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ASSESSING A FRESHWATER MUSSEL POPULATION IN THE NORWOOD ISLAND BACKCHANNEL OF THE WILLAMETTE RIVER

Western Pearlshells (Margaritifera falcata); C.A. Searles Mazzacano

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Executive Summary

This project assessed a large aggregation of freshwater mussels in the Norwood Island channel of the Willamette River, an approximately one-mile backchannel along the western shore of Norwood Island in the upper Willamette River between RM148 and RM149. Surveys to assess population diversity, density, and viability were conducted from 31 July to 2 August 2017. Sampling methodology combined semi-quantitative surveys across larger proportions of the habitat with quantitative searches in a subset of the habitat (i.e., double sampling with excavation) to detect buried adults and juveniles. Transects were set at 40 m intervals within three random starts; 121 quadrats in 66 transects were surveyed, 51 of which were double-sampled. A total of 1,140 *Margaritifera falcata* (Western Pearlshell) and six *Anodonta oregonensis/kennerlyi* (Oregon/Western Floater clade) were counted, and the non-native invasive bivalve *Corbicula fluminea* (Asian Clam) was noted in 13% of the quadrats. The few *Anodonta* found were confined to the more stable gravel/sand substrate near the upstream end of the island. *M. falcata* were abundant in both the upstream and downstream portions of the channel, which had extensive regions of softer, sandier habitat than is typical for this species. Shell length of all mussels in excavated quadrats was measured as a surrogate for age. All *M. falcata* were older (i.e., larger adults), with only 7.3% of measured mussels in smaller size classes (shell length <10 cm); no juveniles of either *Margaritifera* or *Anodonta* were seen in either surface counts or after excavation. Although large numbers of dead mussels and valves were visible throughout the channel, there were almost four live mussels for every dead mussel (overall ratio live:dead = 3.7). The mean proportion of the total population that was buried (32.9%) was greater than expected for *M. falcata*, and many mussels were buried to the entire length of their shells. The shells of many live *M. falcata* were deeply eroded and grooved, especially in the downstream reach of the channel. There were no significant differences among the number of live, dead, or buried mussels within the three series of transects or between the upstream and downstream portions of the channel. The relationship between the true number of mussels in a quadrat to those visible at the surface (i.e., burial factor) was determined to be 1.54, which corresponds to an overall density of 46.3 mussels/m^2. While mussel distributions are often patchy and both the accessible areas of the thalweg and central portion of the channel had lower mussel densities, there may be as many as 40,000 mussels in this back channel. However, this *M. falcata* population appears to be non-viable, with an abundance of older individuals and no reproductive replacements. Reproductive failure in native mussels is caused by a variety of factors, and unnatural flow conditions, lowered bed stability, and seasonal presence of appropriate host fish for mussel glochidia may all be impacting this population. Native mussel populations in the mainstem Willamette River have not been studied systematically, and additional reaches upstream and downstream of this population should be surveyed to determine if there are any other large mussel aggregations in the region and to assess their abundance and viability. In addition, because *Margaritifera* mussels are so long-lived (≥100 years), this and other extant mussel populations in the Willamette should be re-surveyed every few years to assess changes in population status and potential responses to stressors and/or conservation efforts.

Background

Oregon's freshwaters are home to three genera of native mussels: *Margaritifera falcata* (Western Pearlshell), *Gonidea angulata* (Western Ridged Mussel), and several clades of *Anodonta* (Floater), including the Oregon/Western Floater clade (*A. oregonensis/kennerlyi*) and California/Winged Floater clade (*A. californiensis/nuttalliana*). Freshwater mussels in the West are in general more poorly characterized than other aquatic fauna, but they are threatened and declining. The IUCN Red List of Threatened Species has ranked the Western Pearlshell (*Margaritifera falcata*) as Near Threatened (i.e., "does not qualify for Critically Endangered, Endangered or Vulnerable now, but is close to qualifying for or is likely to qualify for a threatened category in the near future"), with a decreasing population trend and declines in watershed area of 17% in western North America (Blevins et al., 2017). *Anodonta oregonensis* is categorized as Least Concern by IUCN (i.e., evaluated but "does not qualify for Critically Endangered, Endangered, Vulnerable or Near Threatened") but is considered to have undergone a 26% decline in watershed area, and the overall population trend is unknown (Blevins et al., 2017). Historic and current records of native mussels occur in scattered locations along the mainstem Willamette River, but these are largely the result of incidental observations, and detailed or long-term surveys are lacking. This project was undertaken to assess the density, age structure, status, and species composition of a population of freshwater mussels in a side channel of the Willamette River at Norwood Island.

Methods

Surveys were conducted from 31 July to 2 August 2017 by staff of CASM Environmental, Willamette Riverkeeper, and volunteers associated with Willamette Riverkeeper and the Pacific Northwest Native Freshwater Mussel Workgroup. The survey period was chosen to coincide with anticipated lower summertime flow levels, which provide increased visibility and ease of movement in the channel. The survey reach is an approximately one-mile backchannel along the western shore of Norwood Island in the upper Willamette River, between RM148 and RM149 around the confluence of the Long Tom River (Figure 1). Sampling methodology was based on techniques described in Smith et al. (2000) and Strayer and Smith (2003), and combined semi-quantitative surveys across larger proportions of the habitat with

Figure 1. Norwood Island backchannel.

