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Population Characteristics of Native Freshwater Mussels in the mid-Columbia and Clearwater Rivers, Washington State

Abstract

Freshwater mussels are thought to have declined in abundance and changed in species composition in the Columbia River in recent years. We surveyed the 118 km of river between Vernita Bridge and Wallula Gap and found only two small aggregations of floaters (*Anodonta* spp.) and no western pearlshell mussels (*Margaritifera falcata)*, a species which was formerly dominant in the river. One of the floater aggregations appears to have been nearly extirpated but may be recovering, while the other aggregation appears to be stable. Scattered individual floaters were also found in McNary Reservoir. Two populations of western pearlshell mussels were studied in the Clearwater River in Jefferson County, WA for comparison. The Clearwater populations were large, densely aggregated, of multiple size classes, and showed little evidence of mortality. Mussel tissues from each site were analyzed for lipid content and levels of arsenic, mercury, and organochlorine pesticides. The highest lipid content and mercury concentration were found in mussels from the Clearwater River. Arsenic concentration and organochlorine pesticides were highest in mussels in the Columbia River. Overall, the mussel aggregations within the Columbia River were small, scattered, and provided a marked contrast to the flourishing mussel beds in the Clearwater River. These results suggest that Columbia River mussels have both declined and changed in species composition over the last century.

Introduction

Freshwater mussels, which provide important ecosystem services such as water filtration (Frest and Johannes 1992), are increasingly becoming recognized as an important component of aquatic ecosystems. Healthy mussel populations can maintain water quality by removing suspended particles, pollutants, nitrates, and phosphates (Baker and Levinton 2003). Unfortunately these same characteristics make mussels vulnerable to anthropogenic influences such as increased turbidity, pollutants, and elevated temperatures (Bogan 1993, Skinner et al. 2003, Van Hassel and Farris 2007). Freshwater mussels are increasingly threatened in North America (Williams et al. 1993, Stein et al. 2000). Three genera of freshwater mussels occur in the Pacific Northwest, including the western pearlshell *Margaritifera falcata* (Gould 1850), the western ridged mussel *Gonidea angulata* (I. Lea 1838), and five species of floater mussels (*Anodonta spp.*) (Stock 1996, Nedeau et al. 2005). Although information is spotty, the few recent observations that exist combined with evidence from archaeological middens suggest that freshwater mussel populations, especially the western pearlshell, have declined in the middle reaches of the Columbia River between Vantage and Wallula Gap, the area of interest for this study.

The western pearlshell is a long-lived species adapted to clean, flowing water (Stober 1972, Toy 1998). Lifespan for both it and its sister species, the eastern pearlshell (*M. margaritifera)*, may range to over 100 years which would place them among the longest-lived invertebrates known (Roscoe and Redelings 1964, Bauer 1992, Stock 1996, Ziuganov et al. 2000). An adult pearlshell may filter 2-6 L of water per hour but will stop feeding and close up if water quality declines (Baker and Levinton 2003). Factors that can trigger closure include increased turbidity and low dissolved oxygen (Roscoe and Redelings 1964). Increased sediment influx was found to be correlated with a replacement of western pearlshells with more sediment-tolerant species such as the western ridged mussel (Vannote and Minshall 1982). Floater mussels are also often more abundant than the western pearlshell in sediment-prone conditions (Clarke 1981, Frest and Johannes 1995).

Although historical and midden evidence suggests that the western pearlshell was one of the most common bivalves in the Columbia River drainage in the past (Landye 1973, Lyman 1980), current known occurrences for the species in this region, especially in the Columbia River itself, are very limited. In the mid-Columbia River, western

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pearlshells have been reported near the Energy Northwest power station in Benton County and at Leslie Groves Park in Richland (Newell 2003). A few dead shells have been found near White Bluffs and some scattered sightings of individuals have been reported along the Hanford Reach. Most current records of western pearlshell populations in the area are from small tributaries. The main known populations exist on the Middle Fork of the John Day River (Brim Box et al. 2006) and in the Little Walla Walla River north of the Washington State line (Confederated Tribes of the Umatilla Indian Reservation 2004).

