 5	705	*Margaratifera falcata*	John Day North Fork	Mussel bed	67.28	1.20233	0.561	0.466
10/9/05	UMP 5	706	*Margaratifera falcata*	John Day North Fork	Mussel bed	74.09	1.48121	0.278	0.187
10/9/05	UMP 5	707	*Margaratifera falcata*	John Day North Fork	Mussel bed	79.88	1.7652	0.275	0.156
10/9/05	UMP 5	709	*Margaratifera falcata*	John Day North Fork	Mussel bed	93.87	2.99965	0.185	0.062
3/20/06	UMP 6	955	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	71.58	1.36788	0.315	0.230
3/20/06	UMP 6	956	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	71.66	1.17983	0.384	0.325
3/20/06	UMP 6	957	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	72.65	1.60987	0.360	0.223
3/20/06	UMP 6	958	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	76.42	1.81311	0.175	0.096
3/20/06	UMP 6	959	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	83.29	1.97059	0.232	0.118
3/20/06	UMP 6	960	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	83.39	1.8839	0.155	0.082
3/20/06	UMP 6	962	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	39.78	0.25189	0.205	0.816
3/20/06	UMP 6	963	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	44.8	0.42368	0.278	0.657
3/20/06	UMP 6	964	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	79.76	0.52437	0.392	0.747
3/20/06	UMP 6	965	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	52.48	0.4918	0.213	0.434
3/20/06	UMP 6	967	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	66.27	1.03728	0.244	0.235
3/20/06	UMP 6	969	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	66.95	1.05091	0.119	0.113
3/20/06	UMP 6	971	*Margaratifera falcata*	John Day North Fork	Mussel bed	58.19	0.68817	0.366	0.532
3/20/06	UMP 6	973	*Margaratifera falcata*	John Day North Fork	Mussel bed	70.65	1.17072	0.419	0.358
3/20/06	UMP 6	974	*Margaratifera falcata*	John Day North Fork	Mussel bed	73.09	1.45121	0.240	0.165
3/20/06	UMP 6	976	*Margaratifera falcata*	John Day North Fork	Mussel bed	79.95	1.55778	0.443	0.284
3/20/06	UMP 6	978	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	46.43	0.46138	0.118	0.256
3/20/06	UMP 6	979	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	53.26	0.50684	0.221	0.437
3/20/06	UMP 6	981	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	65.06	1.12511	0.348	0.310
3/20/06	UMP 6	982	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	74.13	1.39633	0.227	0.163
3/20/06	UMP 6	983	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	77.85	2.25529	0.278	0.123
3/20/06	UMP 6	986	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	38.7	0.13506	0.416	3.076
3/20/06	UMP 6	987	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	42.96	0.3708	0.320	0.862
3/20/06	UMP 6	988	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	46.56	0.55717	0.222	0.398
3/20/06	UMP 6	989	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	50.83	0.57145	0.404	0.707
3/20/06	UMP 6	992	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	50.53	0.45865	0.212	0.463
3/20/06	UMP 6	993	*Anodonta oregonensis?*	Umatilla	Hermiston	56.1	0.69561	0.419	0.602
8/24/06	UMP 7	1525	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	42.08	0.29775	0.639	2.146
8/24/06	UMP 7	1526	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	46.11	0.33201	0.262	0.789
8/24/06	UMP 7	1527	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	56.24	0.73771	0.518	0.703
8/24/06	UMP 7	1528	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	63.29	0.95793	0.464	0.484
8/24/06	UMP 7	1529	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	75	1.56807	0.394	0.251
8/24/06	UMP 7	1530	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	95.43	2.01804	0.344	0.170
8/24/06	UMP 7	1531	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	37.61	0.31934	0.289	0.907
8/24/06	UMP 7	1532	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	41.73	0.33079	0.630	1.904
8/24/06	UMP 7	1533	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	46.3	0.40756	1.101	2.702

Appendix C. Complete set of clearance rate data for freshwater mussels collected from Oregon rivers during 2005-2006.

Date	Experiment Name[1]	Mussel ID	Mussel Species	River	Site Name	Shell Length (mm)	Dry Tissue Weight (g)	Clearance Rate (L h^{-1})	Weight-Specific Clearance Rate (L h^{-1} g^{-1})
10/9/05	UMP 5	2987	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	62.37	0.90656	0.708	0.781
10/9/05	UMP 5	2988	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	77.6	1.62004	1.024	0.632
10/9/05	UMP 5	2989	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	85.28	2.44109	0.410	0.168
10/9/05	UMP 5	2990	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	36.24	0.21233	0.364	1.713
10/9/05	UMP 5	2991	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	37.51	0.20339	0.351	1.723
10/9/05	UMP 5	2992	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	39.92	0.2734	0.304	1.111
10/9/05	UMP 5	2993	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	41.84	0.29755	0.296	0.996
10/9/05	UMP 5	2994	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	44.9	0.46129	0.231	0.501
10/9/05	UMP 5	2995	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	47.95	0.50312	0.240	0.476
10/9/05	UMP 5	2996	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	48.51	0.56753	0.424	0.748
10/9/05	UMP 5	2997	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	44.74	0.43909	0.144	0.328
10/9/05	UMP 5	2998	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	47.09	0.56417	0.302	0.535
10/9/05	UMP 5	2999	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	57.31	0.94179	0.288	0.306
10/9/05	UMP 5	3000	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	60.89	1.06627	0.302	0.283
10/9/05	UMP 5	693	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	73.03	1.63361	0.397	0.243
10/9/05	UMP 5	694	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	77.39	2.6579	0.372	0.140
10/9/05	UMP 5	695	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	78.58	2.26955	0.247	0.109
10/9/05	UMP 5	696	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	44.76	0.28026	0.220	0.784
10/9/05	UMP 5	697	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	65.34	1.06697	0.393	0.368
10/9/05	UMP 5	698	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	69.73	1.07991	0.382	0.353
10/9/05	UMP 5	699	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	65.19	1.03736	0.220	0.212
10/9/05	UMP 5	700	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	70.05	1.1414	0.553	0.485
10/9/05	UMP 5	701	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	73.4	1.24833	0.353	0.283
10/9/05	UMP 5	702	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	78.7	1.66825	0.362	0.217
10/9/05	UMP 5	703	*Margaratifera falcata*	John Day North Fork	Mussel bed	60.61	0.9109	0.349	0.383
10/9/05	UMP 5	704	*Margaratifera falcata*	John Day North Fork	Mussel bed	61.28	0.92951	0.607	0.653
