PROJECT REPORT

STATUS OF THE WESTERN PEARLSHELL MUSSEL (*MARGARITIFERA FALCATA*) IN THE LITTLE CAMPBELL RIVER:
Comparison between 2009 and 2015.

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Photo source: A Rocha Canada

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Executive summary

Freshwater mussels provide a wide variety of ecosystem services to other organisms and to us. Such services include improving water quality by filtering the water, providing food and habitat for macroinvertebrates that are an important food source for fish, and serving as food for fish, birds, and mammals. In addition, they are important indicators of ecosystem health. Despite their usefulness to us, freshwater mussels have become one of the most imperiled groups of organisms in the world, including North America. Due to this dramatic decline in freshwater mussels, an increased effort is underway to determine the status of populations, assess threats to these populations, and improve their chances of survival. In this effort, one of the most important things to determine is whether the level of juvenile recruitment in the population is sufficient to maintain mussel numbers. Despite these efforts, very little is known about the Western Pearlshell (*Margaritifera falcata*, Gould 1850) in British Columbia (B.C.). In fact, we know of only one thorough study on the status of a Western Pearlshell population within the province (Rae 2009). However, even for this study, the investigation into juvenile recruitment was limited. In order to better understand the status of the Western Pearlshell in B.C., further study is needed.

In this study, we evaluated Western Pearlshell population trends in the Little Campbell River (LCR), B.C.. We achieved this by comparing 2009 data from the aforementioned study to our own 2015 data. The comparison suggests that there has been a decline in the densities of Western Pearlshell in the Little Campbell River, although there was only a marginal trend towards significance. However, there is some evidence that there has been a rejuvenation of the population at some of the sites. Further, the 2015 data shows that several of the sites have sufficient recruitment of juveniles to maintain mussel numbers in the future. For the other sites the future is more uncertain, as there is very limited data on recruitment due to the low number of mussels at these sites. Based on these findings, there should be concern that the population has declined since 2009. There should also be optimism that the population should be maintained at its current size into the future, unless there are changes in environmental conditions in the LCR. Finally, our findings on the status of the Western Pearlshell population indicate that the LCR has suffered reduced health before 2009, but that there has been an improvement in ecosystem health over the last years.

Based on our findings, we make several recommendations:

1. Continuing the monitoring of the Western Pearlshell population in the LCR,

2. Adding more sites to the monitoring program,
3. Determining the host fish usage of the mussel in the LCR, and
4. Adapting an ecosystem and watershed conservation approach for the mussel in the LCR, which protects the sites with high conservation value, salmonids, as well as the water quality in the river.

Acknowledgements

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Introduction

Freshwater mussels are an integral part of freshwater ecosystems. They provide multiple ecosystem services that benefit both other organisms and humans. Their primary impact on freshwater systems is that they filter the water and improve water quality. In fact, a single mussel can filter up to 50 L of water per day. When mussels are present in high densities, they can filter up to 90% of the water and remove 90 to 100% of the dissolved particles within that water through filtration. As an indirect result of their tremendous filtering capacity, freshwater mussels also deposit extensive amounts of the particles they filter as pseudofeces on the lake or river bottom. These pseudofeces have been shown to be an important food source for benthic organisms and especially macroinvertebrates. Mussels also improve the habitat availability for macroinvertebrates through improving habitat suitability and availability in various ways. Thus, the mussels may increase fish numbers, as macroinvertebrates are important food sources for many species of fish. In addition, freshwater mussels themselves are important food for some species of fish, birds, and mammals (Larsen 1997, Nedeau *et al.* 2009). Finally, freshwater mussels are also important indicators of ecosystem health (Larsen 1997, Nedeau *et al.* 2009, Jepsen *et al.* 2010).

Even though freshwater mussels provide these important ecosystem services to a variety of organisms, including humans, they are one of the most imperiled groups of organisms in the world. In fact, in North America approximately 70 % of the species are either extinct or are listed as being under some level of threat (e.g. Bogan 1993, Williams *et al.* 1993, Neves *et al.* 1997, Lydeard *et al.* 2004, Nedeau *et al.* 2009). One could argue that they are under threat because of the services they provide. Since they filter water, they are susceptible to reduced water quality due to eutrophication, acidification, chemical and heavy metal pollution, among other impacts. In addition, they are under threat due to other factors such as damming, channel modifications, global warming, reduction in water levels, introduced species, and loss of host fish for their larvae (Bogan 1993, Williams *et al.* 1993, Larsen 1997, Neves *et al.* 1997, Lydeard *et al.* 2004, Nedeau *et al.* 2009, Jepsen *et al.* 2010). All or a subset of these factors may compound to cause the ongoing extinctions of freshwater mussels.