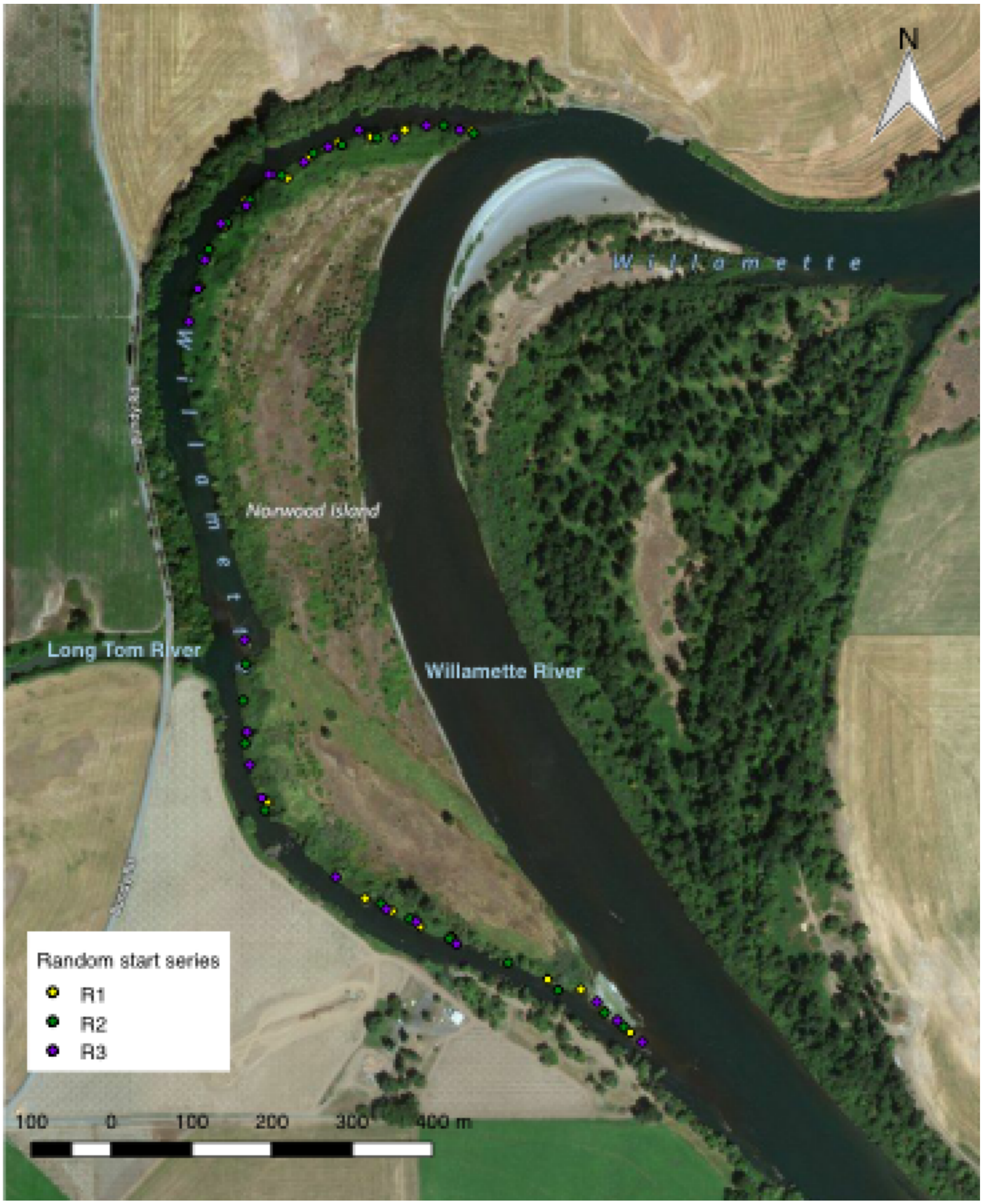
quantitative searches in a subset of the habitat (i.e., double sampling with excavation). Three random starts were used to set transects; the starting point for each random sample set was chosen within the first 40 meters of the downstream end of the channel by generating a random number between 0 and 39 to set the initial transect in each series. Zero was set as the downstream extent of the channel, and initial transects were set at 7 m (series R1), 1 m (series R2) and 20 m (series R3) upstream of the zero point. Each additional transect was then set at 40 m intervals upstream.

The initial protocol called for 40 bank-to-bank transects within each of the three random starts. However, the arrival of the survey team on Norwood Island on 31 July coincided with a large release of water into the river by the US Army Corps of Engineers, leading to an increase in flow from 4,200 cfs to 8,000 cfs virtually overnight. This dramatic increase in depth and flow rendered it impossible to access a substantial portion of the channel, such that we were only able to survey 66 transects total (Figure 2). The initial protocol also called for surveying three 0.25 m^2 quadrats in each transect, with a 200 quadrat minimum goal. The first 0.25 m^2 quadrat in each transect was placed using a random start between 0 and 5 (i.e., from the edge of the bank to 5 m into the channel), and each subsequent quadrat in the transect was located at 15 m intervals from the first. Visual surveys were to be done in all three quadrats in a transect, with double-sampling in the 2nd quadrat. Double-sampling consists of first doing a surface count and then excavating the quadrat to a depth of 4-6 in. and counting the mussels again to determine the proportion that are buried. Juvenile mussels spend the first few years of their life buried in the substrate, and younger mussels (< 2-3 cm) are generally not visible on substrate surface. Thus, surface counts alone are biased towards older (i.e., larger) adults and can underestimate the proportion of reproductive replacements in the population (Jones et al., 2005; Stagliano, 2010). Due to increased flow conditions, it was only possible to count one or two quadrats in many of the accessible transects; if the 2nd quadrat could not be surveyed, and/or of the depth or current was too great to allow it to be excavated, the first quadrat was excavated instead. Surface mussel counts were done in 121 quadrats; 51 of these were double-sampled with excavation. Seventy-three of the quadrats were counted in the downstream portion of the channel (within 11 transects each in series R1 and R2 and 12 transects in series R3), all of which were downstream of the confluence with the Long Tom River. Forty-eight quadrats were counted in the upstream portion of the channel (within 10 transects in series R1 and 11 transects each in series R2 and R3), all upstream of the Long Tom confluence.