10/9/05	UMP 5	705	*Margaratifera falcata*	John Day North Fork	Mussel bed	67.28	1.20233	0.561	0.466
10/9/05	UMP 5	706	*Margaratifera falcata*	John Day North Fork	Mussel bed	74.09	1.48121	0.278	0.187
10/9/05	UMP 5	707	*Margaratifera falcata*	John Day North Fork	Mussel bed	79.88	1.7652	0.275	0.156
10/9/05	UMP 5	709	*Margaratifera falcata*	John Day North Fork	Mussel bed	93.87	2.99965	0.185	0.062
3/20/06	UMP 6	955	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	71.58	1.36788	0.315	0.230
3/20/06	UMP 6	956	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	71.66	1.17983	0.384	0.325
3/20/06	UMP 6	957	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	72.65	1.60987	0.360	0.223
3/20/06	UMP 6	958	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	76.42	1.81311	0.175	0.096
3/20/06	UMP 6	959	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	83.29	1.97059	0.232	0.118
3/20/06	UMP 6	960	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	83.39	1.8839	0.155	0.082
3/20/06	UMP 6	962	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	39.78	0.25189	0.205	0.816
3/20/06	UMP 6	963	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	44.8	0.42368	0.278	0.657
3/20/06	UMP 6	964	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	79.76	0.52437	0.392	0.747
3/20/06	UMP 6	965	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	52.48	0.4918	0.213	0.434
3/20/06	UMP 6	967	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	66.27	1.03728	0.244	0.235
3/20/06	UMP 6	969	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	66.95	1.05091	0.119	0.113
3/20/06	UMP 6	971	*Margaratifera falcata*	John Day North Fork	Mussel bed	58.19	0.68817	0.366	0.532
3/20/06	UMP 6	973	*Margaratifera falcata*	John Day North Fork	Mussel bed	70.65	1.17072	0.419	0.358
3/20/06	UMP 6	974	*Margaratifera falcata*	John Day North Fork	Mussel bed	73.09	1.45121	0.240	0.165
3/20/06	UMP 6	976	*Margaratifera falcata*	John Day North Fork	Mussel bed	79.95	1.55778	0.443	0.284
3/20/06	UMP 6	978	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	46.43	0.46138	0.118	0.256
3/20/06	UMP 6	979	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	53.26	0.50684	0.221	0.437
3/20/06	UMP 6	981	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	65.06	1.12511	0.348	0.310
3/20/06	UMP 6	982	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	74.13	1.39633	0.227	0.163
3/20/06	UMP 6	983	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	77.85	2.25529	0.278	0.123
3/20/06	UMP 6	986	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	38.7	0.13506	0.416	3.076
3/20/06	UMP 6	987	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	42.96	0.3708	0.320	0.862
3/20/06	UMP 6	988	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	46.56	0.55717	0.222	0.398
3/20/06	UMP 6	989	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	50.83	0.57145	0.404	0.707
3/20/06	UMP 6	992	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	50.53	0.45865	0.212	0.463
3/20/06	UMP 6	993	*Anodonta oregonensis?*	Umatilla	Hermiston	56.1	0.69561	0.419	0.602
8/24/06	UMP 7	1525	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	42.08	0.29775	0.639	2.146
8/24/06	UMP 7	1526	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	46.11	0.33201	0.262	0.789
8/24/06	UMP 7	1527	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	56.24	0.73771	0.518	0.703
8/24/06	UMP 7	1528	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	63.29	0.95793	0.464	0.484
8/24/06	UMP 7	1529	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	75	1.56807	0.394	0.251
8/24/06	UMP 7	1530	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	95.43	2.01804	0.344	0.170
8/24/06	UMP 7	1531	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	37.61	0.31934	0.289	0.907
8/24/06	UMP 7	1532	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	41.73	0.33079	0.630	1.904
8/24/06	UMP 7	1533	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	46.3	0.40756	1.101	2.702

Appendix C. Complete set of clearance rate data for freshwater mussels collected from Oregon rivers during 2005-2006.

Date	Experiment Name[1]	Mussel ID	Mussel Species	River	Site Name	Shell Length (mm)	Dry Tissue Weight (g)	Clearance Rate ($L\ h^{-1}$)	Weight-Specific Clearance Rate ($L\ h^{-1}\ g^{-1}$)
8/24/06	UMP 7	1534	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	56.25	0.69329	0.870	1.255
8/24/06	UMP 7	1535	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	56.24	0.66236	0.691	1.043
8/24/06	UMP 7	1536	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	79.24	1.52803	0.310	0.203
8/24/06	UMP 7	1537	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	43.61	0.3638	0.697	1.915
8/24/06	UMP 7	1538	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	56.67	0.97072	1.335	1.375
8/24/06	UMP 7	1539	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	61.06	0.92958	0.157	0.168
8/24/06	UMP 7	1540	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	66.89	1.42517	0.609	0.427
8/24/06	UMP 7	1541	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	68.34	0.9405	0.815	0.867
8/24/06	UMP 7	1542	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	82.4	2.46833	0.397	0.161
8/24/06	UMP 7	1543	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	33.7	0.18706	0.907	4.850
8/24/06	UMP 7	1544	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	38.22	0.23723	0.837	3.530
8/24/06	UMP 7	1545	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	40.43	0.28277	0.485	1.715
8/24/06	UMP 7	1546	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	43.68	0.48962	0.876	1.789
8/24/06	UMP 7	1547	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	51.21	0.42542	0.652	1.533
8/24/06	UMP 7	1548	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	50.17	0.52678	0.675	1.282
8/24/06	UMP 7	1549	*Anodonta oregonensis?*	Umatilla	Hermiston	63	0.63461	1.218	1.919
8/24/06	UMP 7	1550	*Anodonta oregonensis?*	Umatilla	Hermiston	66	1.05476	1.106	1.048
8/24/06	UMP 7	1551	*Anodonta oregonensis?*	Umatilla	Hermiston	73.37	1.03149	1.519	1.473
8/24/06	UMP 7	1552	*Anodonta oregonensis?*	Umatilla	Hermiston	80.68	1.39799	0.641	0.458
8/24/06	UMP 7	1553	*Anodonta oregonensis?*	Umatilla	Hermiston	79.24	1.49195	0.778	0.521
8/24/06	UMP 7	1554	*Anodonta oregonensis?*	Umatilla	Hermiston	83.43	1.42873	0.931	0.652
8/24/06	UMP 7	1555	*Anodonta oregonensis?*	Umatilla	Hermiston	85.58	1.6531	0.631	0.382
8/24/06	UMP 7	1556	*Anodonta oregonensis?*	Umatilla	Hermiston	86.66	1.92135	0.611	0.318
8/24/06	UMP 7	1557	*Anodonta californianus*	Umatilla	Hermiston	51.87	0.54167	0.902	1.665
8/24/06	UMP 7	1558	*Anodonta californianus*	Umatilla	Hermiston	65.15	0.79298	0.793	0.999

APPENDIX D

Appendix D. Physiological data for freshwater mussels collected from Oregon rivers during 2005-2006.