The five floater species which inhabit the Columbia River drainage have a natural history similar to that of other unionid mussels. Species distinctions among floaters are not always clear and in this paper we will usually refer them simply as floaters except where species can be clearly differentiated. Floaters reproduce using a similar strategy as western pearlshells (Frest and Johannes 1995). The host fish species for floaters in the Pacific Northwest are currently unknown, though glochidia from other floater species are known to have a variety of fish hosts (Fuller 1974, Lima et al. 2006). Floaters tend to be more abundant than the western pearlshell in muddy and sandy regions in rivers, slow-flowing streams, and lakes (Clarke 1981, Frest and Johannes 1995). Comparison of current mussel species abundances with prehistoric midden contents, of which floaters were only a small component, suggests that in the present day Columbia River floaters are more common than in the past.

Freshwater mussels in the Columbia River are a potentially imperiled group. Our objectives were to assess the abundance and population structure of freshwater mussels in the Columbia River between Vernita Bridge and Wallula Gap. We used the Clearwater River on the Olympic Peninsula, Washington where the western pearlshell continues to thrive as a reference location. We also report the levels of several important pollutants found within mussel tissues collected from these areas.

Methods

River Surveys

Surveys for mussels were conducted along a 118 km stretch in the middle reaches of the Columbia River (Figure 1A) and a 2 km stretch of the Clearwater River (Figure 1B) for comparison. The Columbia River sites spanned from Vernita Bridge, on the free-flowing reach below Priest Rapids Dam down to Wallula Gap, which is within McNary Reservoir. Sites over knee deep were snorkeled,

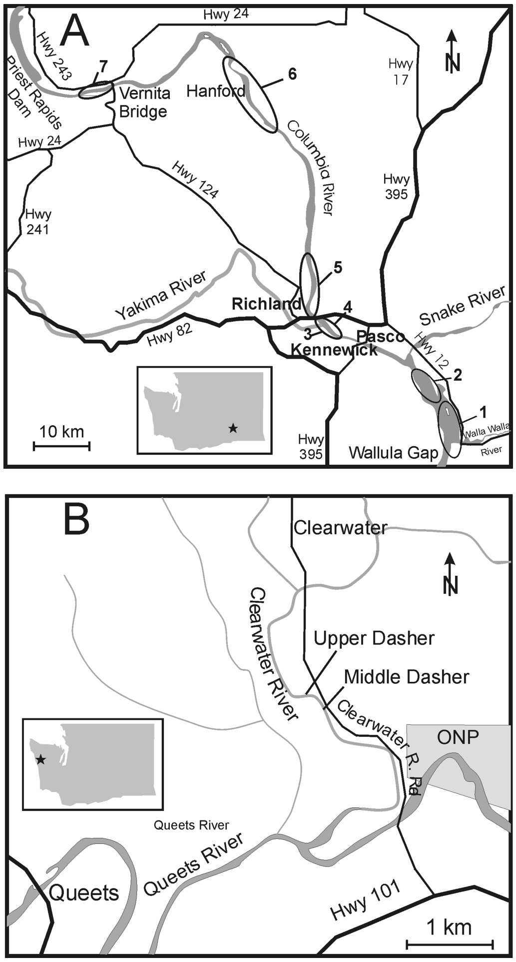

Figure 1. Survey and mussel locations in this study. A. Columbia River from Priest Rapids Dam to Wallula Gap. Numbered areas indicate locations that were searched for freshwater mussels. (1) Walla Walla River mouth and Wallula Gap, (2) Peninsula Management Unit, (3) Bateman Island, (4) Pasco, (5) Richland, (6) Hanford Townsite, (7) Vernita Bridge. Areas 6 and 7 and the upper half of area 5 are in the free-flowing Hanford Reach portion of the river, whereas areas 1-4 and the lower half of 5 are in McNary Reservoir. Live *Anodonta spp.* mussels were only found in areas 4, 5, and 6. B. Lower Clearwater River, Jefferson County, WA. Abundant live *Margaritifera falcata* mussels were found at both the upper and middle Dasher sites. The inset on both maps shows map location in Washington State.

shallower sites were waded using an underwater viewing box, and the shoreline was examined for dead shells. Sites examined most closely were those with characteristics known to be associated with mussels, such as shallows, backwaters, and eddies or other habitats that could provide refuge at high flow; or sites at which mussels had been reported by the public or other biologists. Sites not visited included areas with known high turbidity, heavy boat traffic, high current speeds, proximity to water intakes, or that were otherwise inaccessible. We examined a total of 100.5 km of habitat along the 118 km reach of the Columbia and 2 km of the Clearwater. Details of individual sites surveyed are listed in Helmstetler (2006). Mussels tend to be found in groups separated by large areas devoid of mussels. We called these groups aggregations if more than one mussel species was present, and populations if the group consisted of only one species.