Apart from the changes in transect and quadrat numbers, surveys were carried out as planned. Each series was surveyed by a different team of 3-5 people. Surface counts were done using an Aquascope or by snorkeling; in some cases where the water was deep but sufficiently clear, Aquascopes were used from a boat. Coordinates of each transect and quadrat were recorded using Garmin GPS units, and the number of live and dead mussels visible at the quadrat surface was enumerated. Non-native Asian Clams (*Corbicula fluminea*), an invasive species found in Oregon since 1948 (Foster et al., 2017), were noted but not counted. In excavated quadrats, after the surface count was completed, mussels were hand-picked into a bucket or mesh-bottomed sieve, and then the quadrat was excavated to a depth of 4-6 in. using hands and a small garden trowel, and any buried mussels were added to the bucket or sieve. Once all mussels were collected and counted, calipers were used to measure shell length (a surrogate for mussel age), and each mussel was then replaced in the substrate in its original orientation.

Data analysis and graphing were done in PAST3 software (Hammer et al., 2001). Maps were made using the QGIS software package (Quantum GIS Development Team, 2009).

Figure 2. Survey transects in the Norwood Island backchannel. The first transect for each of the three random starts (R1 [yellow], R2 [green], R3 [purple]) was chosen using a random number generator to select a point within the first 40 meters of the downstream end of the channel; subsequent transects in each series were set at 40 m intervals upstream. No transects were set along the center of the reach, as high flow and depth combined with several large strainers made movement in this region hazardous.



Results & Discussion

MUSSEL DIVERSITY AND ABUNDANCE

Mussel diversity

A total of 1,140 live mussels were counted among all quadrats surveyed (i.e., quadrats in which surface counts only were done and those that were double-sampled via excavation), the majority of which (>99%) were Western Pearlshell (*M. falcata*). Floaters (*Anodonta*) were found in very low abundance (< 6 total) in upstream transects close to the eastern shoreline of Norwood Island and in the long gravel bar that extends from the upstream tip of the island. Based on shell morphology (Figure 3), i.e., more oval than round and with a convex shell margin, brown shell with a greenish cast, low beak, and shell length to height ratio (L:H) ≥2, these floaters were in the *A. oregonensis/kennerlyi* clade (Nedeau et al., 2009). No valves from dead *Anodonta* were found. Asian Clams (*Corbicula fluminea*) were scattered throughout the channel, and their presence was noted in 13% of the quadrats surveyed (Figure 4).

Figure 3. Floater (*Anodonta oregonensis/kennerlyi* clade) found at the upstream end of the Norwood Island backchannel. Photo by C.A. Searles Mazzacano.

Figure 4. Non-native Asian Clams (*Corbicula fluminea*) among native Western Pearlshells. Arrows indicate one live clam (center) and valves from dead clams. Photo by C.A. Searles Mazzacano.

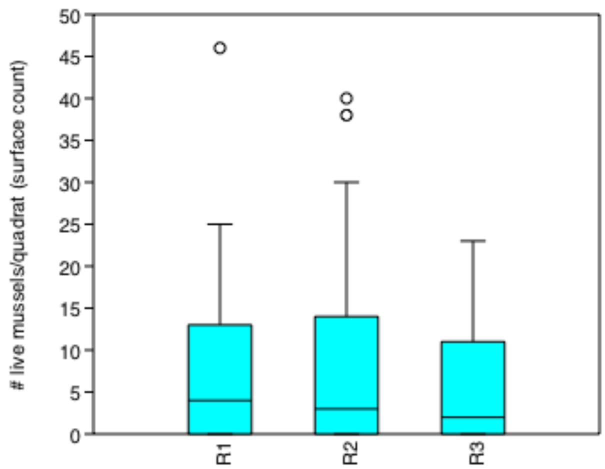
Mussel abundance

Live mussels were found in most quadrats, although many valves and shell fragments were visible throughout much of the accessible channel. Of the 121 quadrats surveyed, 68.6% (83) had live mussels (either at the surface or buried); 28.1% (34 quadrats) contained no live mussels or dead mussels; and 3.3% (4 quadrats) contained only dead mussels. Of the 83 quadrats in which live mussels were found, the majority (67.5%) did not contain any dead mussels. In most (74%) of the individual quadrats that held both live and dead mussels, the ratio of live to dead individuals was $\geq$1.0, and the overall ratio of total live to dead mussels in the survey was 3.7. The mean number of dead mussels per quadrat was higher among downstream (3.86 $\pm$ 13.22) vs. upstream (0.52 $\pm$ 1.2) quadrats but the difference was not quite significant (unpaired t test; $p = 0.0851$), and a one-way ANOVA also showed no significant difference between the number of dead mussels per quadrat among the three random start series ($F = 0.9976$; $p = 0.3719$). Given the fact that the majority of mussels in this population are larger, older adults (see Population Age Structure below), these dead mussels indicate that older members of the population are continually senescing and dying; dead mussels and broken valves may also be carried in to the downstream portion of the channel and accumulate in the sandy nearshore habitat around the downstream end of Norwood Island.