Date	Experiment Name[1]	Mussel ID	Mussel Species	River	Site Name	Shell Length (mm)	Dry Tissue Weight (g)	Weight-Specific Clearance Rate (L h^{-1} g^{-1})	Weight-Specific Filtration Rate (mg PM h^{-1} g^{-1})	Weight-Specific Filtration Rate (mg C h^{-1} g^{-1})	Absorption Efficiency (%)	Weight-Specific Net Absorption Rate (mg C h^{-1} g^{-1})
3/23/05	UMP 1	F-1	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	37.06	0.24281	1.174	7.26	1.42	9.98	0.142
3/23/05	UMP 1	F-9	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	45.48	0.54273	1.026	6.35	1.24	8.86	0.110
3/23/05	UMP 1	N48	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	61.8	0.93755	0.262	1.62	0.32	6.17	0.020
3/23/05	UMP 1	N62	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	64.31	0.80735	0.511	3.16	0.62	8.92	0.055
3/23/05	UMP 1	ALS-83	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	75.47	1.22456	0.144	0.89	0.17	7.22	0.013
3/23/05	UMP 1	N56	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	38.75	0.31121	1.066	6.60	1.29	11.09	0.143
3/23/05	UMP 1	F-5	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	39.5	0.35918	0.988	6.12	1.20	10.77	0.129
3/23/05	UMP 1	F-6	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	44.1	0.45414	0.986	6.11	1.19	9.66	0.115
3/23/05	UMP 1	F-3	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	48.13	0.51463	0.469	2.90	0.57	9.77	0.056
3/23/05	UMP 1	N61	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	48.05	0.4999	0.831	5.14	1.01	10.81	0.109
3/23/05	UMP 1	F-7	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	50.42	0.47471	0.142	0.88	0.17	11.61	0.020
3/23/05	UMP 1	N72	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	56.99	0.66466	0.082	0.51	0.10	10.13	0.010
3/23/05	UMP 1	N37	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	72.84	1.29061	0.345	2.14	0.42	12.13	0.051
3/23/05	UMP 2	N57	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	46.26	0.43267	0.173	1.07	0.21	3.72	0.008
3/23/05	UMP 2	N16	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	74.13	1.25969	0.597	3.70	0.72	8.16	0.059
3/23/05	UMP 2	N35	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	59.02	0.81548	0.387	2.40	0.47	9.08	0.043
3/23/05	UMP 2	N68	*Margaratifera falcata*	John Day, North Fork	Mussel bed	65.26	1.06919	0.261	1.64	0.28	5.66	0.016
3/23/05	UMP 2	N69	*Margaratifera falcata*	John Day, North Fork	Mussel bed	60.35	0.92344	0.196	1.23	0.21	1.09	0.002
3/23/05	UMP 2	F-4	*Margaratifera falcata*	John Day, North Fork	Mussel bed	53.33	0.63278	1.322	8.29	1.44	4.06	0.058
3/23/05	UMP 2	F-8	*Margaratifera falcata*	John Day, North Fork	Mussel bed	69.94	1.27086	0.065	0.41	0.07	1.61	0.001
3/23/05	UMP 2	ALS-94	*Margaratifera falcata*	John Day, North Fork	Mussel bed	89.02	1.70435	0.060	0.38	0.07	4.69	0.003
3/23/05	UMP 2	N51	*Margaratifera falcata*	John Day, North Fork	Mussel bed	73.09	1.32696	0.157	0.99	0.17	5.68	0.010
3/23/05	UMP 2	N71	*Margaratifera falcata*	John Day, North Fork	Mussel bed	60.97	0.77251	0.209	1.31	0.23	3.76	0.009
6/22/05	UMP 3	1001	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	34.52	0.159125	3.208	3.53	1.38	54.17	0.746
6/22/05	UMP 3	1002	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	36.95	0.24788	2.697	2.97	1.16	54.05	0.626
6/22/05	UMP 3	1003	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	44.88	0.47205	1.801	1.98	0.77	54.07	0.418
6/22/05	UMP 3	1004	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	52.05	0.58172	0.671	0.74	0.29	53.62	0.155
6/22/05	UMP 3	1005	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	60.74	0.80336	0.407	0.45	0.17	55.64	0.097
6/22/05	UMP 3	1006	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	69.22	1.23568	0.320	0.35	0.14	56.16	0.077
6/22/05	UMP 3	1007	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	71.26	1.3446	0.283	0.31	0.12	54.85	0.067
6/22/05	UMP 3	1008	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	33.41	0.13307	4.098	4.51	1.76	54.85	0.965
6/22/05	UMP 3	1009	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	36.76	0.14043	4.398	4.84	1.89	no feces	no/bad data
6/22/05	UMP 3	1010	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	37.72	0.22439	1.790	1.97	0.77	56.96	0.430
6/22/05	UMP 3	1011	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	43.4	0.3445	0.920	1.01	0.40	56.66	0.224
6/22/05	UMP 3	1012	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	47.93	0.40515	0.374	0.41	0.16	56.68	0.091
6/22/05	UMP 3	1013	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	49.39	0.44121	0.893	0.98	0.38	54.11	0.207
6/22/05	UMP 3	1014	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	49.61	0.41578	1.199	1.32	0.51	56.47	0.291
6/22/05	UMP 3	1015	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	47.62	0.50267	0.626	0.69	0.27	54.64	0.147
6/22/05	UMP 3	1016	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	57.08	0.75307	0.442	0.49	0.19	53.61	0.102
6/22/05	UMP 3	1017	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	57.65	0.82887	0.394	0.43	0.17	55.29	0.094
6/22/05	UMP 3	1018	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	65.39	0.9625	0.324	0.36	0.14	53.20	0.074
6/22/05	UMP 3	1019	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	67.73	1.22225	0.102	0.11	0.04	54.18	0.024
6/22/05	UMP 3	1021	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	79.29	2.18877	0.159	0.18	0.07	56.36	0.039
6/22/05	UMP 4	1049	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	60.3	0.86587	1.035	1.14	0.44	53.08	0.236
6/22/05	UMP 4	1050	*Margaratifera falcata*	John Day Middle Fork	Wildcat Point	68.87	1.10356	0.235	0.26	0.10	53.80	0.054
6/22/05	UMP 4	1051	*Margaratifera falcata*	John Day Middle Fork	Wildcat Point	71.95	1.43865	0.237	0.26	0.10	53.67	0.055
6/22/05	UMP 4	1052	*Margaratifera falcata*	John Day Middle Fork	Wildcat Point	80.39	1.74088	0.186	0.20	0.08	54.53	0.043
6/22/05	UMP 4	1053	*Anodonta californianus*	John Day Middle Fork	Wildcat Point	47.72	0.32988	1.284	1.41	0.55	54.72	0.302

6/22/05	UMP 4	1054	*Anodonta californianus*	John Day Middle Fork	Wildcat Point	50.27	0.56417	0.134	0.15	0.06	55.77	0.032
6/22/05	UMP 4	1056	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	37.14	0.24683	1.886	2.07	0.81	52.28	0.424