Due to the dramatic decline in freshwater mussels, an increased effort is underway to determine the status of populations, assess the threats to these populations, and improve their chances of survival. One of the most important features to consider when evaluating the status of a population of freshwater mussels is to determine the level of juvenile recruitment in the population. The reason for this is that the larval and juvenile stages of these mussels are the most sensitive to changes in environmental conditions (Larsen 1997, discussion in Stanton *et al.* 2012). Therefore, changes in the environment may eliminate recruitment of juvenile mussels into the population without affecting the adults. Due to the relatively long lifespan of adult freshwater mussels, such an elimination of recruitment might not be reflected in the density/numbers of adult mussels for a long period of time. Without recruitment a population is functionally extinct (Larsen 1997, Jepsen 2010), but if surveys only focus on adult mussels, the conclusion might be drawn that the population is doing fine. Therefore, false conclusions about the conservation status of a freshwater mussel population may be made, if one does not investigate juvenile recruitment in the population.

The Western Pearlshell (*Margaritifera falcata*, Gould 1850) is found west of the Rocky Mountains in North America. Historically, it has been found from central California north to southern Alaska (Figure 1) and from the Pacific Coast east to Montana and Wyoming. Unfortunately, it is declining in numbers and disappearing from parts of its range. In British Columbia (B.C.) the species is considered to not be under any significant threat (Jepsen *et al.* 2010). Unfortunately, the comparison of historical and current records (Figure 1) suggest that the species may be in decline here too. Further, there has been a very limited survey effort for the mussel in the province (Jepsen *et al.* 2010). In fact, we know of only one thorough study of a Western Pearlshell population within B.C. (Rae 2009). However, even for this study, the investigation into juvenile recruitment was limited.

Due to important ecosystem functions that freshwater mussels provide, their importance as ecosystem indicators, the likely decline in the Western Pearlshell populations and the limited knowledge of the status of these populations in B.C., it is important to improve the knowledge of this species of mussel within the province. In this study, we utilized the study by Rae (2009) to evaluate the population trends of one population of Western Pearlshell in British Columbia. We also improved on the methodology of that study to better evaluate juvenile recruitment within the population. To our knowledge, this is the first study to evaluate Western Pearlshell population trends and thoroughly investigate juvenile recruitment in B.C.