The number of mussels per quadrat in surface counts alone ranged from 0 to 46 (mean = 7.52 $\pm$ 9.38, with a 95% confidence interval of 5.83 to 9.21). Although lower water and flow conditions on the first day of work made it possible to survey a greater number of quadrats at the downstream end of the channel (Figure 6), the mean number of live mussels/quadrat in surface counts in downstream (8.32 $\pm$ 8.27) and upstream (6.48 $\pm$ 10.85) quadrats was not significantly different (unpaired t test; $p = 0.3242$), and a one-way ANOVA showed no significant difference between the number of live mussels per quadrat among the three random start series ($F = 1.083$; $p = 0.3418$; see Figure 7).

Figure 6. Location of 0.25 m^2 survey quadrats in the upstream (left) and downstream (right) ends of the channel. Live mussel abundance in surface counts only is indicated by the color and size of the circle, with increasing size and color intensity corresponding to greater mussel abundance.

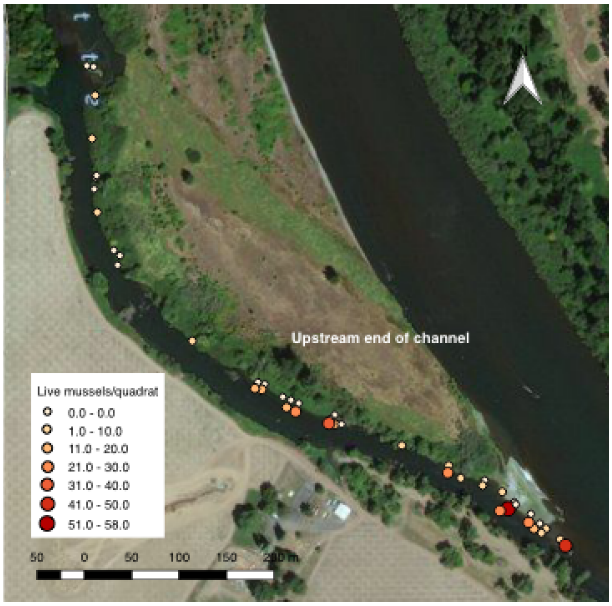
Figure 7. Live mussels/quadrat in surface counts alone in the three series of transects. Horizontal line in each box indicates median value; filled boxes show interquartile ranges; whiskers depict data range; points show outlier values. There were no significant differences between the three series.



Double-sampling with excavation is done to ensure a representative count of juvenile mussels in a population. Young mussels spend the first years of their lives buried and feeding in the substrate (Yeager et al., 1994; Bauer, 1997; Hastie & Young, 2000; Smith et al., 2000), and while a stable/viable population will have some young mussels visible at the surface, surface counts alone bias the data towards larger, older adults. Mussels move vertically in the substrate and change position based on time of day, flow and temperature conditions, and food availability, so adult mussels can also be buried in the substrate. To assess the number of juveniles present (if any) and determine the overall proportion of live mussels not visible at the surface, excavation was done in 51 (42.1%) of the quadrats. The total number of live mussels per excavated quadrat ranged from 1 to 58 (Figure 8), and the proportion that were buried ranged from to 0-100% (mean = 32.9% ± 26.1). The mean proportion of buried mussels was higher at downstream (37.54% ± 25.04) vs. upstream (19.99 ± 25.63) sites, but the difference was not quite significant (unpaired t test; p = 0.0667), and a one-way ANOVA showed no significant difference among the three random start series of transects (F = 0.2186; p = 0.8047; Figure 9).

It is interesting to note that other studies of *M. falcata* found a much smaller proportion of the population buried. Howard & Cuffey (2006) found fewer than 0.5% of the total individuals in an older-skewing population surveyed as buried, while on average one-third of the total live individuals in excavated quadrats in this survey were buried. In addition, while Vannote and Minshall (1982) considered that adult *M. falcata* rarely burrow more deeply than 25-40% of their shell length, we found a substantial proportion of the live mussels in excavated quadrats buried to the entire length of their shells. The greater propensity for deeper burial in this survey is likely a reflection of the extremely sandy habitat in the channel, especially in nearshore locations, which is more liable to mobilization during periods of high flow but apparently permeable enough that even completely buried mussels have access to sufficient water, dissolved organic matter, and oxygen in the interstitial spaces.

Figure 8. Location of 0.25 m^2 survey quadrats upstream (left) and downstream (right) ends of the channel. The total number of live mussels found in each quadrat (includes total live mussel count in excavated quadrats) is indicated by circle color and size, with increasing size and color intensity corresponding to higher mussel abundance.