Population Sampling

Every mussel, either live or dead, found in the small Columbia aggregations (all of which contained < 100 individuals) was measured, whereas in the much larger Clearwater populations a stratified random sampling method distributed across the entire group was used (Strayer and Smith 2003, Helmstetler 2006). Live individuals were keyed using Nedeau et al. (2005), measured for shell length, width, height, drained wet mass, and ligament length (measured from the umbo to the end of the ligament, Toy [1998]) and their spatial position within the population was noted. Dead shells were keyed and measured for length, width, height, and ligament length and retained, while most live mussels were returned to their pre-sampling location. Several live individuals representing the size range present at each site were retained and frozen at -80 °C until analyzed for pollutant accumulation.

Tissue Lipid and Pollutant Levels

Tissue levels of pollutants were analyzed from Middle Dasher (n = 4),Richland (2), and Hanford Townsite (2) sites. All tissue of all individuals from each site was homogenized and combined into a single sample in order to obtain the 40g needed for analysis. These homogenized samples were shipped on dry ice to Columbia Analytical Services (Kelso, WA) for analysis. Frozen samples were freeze dried, weighed, and then analyzed for total lipid content using EPA Method 3540 (detection limit [DL] 0.05%), arsenic using EPA Method 200.8 (DL 0.5 ppm), mercury using EPA Method 7471A (DL 0.02 ppm), and for organochlorine pesticides using EPA Method 8081A (DL for most chlorinated pesticides 1.0 to 2.0 ppb, 50 ppb for toxaphene).

Results

River Surveys

Of the mussel species surveyed, no live or dead western pearlshells were found within the Columbia River. The only live mussels found in the Columbia River were floaters found at the Hanford Townsite and at Richland (Table 1, Figure 1A), and along the north shore of the McNary Reservoir in Pasco. Live western pearlshell mussels were abundant in the Clearwater River, although we did not find floaters or ridgeback mussels.

Population Characteristics

All mussels at the Hanford Townsite were found between 3-6 m depth near a large wooden pipe about 40 cm in diameter which protrudes from a groin on the western shore. The pipe emerges from the groin about 20 m from shore and proceeds directly across the mouth of a large backwater toward the main stem of the river. The site experiences variable and reversible flow influenced by the discharge rate at Priest Rapids Dam but is

TABLE 1. Characteristics of the mussel populations at each site where mussels were found

River	Site	Species Found	Aggregation Area m^2	Live	Dead	Live per m^2
Columbia	Hanford	*Anodonta* spp	125	82	9	0.66
	Richland	*Anodonta* spp	1560	16	107	0.01
Clearwater	Upper Dasher	*M. falcata*	80	690	0	8.6
	Middle Dasher	*M. falcata*	700	15000	6	21.4