6/22/05	UMP 4	1057	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	54.18	0.62431	0.543	0.60	0.23	51.83	0.121
6/22/05	UMP 4	1058	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	68.2	1.32746	0.487	0.54	0.21	52.68	0.110
6/22/05	UMP 4	1059	*Margaratifera falcata*	John Day Middle Fork	Ritter Hot Springs	86.16	2.58718	0.215	0.24	0.09	52.15	0.048
6/22/05	UMP 4	1060	*Margaratifera falcata*	John Day Middle Fork	Ritter Hot Springs	99.14	0.86658	0.711	0.78	0.31	52.71	0.161
6/22/05	UMP 4	1061	*Anodonta californianus*	John Day Middle Fork	Ritter Hot Springs	35.65	0.15057	1.594	1.75	0.68	54.85	0.376
6/22/05	UMP 4	1062	*Anodonta californianus*	John Day Middle Fork	Ritter Hot Springs	48.9	0.81901	0.430	0.47	0.18	45.22	0.084
6/22/05	UMP 4	1064	*Margaratifera falcata*	John Day North Fork	Mussel bed	36.99	0.22541	1.569	3.03	0.98	44.77	0.437
6/22/05	UMP 4	1065	*Margaratifera falcata*	John Day North Fork	Mussel bed	50.81	0.45228	1.314	2.54	0.82	44.84	0.366
6/22/05	UMP 4	066 +107	*Margaratifera falcata*	John Day North Fork	Mussel bed	63.65	2.85904	0.243	0.47	0.15	33.83	0.051
6/22/05	UMP 4	1067	*Margaratifera falcata*	John Day North Fork	Mussel bed	73.52	1.1906	0.378	0.73	0.24	37.20	0.087
6/22/05	UMP 4	1068	*Margaratifera falcata*	John Day North Fork	Mussel bed	80.74	1.65206	0.458	0.88	0.28	34.46	0.098
6/22/05	UMP 4	1069	*Margaratifera falcata*	John Day North Fork	Mussel bed	83.83	1.67677	0.454	0.88	0.28	36.08	0.102
10/9/05	UMP 5	2983	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	24.28	0.0591	10.248	8.10	3.29	63.54	2.089
10/9/05	UMP 5	2984	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	44.51	0.36546	1.922	1.52	0.62	62.29	0.384
10/9/05	UMP 5	2985	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	53.96	0.65858	1.534	1.21	0.49	57.84	0.285
10/9/05	UMP 5	2986	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	49.36	0.53585	3.739	2.95	1.20	56.15	0.673
10/9/05	UMP 5	2987	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	62.37	0.90656	0.781	0.62	0.25	59.65	0.149
10/9/05	UMP 5	2988	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	77.6	1.62004	0.632	0.50	0.20	60.57	0.123
10/9/05	UMP 5	2989	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	85.28	2.44109	0.168	0.13	0.05	61.54	0.033
10/9/05	UMP 5	2990	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	36.24	0.21233	1.713	1.35	0.55	60.13	0.330
10/9/05	UMP 5	2991	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	37.51	0.20339	1.723	1.36	0.55	60.20	0.333
10/9/05	UMP 5	2992	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	39.92	0.2734	1.111	0.88	0.36	59.92	0.214
10/9/05	UMP 5	2993	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	41.84	0.29755	0.996	0.79	0.32	58.45	0.187
10/9/05	UMP 5	2994	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	44.9	0.46129	0.501	0.40	0.16	63.01	0.101
10/9/05	UMP 5	2995	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	47.95	0.50312	0.476	0.38	0.15	59.55	0.091
10/9/05	UMP 5	2996	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	48.51	0.56753	0.748	0.59	0.24	62.01	0.149
10/9/05	UMP 5	2997	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	44.74	0.43909	0.328	0.26	0.11	61.62	0.065
10/9/05	UMP 5	2998	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	47.09	0.56417	0.535	0.42	0.17	61.94	0.106
10/9/05	UMP 5	2999	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	57.31	0.94179	0.306	0.24	0.10	59.84	0.059
10/9/05	UMP 5	3000	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	60.89	1.06627	0.283	0.22	0.09	61.60	0.056
10/9/05	UMP 5	693	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	73.03	1.63361	0.243	0.19	0.08	61.64	0.048
10/9/05	UMP 5	694	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	77.39	2.6579	0.140	0.11	0.04	59.29	0.027
10/9/05	UMP 5	695	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	78.58	2.26955	0.109	0.09	0.03	54.94	0.019
10/9/05	UMP 5	696	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	44.76	0.28026	0.784	1.14	0.35	29.86	0.105
10/9/05	UMP 5	697	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	65.34	1.06697	0.368	0.53	0.16	30.69	0.051
10/9/05	UMP 5	698	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	69.73	1.07991	0.353	0.51	0.16	30.18	0.048
10/9/05	UMP 5	699	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	65.19	1.03736	0.212	0.31	0.09	31.04	0.029
10/9/05	UMP 5	700	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	70.05	1.1414	0.485	0.70	0.22	29.04	0.063
10/9/05	UMP 5	701	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	73.4	1.24833	0.283	0.41	0.13	28.71	0.036
10/9/05	UMP 5	702	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	78.7	1.66825	0.217	0.32	0.10	30.25	0.029
10/9/05	UMP 5	703	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	60.61	0.9109	0.383	0.56	0.17	17.02	0.029
10/9/05	UMP 5	704	*Margaratifera falcata*	John Day North Fork	Mussel bed	61.28	0.92951	0.653	1.07	0.25	15.66	0.039
10/9/05	UMP 5	705	*Margaratifera falcata*	John Day North Fork	Mussel bed	67.28	1.20233	0.466	0.76	0.18	15.85	0.028
10/9/05	UMP 5	706	*Margaratifera falcata*	John Day North Fork	Mussel bed	74.09	1.48121	0.187	0.31	0.07	15.84	0.011
10/9/05	UMP 5	707	*Margaratifera falcata*	John Day North Fork	Mussel bed	79.88	1.7652	0.156	0.26	0.06	17.36	0.010
10/9/05	UMP 5	709	*Margaratifera falcata*	John Day North Fork	Mussel bed	93.87	2.99965	0.062	0.10	0.02	15.38	0.004
3/20/06	UMP 6	955	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	71.58	1.36768	0.230	0.94	0.30	18.54	0.056
3/20/06	UMP 6	956	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	71.66	1.17983	0.325	1.33	0.43	18.98	0.081
3/20/06	UMP 6	957	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	72.65	1.60987	0.223	0.92	0.29	23.87	0.070
3/20/06	UMP 6	958	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	76.42	1.81311	0.096	0.40	0.13	33.68	0.043
3/20/06	UMP 6	959	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	83.29	1.97059	0.118	0.48	0.15	29.34	0.045
3/20/06	UMP 6	960	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	83.39	1.8839	0.082	0.34	0.11	34.16	0.037
3/20/06	UMP 6	962	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	39.78	0.25189	0.816	2.94	0.99	37.49	0.372

3/20/06	UMP 6	963	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	44.8	0.42368	0.657	2.37	0.80	38.11	0.304