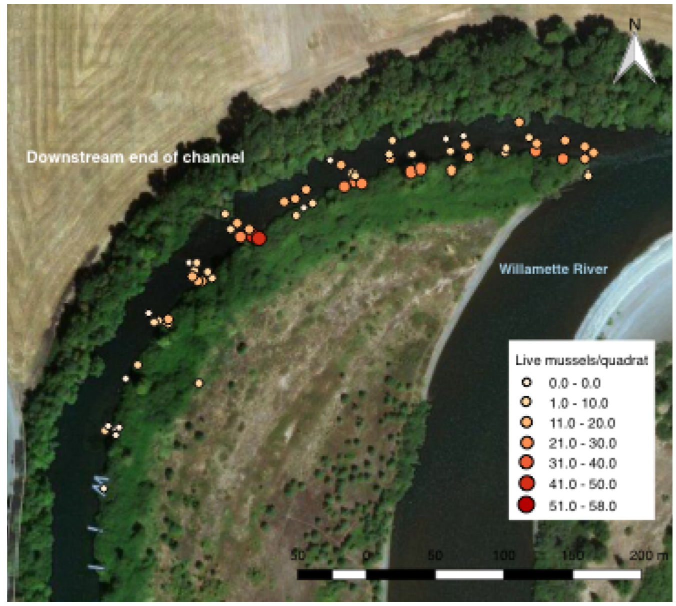
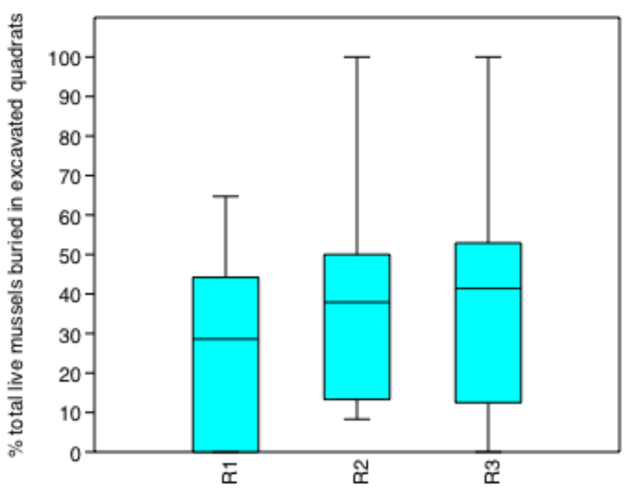


Figure 9. Proportion of live mussels in excavated quadrats that were buried in the substrate in the three series of transects. Horizontal line in each box indicates median value; filled boxes show interquartile ranges; whiskers depict data range; points show outlier values. There were no significant differences between the three series.



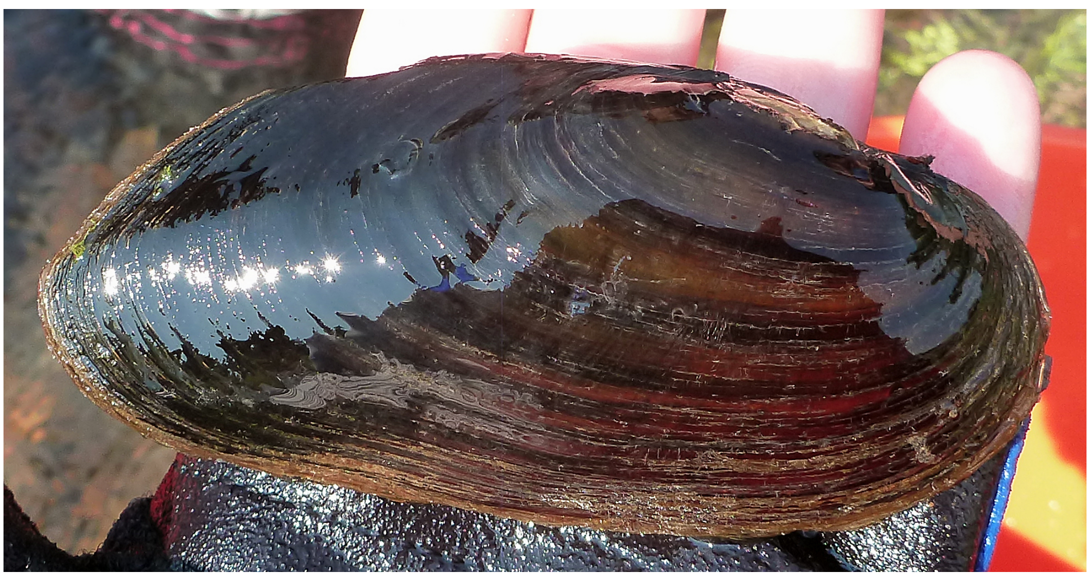
SHELL MORPHOLOGY AND HABITAT

M. falcata preferred habitat includes stable sand and gravel substrates in cool to cold perennial running waters with a width > 2 m and a low to moderate gradient (Vannote & Minshall, 1982; Stagliano, 2010). High velocities influence habitat selection and successful settlement of juveniles (Toy, 1998; Oswald, 2008), and where they are present in larger, faster, or higher-gradient rivers, *M. falcata* are often found in sandy spaces among cobble and in regions where boulders shelter them from high flow and stabilize the substrate against scouring (Vannote & Minshall, 1982; Stagliano, 2010). *Anodonta* are tolerant of slower, warmer waters, inhabiting sand and gravel substrate in lakes, reservoirs, low-gradient rivers, and sloughs. While the two genera can co-occur, they generally occupy different microhabitats.

The outer portion (periostracum) of Western Pearlshell mussels is black to dark brown, and the ventral margin of the shell has a slight concavity. Although many pearlshells in this study had typical shell morphology, a large number in the downstream portion of the channel had such a pronounced concavity at the ventral shell edge that individuals looked almost kinked. Many shells were also deeply eroded around the hinge and umbo, often to a depth of several millimeters and a circumference of several centimeters, and some also had eroded grooves or channels running longitudinally along the shell. Exposed portions of burrowed mussels were often thickly coated with periphyton. Pearlshells at the upstream portion of the channel, especially in and around the large gravel bar at the tip of the island, tended to be less eroded and the characteristic ventral concavity was much reduced (see Figure 10 for a comparison of shell morphologies).