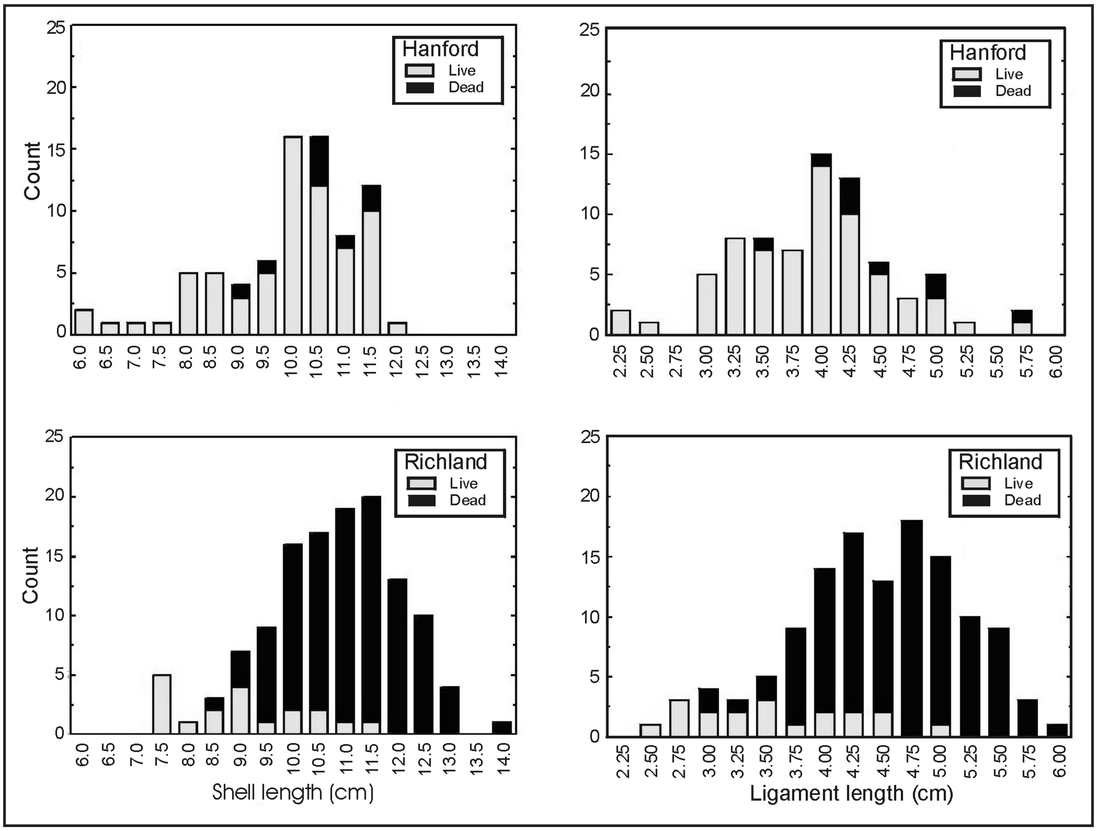

Figure 2. Size distribution of shell and ligament lengths for live and dead floater (*Anodonta spp*.) mussels observed at the Richland (n = 14 live, 77 dead) and Hanford Sites (n = 58 live, 9 dead) of the Columbia River.

separated from the thalweg by a shallow bar. The bottom was composed of mixed cobble except in the area within 2 to 3 m of the pipe where up to 20 cm of sand has accumulated. Mussels were sparsely located in the cobble, common in the sand, and abundant under the edges of the pipe. In places the wooden pipe has broken and the fine silty sand inside the pipe is densely packed with floater mussels and the Asian clam *Corbicula fluminea* (O. F. Müller, 1774), an introduced freshwater bivalve. No western pearlshells were found. The smallest floaters were found within the pipe. We counted 82 live floaters and 9 dead shells in the portion of this site we were able to survey, or approximately 9 live individuals for every one dead shell (Figure 2). We were not able to examine the deepest portion of the site most distant from shore, and more individuals may have been present there. Many small floaters were present and mortality was confined mainly to the larger size classes.

The Richland aggregation was immediately upstream of the water intake structure for the City of Richland. It was mostly within a 13 m wide by 120 m long swath that was centered approximately 25 m from the west shore of the river and began approximately 10 m upstream of the intake structure. More mussels may occur near the intake, which was not sampled for safety reasons. The flow at this site was variable because it is near the interface between the free-flowing Hanford Reach above and McNary Reservoir below. The substrate was primarily a sand, silt, and cobble mix with occasional boulders ranging from 0.5 to 1m in diameter. Besides a large patch of aquatic vegetation at the lower end, other tufts of aquatic vegetation were found thinly scattered throughout the aggregation. Several small brush piles were also scattered throughout the site.

At the Richland site we found 16 live floaters and 107 dead shells, or a ratio of approximately

6.7 dead shells per live individual observed (Figure 2). Live and dead individuals were intermixed.

Scattered floater individuals were found in the McNary reservoir along the north side of the Columbia River between Road 108 and Chiawanna Park in Pasco, with a maximum density of approximately 1 per 1000 m^2. The substrate was mixed cobble with occasional large submerged boulders and cement blocks and large patches of aquatic vegetation. This area was searched from shore to 3 m depth, with the majority of mussels being found near 1 m depth at low water.

At least 50 dead floater shells were found at the Walla Walla River delta but we found no live individuals despite intensive searching. Extreme turbidity of the water in this area hampered visual searches. Flow was variable and influenced both by the level of the McNary reservoir and the flow rate of the Walla Walla River. The substrate was a mixture of sand, silt, and clay with areas ranging from nearly pure sand to heavy clay. Individual dead shells were found scattered throughout the site with no obvious pattern of distribution.