3/20/06	UMP 6	964	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	79.76	0.52437	0.747	2.69	0.91	38.23	0.347
3/20/06	UMP 6	965	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	52.48	0.4918	0.434	1.56	0.53	36.35	0.192
3/20/06	UMP 6	967	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	66.27	1.03728	0.235	0.85	0.29	38.47	0.110
3/20/06	UMP 6	969	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	66.95	1.05091	0.113	0.41	0.14	36.59	0.050
3/20/06	UMP 6	971	*Margaratifera falcata*	John Day North Fork	Mussel bed	58.19	0.68817	0.532	1.04	0.47	76.24	0.355
3/20/06	UMP 6	973	*Margaratifera falcata*	John Day North Fork	Mussel bed	70.65	1.17072	0.358	0.70	0.31	76.11	0.238
3/20/06	UMP 6	974	*Margaratifera falcata*	John Day North Fork	Mussel bed	73.09	1.45121	0.165	0.32	0.14	76.45	0.110
3/20/06	UMP 6	976	*Margaratifera falcata*	John Day North Fork	Mussel bed	79.95	1.55778	0.264	0.56	0.25	74.36	0.185
3/20/06	UMP 6	978	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	46.43	0.46138	0.256	0.92	0.31	28.68	0.089
3/20/06	UMP 6	979	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	53.26	0.50684	0.437	1.57	0.53	31.99	0.170
3/20/06	UMP 6	981	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	65.06	1.12511	0.310	1.11	0.38	30.63	0.115
3/20/06	UMP 6	982	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	74.13	1.39633	0.163	0.59	0.20	27.27	0.054
3/20/06	UMP 6	983	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	77.85	2.25529	0.123	0.44	0.15	28.95	0.043
3/20/06	UMP 6	986	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	38.7	0.13506	3.076	11.08	3.74	31.30	1.170
3/20/06	UMP 6	987	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	42.96	0.3708	0.862	3.10	1.05	33.96	0.356
3/20/06	UMP 6	988	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	46.56	0.55717	0.398	1.43	0.48	no data	no data
3/20/06	UMP 6	989	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	50.63	0.57145	0.707	2.55	0.86	30.78	0.264
3/20/06	UMP 6	992	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	50.53	0.45865	0.463	1.67	0.56	32.73	0.184
3/20/06	UMP 6	993	*Anodonta oregonensis?*	Umatilla	Hermiston	56.1	0.69561	0.602	2.97	0.53	7.15	0.038
8/24/06	UMP 7	1525	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	42.08	0.29775	2.146	5.69	1.87	29.75	0.555
8/24/06	UMP 7	1526	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	46.11	0.33201	0.789	2.09	0.69	32.54	0.223
8/24/06	UMP 7	1527	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	56.24	0.73771	0.703	1.86	0.61	28.60	0.175
8/24/06	UMP 7	1528	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	63.29	0.95793	0.484	1.28	0.42	31.16	0.131
8/24/06	UMP 7	1529	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	75	1.56807	0.251	0.67	0.22	31.03	0.068
8/24/06	UMP 7	1530	*Margaratifera falcata*	John Day Middle Fork	Big Boulder Creek	95.43	2.01804	0.170	0.45	0.15	22.16	0.033
8/24/06	UMP 7	1531	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	37.61	0.31934	0.907	1.72	0.56	53.79	0.304
8/24/06	UMP 7	1532	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	41.73	0.33079	1.904	3.62	1.19	52.90	0.628
8/24/06	UMP 7	1533	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	46.3	0.40756	2.702	5.13	1.68	52.11	0.877
8/24/06	UMP 7	1534	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	56.25	0.69329	1.255	2.39	0.78	51.38	0.402
8/24/06	UMP 7	1535	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	56.24	0.66236	1.043	1.98	0.65	53.17	0.346
8/24/06	UMP 7	1536	*Margaratifera falcata*	John Day Middle Fork	Fishing Hole - Site 3742	79.24	1.52803	0.203	0.39	0.13	52.08	0.066
8/24/06	UMP 7	1537	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	43.61	0.3638	1.915	3.64	1.19	46.95	0.584
8/24/06	UMP 7	1538	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	56.67	0.97072	1.375	2.61	0.86	53.57	0.459
8/24/06	UMP 7	1539	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	61.06	0.92958	0.168	0.32	0.10	55.08	0.058
8/24/06	UMP 7	1540	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	66.89	1.42517	0.427	0.81	0.27	53.64	0.143
8/24/06	UMP 7	1541	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	68.34	0.9405	0.867	1.65	0.54	51.67	0.279
8/24/06	UMP 7	1542	*Gonidea sp.*	John Day Middle Fork	Fishing Hole - Site 3742	82.4	2.46833	0.161	0.31	0.10	50.94	0.051
8/24/06	UMP 7	1543	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	33.7	0.18706	4.850	9.22	3.02	51.14	1.546
8/24/06	UMP 7	1544	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	38.22	0.23723	3.530	6.71	2.20	53.71	1.182
8/24/06	UMP 7	1545	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	40.43	0.28277	1.715	3.26	1.07	53.89	0.576
8/24/06	UMP 7	1546	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	43.68	0.48962	1.789	3.40	1.11	53.27	0.594
8/24/06	UMP 7	1547	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	51.21	0.42542	1.533	2.91	0.96	53.48	0.511
8/24/06	UMP 7	1548	*Anodonta californianus*	John Day Middle Fork	Fishing Hole - Site 3742	50.17	0.52678	1.282	2.44	0.80	52.99	0.423
8/24/06	UMP 7	1549	*Anodonta oregonensis?*	Umatilla	Hermiston	63	0.63461	1.919	7.16	1.55	10.74	0.167
8/24/06	UMP 7	1550	*Anodonta oregonensis?*	Umatilla	Hermiston	66	1.05476	1.048	3.91	0.85	8.61	0.073
8/24/06	UMP 7	1551	*Anodonta oregonensis?*	Umatilla	Hermiston	73.37	1.03149	1.473	5.49	1.19	5.98	0.071
8/24/06	UMP 7	1552	*Anodonta oregonensis?*	Umatilla	Hermiston	80.68	1.39799	0.458	1.71	0.37	10.28	0.038
8/24/06	UMP 7	1553	*Anodonta oregonensis?*	Umatilla	Hermiston	79.24	1.49195	0.521	1.94	0.42	11.13	0.047
8/24/06	UMP 7	1554	*Anodonta oregonensis?*	Umatilla	Hermiston	83.43	1.42873	0.652	2.43	0.53	9.62	0.051
8/24/06	UMP 7	1555	*Anodonta oregonensis?*	Umatilla	Hermiston	85.58	1.6531	0.382	1.42	0.31	10.99	0.034
8/24/06	UMP 7	1556	*Anodonta oregonensis?*	Umatilla	Hermiston	86.66	1.92135	0.318	1.19	0.26	9.36	0.024
8/24/06	UMP 7	1557	*Anodonta californianus*	Umatilla	Hermiston	51.87	0.54167	1.665	6.21	1.35	10.29	0.139
8/24/06	UMP 7	1558	*Anodonta californianus*	Umatilla	Hermiston	65.15	0.79298	0.999	3.73	0.81	7.81	0.063

APPENDIX E

Appendix E. Excretion rate, respiration rate and O:N ratios for freshwater mussels collected from Oregon rivers during 2005-2006.