Freshwater mussels are epibenthic, i.e., partially buried with their muscular foot anchoring them in the substrate and their siphons extended into the water column for feeding (Strayer et al., 2004; Vaughn et al., 2008), but even buried mussels can be scoured out. Mussel beds (i.e. patches where densities may be 10-100 times greater than surrounding areas) occur in places with lower shear stress and greater sediment stability (Layzer & Madison, 1995; Strayer, 1999; Hastie et al., 2001; Strayer et al., 2004), and substrate stability during high flows is a strong filter on mussel distributions and establishment of juveniles (Allen & Vaughn, 2010; French & Ackerman, 2014; May & Pryor, 2015). Although the difference was not quite significant, the mean proportion of buried mussels was higher at downstream vs. upstream sites, and the mean number of dead mussels was also higher in the downstream reach, although again not quite significantly so. The substrate in the downstream reach was softer and sandier compared to the more gravelly upstream end. Although the large strainers and old bridge footings in the middle portion of the channel around the confluence with the Long Tom River may help reduce scour in the downstream end of the channel, this sandy substrate will be more liable to mobilization under high flows. This could account for the trend towards more buried live mussels and higher dead mussel abundances at the downstream end of the channel, as well as the deeply eroded profile of mussels in this reach, as their shells are essentially being sandblasted throughout the long years of their adult lives. The thinner-shelled *Anodonta* are less able to withstand flow variability and scouring, which would explain both their low abundance in the channel and their restriction to the gravel bar in a shallower, lower velocity region at the upstream end of the island.

Figure 10. Differences in *M. falcata* shell appearance in the downstream and upstream portions of the Norwood Island channel. Upper photo shows extensive deep shell erosion, pronounced concavity of the ventral edge, and thick coating of periphyton. Lower photo shows individual with much smoother, less eroded shell, reduced concavity of ventral edge, and lacking periphyton coat.



MUSSEL POPULATION DENSITY

To minimize variance of population estimates and obtain density estimates closer to the true density, Smith et al. (2000) recommend excavating 50% of all quadrats in a survey when 40-50% of the mussels are visible at the surface, excavating 33% of all quadrats in a survey when 50-60% of the population is visible at the substrate surface, and excavating 25% of all quadrats surveyed when >60% of the mussels are detectable at the surface. A sample size of 100-200 quadrats is also recommended for mussel populations $\geq 1/m^2$ to attain more precise density estimates (Smith et al., 2000). Based on the dense mussel aggregations seen in some parts of the site during informal observations and the preponderance of soft sand/gravel habitat in the nearshore portions of the reach, we used the cautious estimation that 50-60% of the mussels present would be visible at the surface, and determined to excavate a minimum of 1/3 of all quadrats sampled. As a result of the conditions at sampling time, 42% of the quadrats surveyed were actually excavated (51 of 121 quadrats total).

Surface counts found a total of 910 mussels across all 121 quadrats surveyed. Mussel surface counts varied greatly within each of the three random start series, although mean surface densities (# mussels/m^2) were similar between the three series (R1 = 30.27/m^2 $\pm$ 38.29 [CV = 1.26]; R2 = 36.46/m^2 $\pm$ 45.61 [CV = 1.25]; R3 = 24.00/m^2 $\pm$ 28.08 [CV = 1.17]. In the 51 excavated quadrats, 418 live mussels were visible at the surface and 227 were found buried. The relationship between the true number of mussels in a quadrat to those visible at the surface (i.e., burial factor) is calculated as [#surface + #buried]/#surface (Strayer & Smith, 2003); for these surveys, this factor equals 1.54. Based on this burial factor, the number of mussels in all quadrats is 1.54 x 910 = 1,401. The 121 quadrats surveyed covered a total area of 30.25 m^2, so this corresponds to a mussel density of 46.3/m^2. Given that the area encompassed by survey transects encompassed at least 1000 m of stream length (700 m at the downstream end and 700 m at the upstream end), these densities suggest that there may be as many as 46,000 mussels in this channel.

The burial factor was the same for mussels in the upstream and downstream portions of the channel. In the 32 quadrats excavated in the downstream reach, 293 mussels were visible at the surface and 161 were buried; and in the 19 quadrats excavated in the upstream reach, 125 live mussels were counted at the surface and 69 were buried, giving a burial factor of 1.55 for both reaches. Application of these burial factors to total surface mussel abundances and number of quadrats counted in these reaches gives densities of 50.8 mussels/m^2 in the downstream reach and 40.2 mussels/m^2 in the upstream reach.

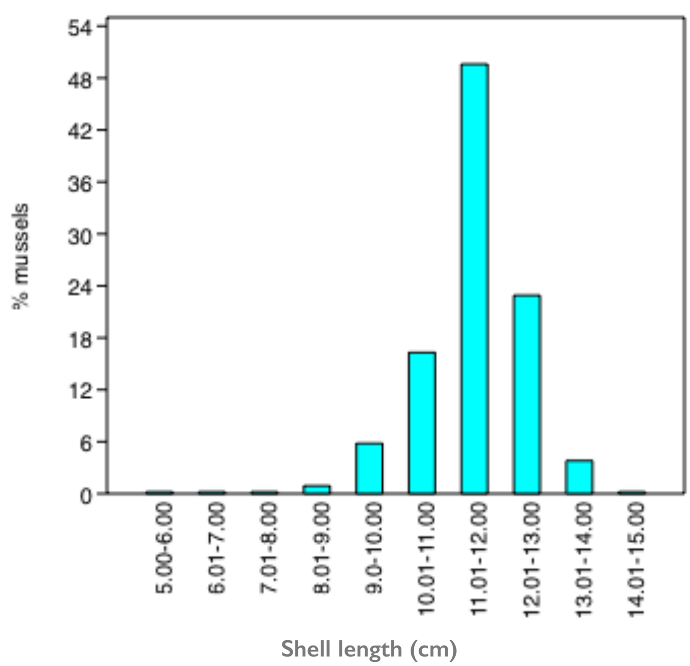
These density estimates should not be extrapolated to the middle portion of the channel that was not accessible for surveys. Although mean counts and the proportion buried in the downstream and upstream reaches were not significantly different, larger numbers of mussels were generally present in quadrats closer to the downstream and upstream extents of the survey reach, with more negative (zero mussel) or low abundance counts occurring as surveyors moved closer to the middle portion of the channel (see Figures 6 and 8). While it was difficult to fully assess habitat conditions in this unsurveyed region due to high flows, this portion of the reach was deeper and faster, with several tangles of large woody debris, and is thus less suitable habitat for either *M. falcata* or *Anodonta* mussels.