The Upper Dasher population, consisting of 690 western pearlshells, was located 3.5 km upstream from the confluence of the Clearwater with the Queets River (Figure 1B). The population extended 5 m from shore and 20 m in length in a backwater behind a gravel bar on the outside portion of a bend in the river. At high flow the population is likely more directly in the flow due to overtopping of the gravel bar. The depth during baseflow ranged from 0.05 to 1.35 m. Two-thirds of the population occurred in sandy substrate, while the shoreward third was found mainly in gravel and pondweed (*Potamogeton* spp.). Population density at the site averaged 8.6 m^{-2} with maximum densities reaching 39 m^{-2}. No dead mussels were found at the site.

The Middle Dasher population of western pearlshells was located approximately 400 m downstream from the upper site (Figure 1B). This population extended 7.5 m from the shore at the downstream end and 12 m from shore at the upstream end with a total length of 69 m. The upstream extent of the population was located within a backwater at low flow that was protected by a gravel bar. Current at base flow was negligible in the backwater and near shore while the downstream and outer regions were more affected by current. None of the population was in the thalweg although current would likely increase substantially during times of greater flow due to overtopping the gravel bar. Substrate at the downstream end was dominated by large boulders and bedrock. The middle and upper regions were primarily cobble and gravel with the backwater area being covered by aquatic vegetation and algae . Much of the Middle Dasher population was shaded by overhanging red alder (*Alnus rubra*).

The Middle Dasher population was comprised of about 15,000 western pearlshell mussels covering approximately 700 m^2. The densest 1/25 m^2 contained 25 mussels at a density of 625 m^{-2}while the densest full 1m^2 contained 223 live mussels. Average population density was about 20 m^{-2}. Actual densities ranged from patches such as bedrock devoid of mussels except in cracks to the patch with 223 m^{-2}. Only six dead shells were found within this population.

The size of individual floaters at the Richland site approximated a normal distribution in size, with the majority of mussels being between 10 and 12.5 cm in shell length and 4 to 5.25 cm ligament length (Figure 2). This aggregation, however, was primarily comprised of dead shells. The few live mussels found at the site were all shorter than 12 cm in shell length and 5.25 cm in ligament length. Dead individuals averaged significantly larger size than the live individuals (t-test, $P<0.01$, t-test; Figure 2), and all of the largest individuals found at the site were dead. Floaters at the Hanford site also exhibited an approximately normal distribution, or one skewed toward the smaller sizes (Figure 2). Most mussels at Hanford Townsite were between 3.25 and 4.5 cm in ligament length and 10 and 12 cm in shell length. The few dead shells that were found were large. Both western pearlshell populations in the Clearwater River exhibited a normal distribution when arranged by either ligament length or shell length (Figure 3). The majority of mussels found were between 2.75 and 3.75 cm in ligament length and 6.75 to 9.25 cm shell length.

Lipid and Pollutant Levels in Mussel Tissues

The Clearwater mussels had double the lipid content of the Columbia River mussels (Table 2). Mercury was also 4 times higher in the Clearwater mussels than in those from the Columbia. Arsenic levels were highest at the Richland Site, followed by the Hanford Townsite. The DDT breakdown