Date	Experiment Name[1]	Mussel ID	Mussel Species	River	Shell Length (mm)	Dry Tissue Weight (g)	Oxygen Consumption Rate (ml O_2 h^{-1})	Weight-Specific Oxygen Consumption Rate (ml O_2 h^{-1} g^{-1})	Weight-Specific Oxygen Consumption Rate (µg at O2 O h^{-1} g^{-1})	Ammonia Excretion (µM h^{-1})	Weight-Specific Ammonia Excretion (µg at NH4 N h^{-1} g^{-1})	O:N Ratio
3/23/05	UMP 1	F-1	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	37.06	0.24281				0.27	19.86	
3/23/05	UMP 1	F-9	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	45.48	0.54273	0.27	0.51	31.6	0.45	15.02	2.10
3/23/05	UMP 1	N67	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	47.71	0.3844				0.60	28.29	
3/23/05	UMP 1	N48	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	61.0	0.93755	6.65	7.09	443.0	0.70	13.42	33.02
3/23/05	UMP 1	N62	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	64.31	0.80735				0.62	13.89	
3/23/05	UMP 1	AL5-83	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	75.47	1.22456	2.97	2.42	151.4	0.51	7.49	20.21
3/23/05	UMP 1	N44	*Anodonta californiensis*	John Day, Middle Fork, Fishing Hole	30.64	0.07232				0.21	53.30	
3/23/05	UMP 1	N56	*Anodonta californiensis*	John Day, Middle Fork, Fishing Hole	38.75	0.31121				0.34	19.62	
3/23/05	UMP 1	F-5	*Anodonta californiensis*	John Day, Middle Fork, Fishing Hole	39.5	0.35918	2.46	6.84	427.4	0.23	11.63	36.75
3/23/05	UMP 1	N60	*Anodonta californiensis*	John Day, Middle Fork, Fishing Hole	43.50	0.34458				0.40	20.70	
3/23/05	UMP 1	F-6	*Anodonta californiensis*	John Day, Middle Fork, Fishing Hole	44.1	0.40414				0.34	13.48	
3/23/05	UMP 1	F-3	*Anodonta californiensis*	John Day, Middle Fork, Fishing Hole	48.13	0.51453				0.17	5.95	
3/23/05	UMP 1	N61	*Anodonta californiensis*	John Day, Middle Fork, Fishing Hole	48.05	0.4999	2.08	4.15	259.5	0.31	12.21	21.25
3/23/05	UMP 1	F-7	*Anodonta californiensis*	John Day, Middle Fork, Fishing Hole	50.42	0.47471				0.49	18.61	
3/23/05	UMP 1	N72	*Anodonta californiensis*	John Day, Middle Fork, Fishing Hole	55.99	0.66466	9.57	14.39	899.5	0.45	12.27	73.33
3/23/05	UMP 1	N37	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	72.84	1.29061	9.17	7.11	444.1	0.70	9.75	45.57
3/23/05	UMP 2	N57	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	46.26	0.43267	14.84	34.31	2144.3	0.47	19.64	109.18
3/23/05	UMP 2	N16	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	74.13	1.25969	7.12	5.65	353.4	1.02	14.57	24.26
3/23/05	UMP 2	N35	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	59.02	0.81548	14.37	17.63	1101.6	0.89	19.59	56.24
3/23/05	UMP 2	N68	*Margaritifera falcata*	John Day, North Fork	65.28	1.06919				0.16	2.71	
3/23/05	UMP 2	N69	*Margaritifera falcata*	John Day, North Fork	60.35	0.92344	5.37	5.81	363.4	0.26	5.15	70.57
3/23/05	UMP 2	N46	*Margaritifera falcata*	John Day, North Fork	67.43	1.72424				0.70	10.24	
3/23/05	UMP 2	F-4	*Margaritifera falcata*	John Day, North Fork	53.33	0.63279	14.01	22.14	1384.0	0.57	16.25	65.17
3/23/05	UMP 2	F-8	*Margaritifera falcata*	John Day, North Fork	69.94	1.27086				0.00	0.00	
3/23/05	UMP 2	AL5-94	*Margaritifera falcata*	John Day, North Fork	89.07	1.70435	6.28	3.69	230.3	0.93	9.80	23.51
3/23/05	UMP 2	N53	*Margaritifera falcata*	John Day, North Fork	83.93	1.92749	18.07	9.37	585.9	0.07	0.67	875.44
3/23/05	UMP 2	N51	*Margaritifera falcata*	John Day, North Fork	73.09	1.32896	15.25	11.49	718.2	0.11	1.45	494.43
3/23/05	UMP 2	N71	*Margaritifera falcata*	John Day, North Fork	60.97	0.77251				0.46	10.82	
6/22/05	UMP 3	1001	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	34.52	0.159125				1.69	190.53	
6/22/05	UMP 3	1002	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	36.95	0.24788				2.31	167.79	
6/22/05	UMP 3	1003	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	44.88	0.47205	20.19	42.77	2673.0	2.47	94.21	28.37
6/22/05	UMP 3	1004	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	52.05	0.58172	6.42	11.03	689.7	2.10	65.10	10.59
6/22/05	UMP 3	1005	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	60.74	0.80336				3.00	67.22	
6/22/05	UMP 3	1006	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	69.22	1.23568	37.16	30.08	1879.7	4.38	63.80	29.46
6/22/05	UMP 3	1007	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	71.26	1.3446	43.88	32.63	2039.5	4.95	66.25	30.79
6/22/05	UMP 3	1008	*Anodonta californiensis*	John Day, Middle Fork, Fishing Hole	33.41	0.13307	3.41	25.60	1600.1	1.44	195.38	8.19
6/22/05	UMP 3	1009	*Anodonta californiensis*	John Day, Middle Fork, Fishing Hole	36.76	0.14043				0.99	125.93	
6/22/05	UMP 3	1010	*Anodonta californiensis*	John Day, Middle Fork, Fishing Hole	37.72	0.22439	15.36	68.45	4278.3	1.84	147.50	29.01
6/22/05	UMP 3	1011	*Anodonta californiensis*	John Day, Middle Fork, Fishing Hole	43.4	0.3445				1.15	60.12	
6/22/05	UMP 3	1012	*Anodonta californiensis*	John Day, Middle Fork, Fishing Hole	47.93	0.40515	19.25	47.51	2969.1	2.79	123.70	24.00
6/22/05	UMP 3	1013	*Anodonta californiensis*	John Day, Middle Fork, Fishing Hole	49.39	0.44121	24.47	55.46	3466.0	2.47	100.69	34.42
6/22/05	UMP 3	1014	*Anodonta californiensis*	John Day, Middle Fork, Fishing Hole	49.61	0.41578	22.18	53.34	3333.8	2.95	127.63	26.12
6/22/05	UMP 3	1015	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	47.62	0.50267	26.97	53.66	3353.8	2.27	81.42	41.19
6/22/05	UMP 3	1016	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	57.08	0.75307				3.84	91.81	
6/22/05	UMP 3	1017	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	57.65	0.82887	46.84	56.51	3531.9	4.39	95.75	37.08
6/22/05	UMP 3	1018	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	65.39	0.9625	58.95	61.24	3827.8	3.45	64.50	59.35