MUSSEL POPULATION AGE STRUCTURE & STATUS

Freshwater mussels continue to grow throughout their lifespans, which in the case of *Margaritifera* can be 100 years or more (Vannote & Minshall, 1982; Bauer, 1992). However, growth rates vary within years and populations based on food quality and availability, hydrology, temperature, and other habitat variables (Bauer, 1992; Hastie et al., 2000; Haag & Rypel, 2011; Bartsch et al., 2017). Different species also exhibit different growth rates; *Margaritifera* mussels are considered to be one of the slowest-growing mussel species (Haag & Rypel, 2011; Fernandez, 2013; Allard et al., 2017). Accurate aging of mussels requires examination of growth rings in thin sections of slide-mounted shell (Black et al., 2010), often requiring a calibration to watershed, but shell length can be used as a surrogate for mussel age to assess the overall age structure of a population (Toy, 1998).

Shells of all live mussels in excavated quadrats were measured to assess the population age structure. *M. falcata* shell lengths ranged from 5.60-14.78 cm (mean length = 11.48 cm ± 0.95), and the majority of measured mussels (92.7%) had a shell length greater than 10 cm (Figure 11). No juvenile *M. falcata* (length <3.0 cm) were observed, either in surface counts or after excavation, indicating an older population with no reproductive replacements. Only 40% of the excavated quadrats contained mussels ≤10 cm long; where present, these smaller/younger mussels comprised anywhere from 2.2 to 50% of the total mussel abundance in the quadrat. Smaller *M. falcata* were not concentrated in any particular region of the channel; quadrats with >10% of the measured mussels in the smallest size classes (i.e., from 5.6 to 10 cm) occurred in both the upstream and downstream reaches (Figure 12). All the *Anodonta* found were also adults, with shell lengths ranging from 5.60-7.08 cm (mean = 6.37 cm ± 0.62), which is also at the upper end of the adult length for this clade (Nedeau et al., 2009).

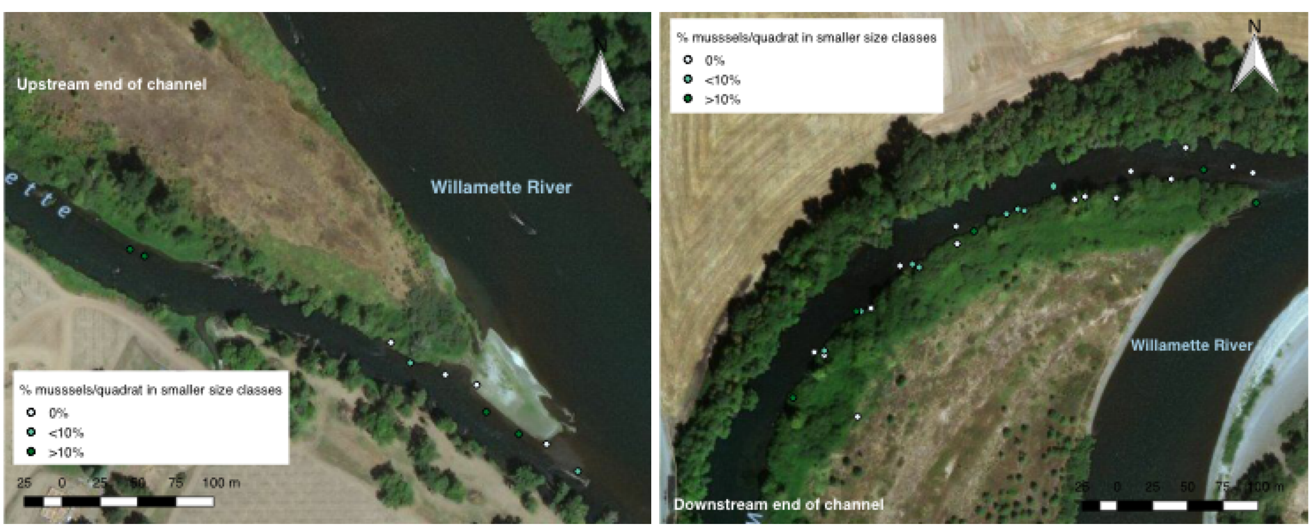
Figure 11. Proportion of *M. falcata* (Western Pearlshell) population in different size classes. Shell length was measured only in excavated quadrats.



Adults in the genus *Margaritifera* reach maximum lengths of 77-158 mm (Hastie et al., 2000), and most of the adults in this study were at the middle to upper end of this range. Little detailed work has been done regarding reproduction in *M. falcat*a, but individuals in this species are considered to be reproductively active by the time they have attained at least 40 mm in length (Toy, 1998; Allard et al., 2017). it is not possible to determine what proportion of the Norwood channel mussels are still reproductively active without examining mussels during the breeding season to determine if they are gravid, and such studies have proven to be challenging and inconclusive (Allard et al., 2015). This population may still be spawning and contributing glochidia to the river, but it lacks the reproductive replacements needed to maintain it as a viable population.