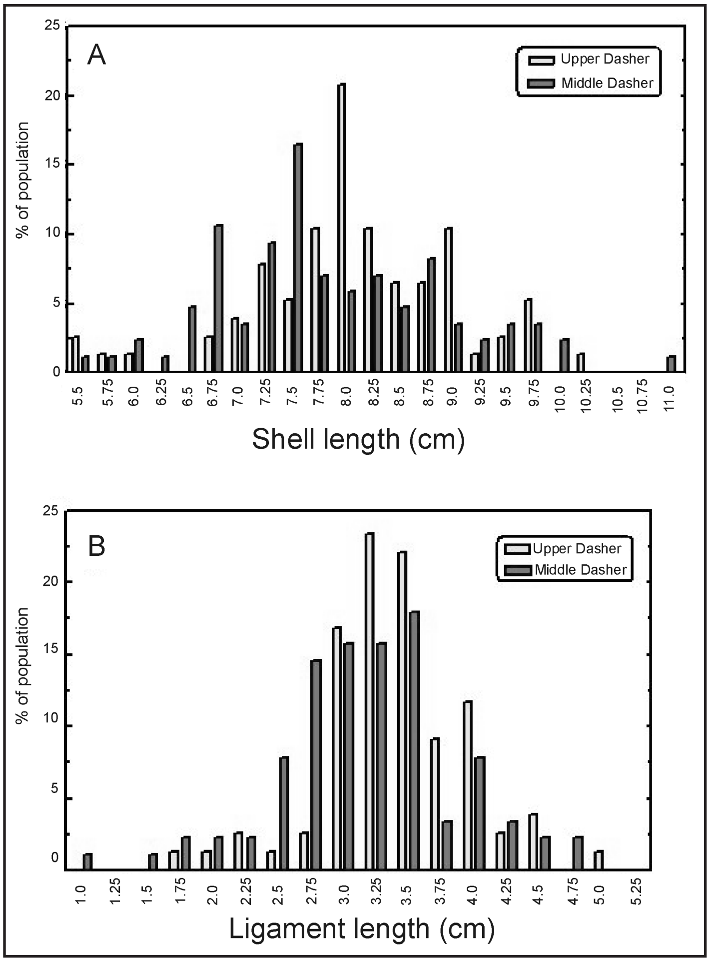

Figure 3. A: Shell length and B: ligament length for all live western pearlshell (*Margaritifera falcata)* measured in the Upper (n = 78) and Middle Dasher (n = 89) populations in the Clearwater River.

TABLE 2. Lipid and pollutant concentrations (by wet weight) in the tissues of freshwater mussels collected at three study sites (Middle Dasher in the Clearwater River and Richland and Hanford in the Columbia River) in 2005. Values for each site are based upon a single composite sample from several individuals. Values of ND were below the detection limit of the assay (see Methods). The Hanford and Richland mussels were floaters and the Middle Dasher mussels were western pearlshells. DDD = dichloro-diphenyl dichloroethane, DDE = dichloro-diphenyl dichloroethylene, DDT = dichloro-diphenyl chloroethane, BHC = hexachlorocyclohexane. Pesticides tested for but not detected: alpha-BHC, beta-BHC, gamma-BHC (Lindane), delta-BHC, Heptachlor, Heptachlor epoxide, Aldrin, alpha-Chlordane, gamma-Chlordane, DDT, Endosulfan I, Endosulfan II, Endosulfan sulfate, Dieldrin, Endrin, Endrin aldehyde, Endrin ketone, Methoxychlor, and Toxaphene.

Sample	Arsenic (ppm)	Mercury (ppm)	% Lipid	Dry tissue weight as % of wet wt.	DDE (ppb)	DDD (ppb)
Hanford	9.7	0.06	0.42	7.28%	4.1	1.3
Richland	13.8	0.06	0.33	6.12%	2.7	ND
Middle Dasher	6.9	0.25	0.8	12.5%	1.8	ND

product DDE was highest at the Hanford Townsite followed by the Richland site and another DDT breakdown product, DDD, was found only at the Hanford Townsite. Neither DDT nor a number of other organochlorine pesticides were detected in tissues from any site (Table 2).

Discussion

Freshwater mussel aggregations in the Columbia River appear to be different in species composition and abundance from what they were historically. The more sedimentation and pollution-sensitive species native to the Pacific Northwest, the western pearlshell, which was once common in the Columbia River system (Leonhardy and Rice 1970, Landye 1973, Lyman 1980, 1984) is now rarely encountered in this reach of the Columbia. This species, which as recently as the mid 20th century outnumbered *Gonidea* by 9 to 1 in the mid-Columbia River region (Swanson 1962) appears to have been largely replaced by the less ecologically sensitive floaters (*Anodonta* spp.; Frest and Johannes 1995). Our surveys suggest that substantial portions of the Columbia River appear to be nearly devoid of even these more tolerant species of freshwater mussel. Regions such as the Richland portion of McNary Reservoir still have some floaters but the populations show evidence of high mortality.

The aggregation of floaters at the Hanford Townsite, located within the only free-flowing part of this reach of the river, appears to be maintaining itself. This aggregation contains many small mussels that are presumably younger, indicating that successful reproduction is occurring. Only about 10% of the shells found at this site were dead and mortality was exclusively in the larger size classes, suggesting that mortality at this site may be associated with old age.

The sheltered nature of the location where the Hanford Townsite aggregation is found may be an important element promoting the survival of this aggregation. At this site, the backwater location and the pipe that mussels are congregated around may provide protection from current and prevent washout. The sand accumulated around the pipe appears to be a favored substrate here, though mussels are often found in cobble at other locations. The smallest individuals were inside the pipe in fine silty sand. It may be that small individuals flourish best in finer sediment, or the pipe may have afforded them quiet water or protection from predators such as sturgeon, suckers, and channel catfish (Nedeau et al. 2005), all of which are found in the mid-Columbia River (Wydoski and Whitney 2003).