6/22/05	UMP 3	1019	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	67.73	1.22225	18.94	15.50	968.6	5.86	86.28	11.23
6/22/05	UMP 3	1020	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	76.13	1.41094	50.54	35.82	2238.9	6.08	77.37	28.94
6/22/05	UMP 3	1021	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	79.29	2.18877	10.95	5.00	312.8	8.22	67.62	4.63
6/22/05	UMP 4	1049	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	60.3	0.86587	29.19	33.71	2106.8	2.72	56.61	37.22
6/22/05	UMP 4	1050	*Margaritifera falcata*	John Day Middle Fork, Wildcat Point	68.97	1.10356	29.62	26.84	1677.4	3.50	57.16	29.35
6/22/05	UMP 4	1051	*Margaritifera falcata*	John Day Middle Fork, Wildcat Point	71.95	1.43865	57.51	39.98	2498.4	4.01	50.16	49.81
6/22/05	UMP 4	1052	*Margaritifera falcata*	John Day Middle Fork, Wildcat Point	80.39	1.74080	49.91	28.67	1791.9	5.24	54.20	33.06
6/22/05	UMP 4	1053	*Anodonta californiensis*	John Day Middle Fork, Wildcat Point	47.72	0.32980	30.08	93.54	5846.0	2.53	137.08	42.40
6/22/05	UMP 4	1054	*Anodonta californiensis*	John Day Middle Fork, Wildcat Point	50.27	0.56417	14.04	24.89	1555.8	3.76	120.02	12.96
6/22/05	UMP 4	1055	*Anodonta californiensis*	John Day Middle Fork, Wildcat Point	53.8	0.51134	7.91	15.47	968.6	4.48	157.13	6.15

Date	Experiment Name[1]	Mussel ID	Mussel Species	River	Shell Length (mm)	Dry Tissue Weight (g)	Oxygen Consumption Rate (ml O_2 h^{-1})	Weight-Specific Oxygen Consumption Rate (ml O_2 h^{-1} g^{-1})	Weight-Specific Oxygen Consumption Rate (µg at O2-O h^{-1} g^{-1})	Ammonia Excretion (µM h^{-1})	Weight-Specific Ammonia Excretion (µg at NH4-N h^{-1} g^{-1})	O:N Ratio
6/22/05	UMP 4	1056	*Margaritifera falcata*	John Day Middle Fork, Big Boulder Crk	37.14	0.24883	17.72	71.79	4487.1	1.49	108.48	41.36
6/22/05	UMP 4	1057	*Margaritifera falcata*	John Day Middle Fork, Big Boulder Crk	54.18	0.62431	61.77	98.93	6193.3	1.63	43.91	131.82
6/22/05	UMP 4	1058	*Margaritifera falcata*	John Day Middle Fork, Big Boulder Crk	68.2	1.32746	24.23	18.29	1143.3	3.58	53.98	21.18
6/22/05	UMP 4	1059	*Margaritifera falcata*	John Day Middle Fork, Big Boulder Crk	86.18	2.58718				6.73	48.78	
6/22/05	UMP 4	1060	*Margaritifera falcata*	John Day Middle Fork, Big Boulder Crk	99.14	0.86858	25.39	29.30	1831.0	9.19	190.97	9.59
6/22/05	UMP 4	1061	*Anodonta californiensis*	John Day Middle Fork Ritter Hot Springs	35.65	0.15057	15.53	103.55	6472.1	1.99	238.05	27.19
6/22/05	UMP 4	1062	*Anodonta californiensis*	John Day Middle Fork Ritter Hot Springs	48.5	0.81901	7.00	8.55	534.1	2.98	65.43	8.17
6/22/05	UMP 4	1063	*Anodonta californiensis*	John Day Middle Fork Ritter Hot Springs	59.9	0.36502	32.98	90.30	5643.8	2.25	110.74	53.96
6/22/05	UMP 4	1064	*Margaritifera falcata*	John Day, North Fork	36.99	0.22541	1.23	5.48	339.4	2.25	180.02	1.38
6/22/05	UMP 4	1065	*Margaritifera falcata*	John Day, North Fork	50.81	0.45278				2.29	94.97	
6/22/05	UMP 4	1066 +1071	*Margaritifera falcata*	John Day, North Fork	63.65	2.85904	44.14	15.44	964.9	3.65	22.98	41.99
6/22/05	UMP 4	1067	*Margaritifera falcata*	John Day, North Fork	73.52	1.1906				5.67	85.74	
6/22/05	UMP 4	1068	*Margaritifera falcata*	John Day, North Fork	80.74	1.65206	9.26	5.60	350.2	4.91	53.43	6.55
6/22/05	UMP 4	1069	*Margaritifera falcata*	John Day, North Fork	83.93	1.62877	333.74	198.04	12428.2	7.08	75.95	163.79
10/9/05	UMP 5	2983	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	21.28	0.0591	18.00	304.52	19032.7	1.96	596.19	31.92
10/9/05	UMP 5	2984	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	44.51	0.36546				2.34	115.25	
10/9/05	UMP 5	2985	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	53.98	0.65858	37.83	57.44	3589.8	3.11	84.88	42.30
10/9/05	UMP 5	2986	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	49.36	0.53585				2.75	92.21	
10/9/05	UMP 5	2987	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	62.37	0.90896				3.74	74.17	
10/9/05	UMP 5	2988	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	77.8	1.62004	25.88	22.15	1384.6			
10/9/05	UMP 5	2989	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	65.28	2.44109	46.43	19.02	1188.8	6.63	50.36	23.60
10/9/05	UMP 5	2990	*Anodonta californiensis*	John Day, Middle Fork, Fishing Hole	36.24	0.21235	12.62	59.42	3713.9	2.12	179.68	20.67
10/9/05	UMP 5	2991	*Anodonta californiensis*	John Day, Middle Fork, Fishing Hole	37.51	0.20339				3.04	268.82	
10/9/05	UMP 5	2992	*Anodonta californiensis*	John Day, Middle Fork, Fishing Hole	39.92	0.2734	3.23	11.83	739.2	1.41	95.00	7.76
10/9/05	UMP 5	2993	*Anodonta californiensis*	John Day, Middle Fork, Fishing Hole	41.84	0.29755				1.19	72.28	
10/9/05	UMP 5	2994	*Anodonta californiensis*	John Day, Middle Fork, Fishing Hole	44.9	0.46129				2.28	88.92	
10/9/05	UMP 5	2995	*Anodonta californiensis*	John Day, Middle Fork, Fishing Hole	47.95	0.50312	38.90	77.32	4832.5	1.35	48.39	99.87
10/9/05	UMP 5	2996	*Anodonta californiensis*	John Day, Middle Fork, Fishing Hole	48.51	0.56753	34.72	61.18	3823.7	3.49	110.63	34.56
10/9/05	UMP 5	2997	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	44.74	0.43909				1.80	73.93	
10/9/05	UMP 5	2998	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	47.09	0.58417				2.41	75.81	
10/9/05	UMP 5	2999	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	57.31	0.94179	30.46	32.34	2021.6	2.90	55.47	36.41
10/9/05	UMP 5	3000	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	60.83	1.06527	42.81	40.19	2509.6	3.76	63.44	39.56
10/9/05	UMP 5	693	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	73.03	1.63361	51.61	31.59	1974.6	3.71	40.91	48.26
10/9/05	UMP 5	694	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	77.39	2.6579	42.65	16.05	1002.8	4.97	33.68	29.78