The viability of mussel populations is assessed based on both population density and age structure. Stagliano (2010) used the following criteria to rank the viability of *M. falcata* populations in Montana streams: excellent viability = density >1/m^2 of stream, beds with >50 individuals, wide range of size classes, mussels <30 mm (juveniles) present; good viability = densities >0.5/m^2 of stream, beds with >25-50 individuals, wide range of size classes, mussels <30 mm present; fair population, not viable = low densities >0.1/m^2 of stream, beds with <25 individuals, limited size classes, no juveniles; not viable = very low densities, single live individual in large size class; and verified extant = recent shell records but no live mussels. While the Norwood Island *M. falcata* is one of the largest known populations in the Willamette River, it contains a limited range of size classes, is skewed strongly towards larger/older adults with few smaller/younger mussels, and contains no reproductive replacements, rendering it an aging, non-viable population at this point.

Figure 12. Proportion of *M. falcata* (Western Pearlshell) mussels in the five smallest measured size classes (5-10 cm) in all excavated quadrats that contained any live mussels. Dots show quadrat locations; white = 0 mussels/quadrat in smallest size classes; light green = <10% of mussels/quadrat in the smallest size classes; dark green = ≥10% of mussels/quadrat in the smallest size classes.



Because mussels are so long-lived, it is not uncommon for a failing population to first be noted as one with large numbers of adult mussels but little to no juvenile recruitment (Hanson & Locke, 2001; Österling et al., 2010). The presence of large numbers of apparently healthy older adults but no juveniles means that at some time in the past the habitat was suitable for mussels, but conditions within the lifespan of this aged population have changed. Reproductive and recruitment failure is due to a variety of causes including altered hydrology, high hydrologic variation, increased sedimentation, absence of appropriate host fish, pollution, and impacts of invasive species (Newton & Bartsch, 2007; Österling et al., 2008, 2010; Strayer & Malcolm, 2012; Gascho Landis & Stoeckel, 2016). Inadequate sperm dispersal from males can also be a cause of mussel population declines, and previous studies have indicated that for some species, local densities of at least 10 mussels/m^2 are needed to ensure successful reproduction (Downing et al., 1993). Any of these stressors may operate cumulatively to impact mussel reproduction and recruitment at a single site.

Successful mussel reproduction and maintenance of viable populations depends on the presence of native host fish for mussel glochidia (larvae). Younger fish within a suitable mussel host species, especially young-of-the-year, are among the most important hosts, as individual fish become less susceptible to glochidial infection with age and repeated infection (Bauer, 1987; Bauer & Vogel, 1987). Thus, presence of young salmonids in the channel will impact both the entry of reproductive replacements (i.e., new juvenile mussels) into and dispersal of glochidia from this population, as juvenile mussels drop off of host fish carriers and new host fish are infected with glochidia. Host fish for *M. falcata* are thought to include native and non-native salmonids such as cutthroat, rainbow, sockeye, steelhead, brook and bull trout, and coho and Chinook salmon (Meyers & Milleman, 1977; Karna & Milleman, 1978; Stock, 1996; Stagliano, 2010). *Anodonta* are considered less host-specific than *Margaritifera*; their glochidial host species are less well-characterized but include three-spine stickleback, prickly sculpin, coho salmon, and some trout species (Moles, 1983; Martel & Lauzon-Guay, 2005).

Unnatural flow regimes, such as those associated with reservoir management systems, can also impact mussel populations. Galbraith & Vaughn (2010), for example, found more severe negative impacts on mussel populations in regions where reservoir releases created colder, deeper water conditions compared to populations downstream of dams with water releases more closely approximating natural flow regimes, and Howard & Cuffey (2006) noted a 60% decrease in *M. falcata* recruitment success with a two-fold increase in river discharges. It should be noted that in the course of these surveys, flows doubled within 24 hours—an unnatural situation for the Willamette River in early August—and few of the Western Pearlshells observed at the surface appeared to have their siphons extended, meaning they were not actively filter feeding at that time and may have been responding to this recent habitat perturbation.

Conclusions

The *Margaritifera falcata* (Western Pearlshell) population in the Norwood Island backchannel is one of the largest currently known in the Willamette River, with densities of 40-50/m^2 and as many as 40,000 mussels in the channel. However, this is an aging relict population, with over 90% of the measured individuals consisting of older, larger (>10 cm) mussels, few younger mussels, and no juveniles. The upstream end of this reach is also inhabited by a small number of *Anodonta* (Floater mussels) in the *A. oregonensis/kennerlyi* clade, again with older/larger adults and no juveniles. Native mussel populations in the mainstem Willamette River have not been studied systematically, and it would be informative to survey additional reaches upstream and downstream of this population to determine if there are any other large mussel aggregations in the region and to assess their abundance and viability.

Numerous factors can contribute to loss of mussel population viability, and any or all of them may be operating along the Willamette River. Examining fish passage and native fish diversity as well as seasonal flow regimes in areas where mussel surveys are done would be informative for potential impacts on glochidial dispersal and juvenile mussel settlement. Depending on densities of other surrounding populations, local reproductive failure may also be an issue, such that even if this bed is spawning successfully, there are fewer glochidia in the system overall to provide reproductive replacements. In addition, because *Margaritifera* mussels are so long-lived, extant mussel populations should be re-surveyed every few years to assess changes in population status and potential responses to stressors and/or conservation efforts.

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