The aggregation of mussels at the Richland site presents a sharp contrast to that at Hanford, with nearly seven times as many dead shells as live individuals. Those live mussels that were found were scattered throughout the site and appeared to be in microhabitats that provided refuge from strong flow. There appeared to be no preference for any particular substrate type indicating that protection from high flow was more important than substrate. Because most of the aggregation consisted of dead shells, our initial assessment was that this aggregation was in decline. Further examination, however, presented another possibility. This aggregation appears to have suffered extensive mortality in the past but may be re-establishing itself. Most of the live individuals were in the shorter end of the adult size range, suggesting younger age. Dead individuals, on the other hand, were found in a large size range but were significantly larger than the live individuals (Figure 2). All of the largest shells found at this site were dead. This suggests some past mortality event affected much of the population including all the large mussels, with subsequent reestablishment of younger mussels.

Although alternatives to an in situ mortality event as the source for the Richland aggregation of dead mussel shells are possible, we believe they are unlikely. Mussel shells may be dislodged and carried downstream to a depositional site. The fact that the Richland aggregation is found at the point where the free-flowing Columbia Reach enters the quieter waters of McNary Reservoir suggests the possibility that the aggregation could represent an accumulation from washout of an upstream source. However, an extensive search upstream did not reveal any such source. Further, live mussels are considerably denser than are empty shells, especially for thin-shelled "floater" mussels such as *Anodonta* spp. If this accumulation was from a washout one would expect the dense live mussels to settle out upstream of the lighter dead shells, but the live and dead shells were intermixed. Finally, many of the dead shells were found vertically in the sediment with their anterior end buried and the posterior end exposed, as in life. It is also unlikely that the large number of dead shells here resulted from differential preservation. Mussel shells do dissolve over time and dissolution rate can be affected by water characteristics such as pH and turbulence. However, the Richland aggregation is only 30 km downstream from the Hanford population in a swift, free-flowing reach so it is unlikely to be much different in pH. It is also in more turbulent water than is the Hanford aggregation, which should make preservation of fragile empty shells less likely, yet it has a dramatically higher ratio of dead to live shells than does Hanford.

The sparsely scattered mussels found within the McNary reservoir are unlikely to comprise a viable, reproducing population. The mussels scattered around Bateman Island, for example, are spaced at least 50 m apart in an area with slow flow and are probably too far apart for effective interfertilization due to extended dispersal time and the low probability of sperm encountering a distant female. Downing (1993) found that freshwater mussels had reproductive failure at densities below 10 m^{-2}. If the same densities apply to reproduction in these floater mussels, the individuals in McNary Reservoir are far too sparsely scattered to comprise a viable reproducing population, while the Richland aggregation probably has few reproducing individuals and the Hanford aggregation is likely reproductively viable. The mussels in the Clearwater populations achieved local densities of 40 m^{-2} in many areas, a density associated with high reproductive success (Downing 1993, Toy 1998). Shells collected at the mouth of the Walla Walla River where it empties into the Columbia indicate that some floaters are present nearby but it is impossible to infer more about them due to turbidity.

The Columbia River was historically dominated by western pearlshells but more recently other mussels such as floaters have become prevalent (Lyman 1980). Newell (2003) reported three live western pearlshell mussels at Leslie Groves Park in Richland. After extensive searches in that area, however, we were only able to locate floaters and we suspect that the last western pearlshell may have been extirpated from the site. Potential causes of this decline of the ecologically sensitive western pearlshell mussels with a related increase in floaters include eutrophication, reduced host fish abundance, and a significant change in flow patterns due to dams (Fuller 1974, Blalock and Sickel 1996). Recent research has also suggested that antidepressant residues and other compounds in treatment plant effluent (Gagné et al. 2006) may also alter physiology or limit reproduction in mussels, although no obvious source for these exists for many miles upstream. Other factors that may affect Columbia River mussels include impoundment, siltation (Frest and Johannes 1995), introduction of predator species or competitors, and reductions in populations of fish hosts. The relative importance of these factors and their interactions remains to be evaluated.