10/9/05	UMP 5	695	*Gonidea sp.*	John Day, Middle Fork, Fishing Hole	78.58	2.26955				4.01	31.77	
10/9/05	UMP 5	696	*Margaritifera falcata*	John Day Middle Fork, Big Boulder Crk	44.78	0.28026				2.50	160.40	
10/9/05	UMP 5	697	*Margaritifera falcata*	John Day Middle Fork, Big Boulder Crk	65.34	1.06597	15.33	14.37	898.2	1.83	30.80	29.16
10/9/05	UMP 5	698	*Margaritifera falcata*	John Day Middle Fork, Big Boulder Crk	69.73	1.07891				1.87	31.13	
10/9/05	UMP 5	699	*Margaritifera falcata*	John Day Middle Fork, Big Boulder Crk	65.19	1.03736				3.02	52.32	
10/9/05	UMP 5	700	*Margaritifera falcata*	John Day Middle Fork, Big Boulder Crk	70.05	1.1411	45.23	39.62	2476.4	2.68	42.22	58.65
10/9/05	UMP 5	701	*Margaritifera falcata*	John Day Middle Fork, Big Boulder Crk	73.4	1.24833				3.04	43.80	
10/9/05	UMP 5	702	*Margaritifera falcata*	John Day Middle Fork, Big Boulder Crk	78.7	1.66025	30.28	18.14	1133.5	2.77	29.88	37.96
10/9/05	UMP 5	703	*Margaritifera falcata*	John Day, North Fork	60.61	0.9109	9.56	10.49	655.9	2.48	49.01	13.38
10/9/05	UMP 5	704	*Margaritifera falcata*	John Day, North Fork	61.28	0.92951				2.61	51.08	
10/9/05	UMP 5	705	*Margaritifera falcata*	John Day, North Fork	67.29	1.20233	30.59	25.44	1590.2	3.15	47.18	33.72
10/9/05	UMP 5	706	*Margaritifera falcata*	John Day, North Fork	74.09	1.48121	31.02	20.95	1309.1	3.97	48.22	27.15
10/9/05	UMP 5	707	*Margaritifera falcata*	John Day, North Fork	79.88	1.7652				6.57	67.00	
10/9/05	UMP 5	708	*Margaritifera falcata*	John Day, North Fork	90.01	2.31003	17.09	7.37	460.9	3.95	30.64	15.04
10/9/05	UMP 5	709	*Margaritifera falcata*	John Day, North Fork	93.67	2.99965	31.88	10.62	663.7	7.58	45.48	14.30
3/20/06	UMP 6	997	*Margaritifera falcata*	John Day Middle Fork, Big Boulder Crk	69.78	0.98003				3.80	69.85	
3/20/06	UMP 6	955	*Margaritifera falcata*	John Day Middle Fork, Big Boulder Crk	71.50	1.38730				0.00	0.00	
3/20/06	UMP 6	956	*Margaritifera falcata*	John Day Middle Fork, Big Boulder Crk	71.88	1.17983				4.36	66.50	
3/20/06	UMP 6	957	*Margaritifera falcata*	John Day Middle Fork, Big Boulder Crk	72.65	1.60987				4.96	55.15	
3/20/06	UMP 6	958	*Margaritifera falcata*	John Day Middle Fork, Big Boulder Crk	76.43	1.01311				1.05	18.37	
3/20/06	UMP 6	959	*Margaritifera falcata*	John Day Middle Fork, Big Boulder Crk	83.29	1.97059				0.12	1.08	
3/20/06	UMP 6	960	*Margaritifera falcata*	John Day Middle Fork, Big Boulder Crk	88.39	1.8839				5.48	52.37	
3/20/06	UMP 6	962	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	29.79	0.25189				1.79	127.79	
3/20/06	UMP 6	963	*Margaritifera falcata*	John Day, Middle Fork, Fishing Hole	44.6	0.42368				1.65	70.24	

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3/20/06	UMP 6	964	*Margaratifera falcata*	John Day, Middle Fork, Fishing Hole	79.76	0.52437				0.37	12.76	
3/20/06	UMP 6	965	*Margaratifera falcata*	John Day, Middle Fork, Fishing Hole	52.48	0.4918				1.36	49.67	
3/20/06	UMP 6	967	*Margaratifera falcata*	John Day, Middle Fork, Fishing Hole	66.27	1.03728				0.40	6.85	
3/20/06	UMP 6	968	*Margaratifera falcata*	John Day, Middle Fork, Fishing Hole	68.68	1.35577				3.00	39.83	
3/20/06	UMP 6	969	*Margaratifera falcata*	John Day, Middle Fork, Fishing Hole	66.95	1.05091				0.00		
3/20/06	UMP 6	970	*Margaratifera falcata*	John Day, North Fork	46.04	0.31468				1.28	73.15	
3/20/06	UMP 6	971	*Margaratifera falcata*	John Day, North Fork	58.19	0.68817				0.19	4.91	
3/20/06	UMP 6	972	*Margaratifera falcata*	John Day, North Fork	67.75	0.84523				5.48	116.71	
3/20/06	UMP 6	973	*Margaratifera falcata*	John Day, North Fork	70.65	1.17072				0.00		
3/20/06	UMP 6	974	*Margaratifera falcata*	John Day, North Fork	73.09	1.45121				0.19	2.31	
3/20/06	UMP 6	975	*Margaratifera falcata*	John Day, North Fork	80.22	1.66931				1.43	15.42	
3/20/06	UMP 6	976	*Margaratifera falcata*	John Day, North Fork	79.95	1.55778				2.41	27.84	
3/20/06	UMP 6	977	Gonidea sp.	John Day, Middle Fork, Fishing Hole	44.13	0.33296				0.00		
3/20/06	UMP 6	978	Gonidea sp.	John Day, Middle Fork, Fishing Hole	46.43	0.46128				0.00		
3/20/06	UMP 6	979	Gonidea sp.	John Day, Middle Fork, Fishing Hole	53.26	0.60684				0.00		
3/20/06	UMP 6	980	Gonidea sp.	John Day, Middle Fork, Fishing Hole	56.48	0.87511				0.00		
3/20/06	UMP 6	981	Gonidea sp.	John Day, Middle Fork, Fishing Hole	65.06	1.12511				0.14	2.23	
3/20/06	UMP 6	982	Gonidea sp.	John Day, Middle Fork, Fishing Hole	74.13	1.39633				0.21	2.70	
3/20/06	UMP 6	983	Gonidea sp.	John Day, Middle Fork, Fishing Hole	77.85	2.25529				0.00		
3/20/06	UMP 6	984	*Anodonta californianus*	John Day, Middle Fork, Fishing Hole	34.87	0.13489				1.66	222.11	
3/20/06	UMP 6	985	*Anodonta californianus*	John Day, Middle Fork, Fishing Hole	37.22	0.13925				1.41	182.19	
3/20/06	UMP 6	986	*Anodonta californianus*	John Day, Middle Fork, Fishing Hole	38.7	0.13506				0.00		
3/20/06	UMP 6	987	*Anodonta californianus*	John Day, Middle Fork, Fishing Hole	42.96	0.3708				1.58	76.83	
3/20/06	UMP 6	988	*Anodonta californianus*	John Day, Middle Fork, Fishing Hole	46.56	0.55717				0.94	30.37	
3/20/06	UMP 6	989	*Anodonta californianus*	John Day, Middle Fork, Fishing Hole	50.83	0.57145				0.00		
3/20/06	UMP 6	992	*Anodonta californianus*	John Day, Middle Fork, Fishing Hole	50.53	0.45865				1.98	77.86	
3/20/06	UMP 6	993	*Anodonta oregonensis?*	Umatilla - Hermiston Bridge (new)	56.1	0.69561				0.00		
3/20/06	UMP 6	994	*Anodonta oregonensis?*	Umatilla - Hermiston Bridge (new)	85.14	1.58972				0.00		
3/20/06	UMP 6	995	*Anodonta oregonensis?*	Umatilla - Hermiston Bridge (new)	92.13	2.05096				5.30	46.50	
3/20/06	UMP 6	998	*Anodonta californianus*	Umatilla - Hermiston Bridge (new)	67.78	0.816				4.67	103.05	