In contrast to the mid-Columbia River, the Clearwater River western pearlshell populations appear to be robust and flourishing. The mussels are abundant and densely aggregated. Indeed, the estimated 15,000 individuals occupying 700 m^2 along just 69 m of river at the Middle Dasher site rivals the high count from the literature of 20,000 mussels reported by Murphy (1942) for a 0.8 km stretch of the Truckee River in California. In addition, the populations include very few dead shells, indicating low mortality, and are found in a broad range of sizes suggesting a mix of age classes. The maximum density of 223 to 625 m^{-2} is also higher than that observed at other sites (Roscoe and Redelings 1964, Toy 1998, Howard and Cuffey 2003). Interestingly, none of these mussels reached the largest size class reported for western pearlshells, suggesting that these populations may have further potential to mature. Shape and maximum size of pearlshell species, however, have been noted to vary among sites (Roscoe and Redelings 1964, Bauer 1992), so the small size in the Clearwater may simply be due to ecological, population, or latitudinal characteristics. The reduced water velocity over the mussel bed and the overhanging trees present at the middle Dasher site are characteristics associated with other pearlshell populations (Roscoe and Redelings 1964, Stober 1972, Howard and Cuffey 2003).

The 6.9 ppm concentration of arsenic in mussel tissues from the Clearwater River was surprising because they come from a relatively pristine setting. The arsenic within these mussels may stem from natural sources such as weathering of rocks and soils (Eisler 1988), because very little human disturbance except for logging has occurred upstream of this site. In marine bivalves, 6.8 ppm arsenic was found to have no detectable effect on mussel health (Applied Biomonitoring 2004) while 16 ppm sodium arsenite was fatal to the freshwater clam *Amblema plicata* within a few weeks (Fuller 1974). Arsenic was higher in mussel samples from the Columbia River (Table 2), and was at levels associated with reduced growth and feeding in marine bivalves (Eisler 1988, Applied Biomonitoring 2004).

The fact that mercury levels were highest in mussel tissue from the Clearwater River was also surprising. Possible sources of mercury include fungicide which is sometimes used in replanting logged sites or from the salmon that spawn in this river. Mercury accumulates in tissues over time and the long lifespan of western pearlshells may have contributed to the measured levels. The "no effects" concentration for mercury in freshwater mussels has been estimated at 2.32 ppm (Applied Biomonitoring 2004). This level is nearly 10 times higher than found in any of our study areas, suggesting that mercury is having little effect on any of the mussel populations.

Tissue DDE concentrations from the Hanford Townsite were over twice those from the Clearwater and one and a half times the level at the Richland site. DDD was detected only in tissue of mussels from Hanford Townsite. Freshwater mussels are capable of concentrating DDT and its residues DDE and DDD in their tissues to levels 2400 times higher than those found in the surrounding water (Bedford et al. 1968). Floater mussels living in the Columbia River estuary contained up to 14.9 ppb wet weight of DDT residues in 1972 (Claeys et al. 1975), though none was detected in our samples. A related species, *Anodonta grandis*, accumulated up to 0.36 ppm of DDT and metabolites after 2-12 weeks of exposure (Bedford et al. 1968). This level was associated with some mortality but the cause of mortality was not determined. It is not possible to definitively conclude whether the observed concentrations of DDT residues in this study are having any effect on the health of these mussels although the tissues of many living mollusks have been found to harbor much higher levels (Claeys et al. 1975). Most studies of the effects of pesticides on freshwater bivalves have concluded that measurable effects occur only at fairly high concentrations (Keller et al. 2007).

Tissue lipid levels can be an indicator of the nutritional state of an organism. The mussels collected from the Clearwater River were 0.8% lipid. This can be compared to a study conducted near Woodinville, WA which found that western pearlshells from Bear Creek had a mean lipid concentration of only 0.17% (Applied Biomonitoring 2004). This suggests that the mussels from the Clearwater River are likely well fed. The two Columbia River aggregations, Richland and Hanford, had lipid levels of 0.33 % and 0.42% respectively. It appears from the lipid concentrations that the individuals at the Hanford Townsite may be feeding more successfully than those at the Richland site. Comparisons of wet and dry weights reinforce this conclusion. Mussel tissue from the Clearwater had a higher dry weight per unit wet weight, indicating robust tissue, while the lower dry weights of the Columbia mussels suggested less robust, watery tissues.

In summary, freshwater mussel aggregations in the Columbia River are markedly different than they were in the past in several ways. Historically, the Columbia was dominated by western pearlshells but is now sparsely populated by the more tolerant floater species native to our area. Aggregations of floaters that are found along the free-flowing Hanford Reach appear more robust than those that are found in areas affected by McNary Dam. Concentrations of pollutants within the tissues of mussels found in the Columbia are on the whole higher than those found in pristine areas but it is not clear whether these levels are high enough to have caused the decline of freshwater mussel populations in the Columbia River.

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