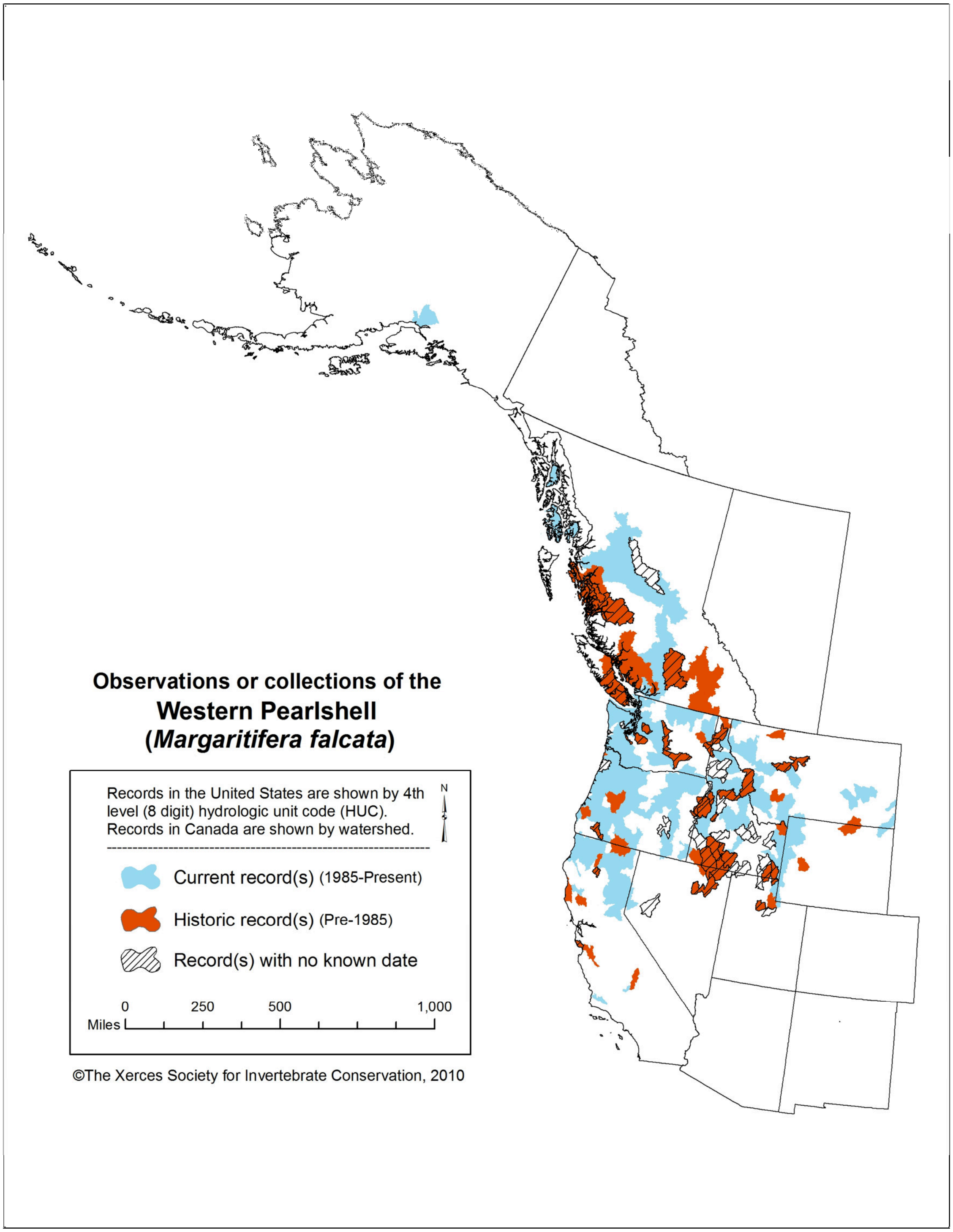

Figure 1. Current and historical range of the Western Pearlshell.

Note, that an area only contains historical records could indicate that there have been no recent surveys in this area or that the mussel is extirpated from the area. For further details on areas from which the mussel has been extirpated, see Jepsen *et al.* (2010). This figure is reproduced here with permission from the Xerces Society for Invertebrate Conservation.

Methods

2009 study

In the 2009 study (Rae 2009), the Little Campbell River was divided into sections based on mussel presence and the habitat type. Initial surveying showed that the mussels were limited to reaches downstream from Campbell Valley Regional Park. Within these reaches, sites were selected within each section based on accessibility, spatial diversity, habitat type, and channel morphology (pool, run, and riffle). The overall goal was to choose sites that would give a representative overview of the river as a whole. Based on these criteria, six sites were chosen (Figure 2).

For each site, habitat measures such as mean wetted width, depth, and current of the river were estimated. Vegetative cover and substrate types were also recorded. Further, each site was surveyed for mussels. The sites were surveyed without any aids in shallow water, with view buckets in deeper or more turbulent water, and by snorkelling in water deeper than 1 to 1.5 m. Different survey methodologies were used at sites with differing mussel densities. For details on the different survey methodologies, see the following paragraphs.

At sites with less than 25 mussels (live and dead combined), this methodology was followed: 1. Each site was subdivided into three transects that stretched across the river. These transects were placed evenly within the site. 2. Water depth and substrate was recorded at three points along the transects. These points were placed evenly along the transects. 3. All live and dead mussels within the site were identified to species and counted. The lengths of the live mussels were also measured. 4. All mussels were returned to their original position.

At sites with more than 25 mussels (live and dead combined), this methodology was followed: 1. Each site was subdivided into three separate transects that stretched across the river. These transects were placed evenly within the site. 2. Water depth and substrate was recorded at three points along the transects. These points were placed evenly along the transects. 3. Three 0.5 m x 0.5 m quadrats were placed evenly along the transects. 4. All live and dead mussels within the quadrats were identified to species and counted. The lengths of the live mussels were also measured. 5. Larger cobbles, stones, and other objects were removed from the quadrats and small samples of the finer substrate were collected. These samples were sieved in an effort to located buried mussels. 6. All mussels were returned to their original position. See Figure 3 for an overview of the transect layout.

For further details on the 2009 methodology and the Little Campbell River, see Rae's report (2009).

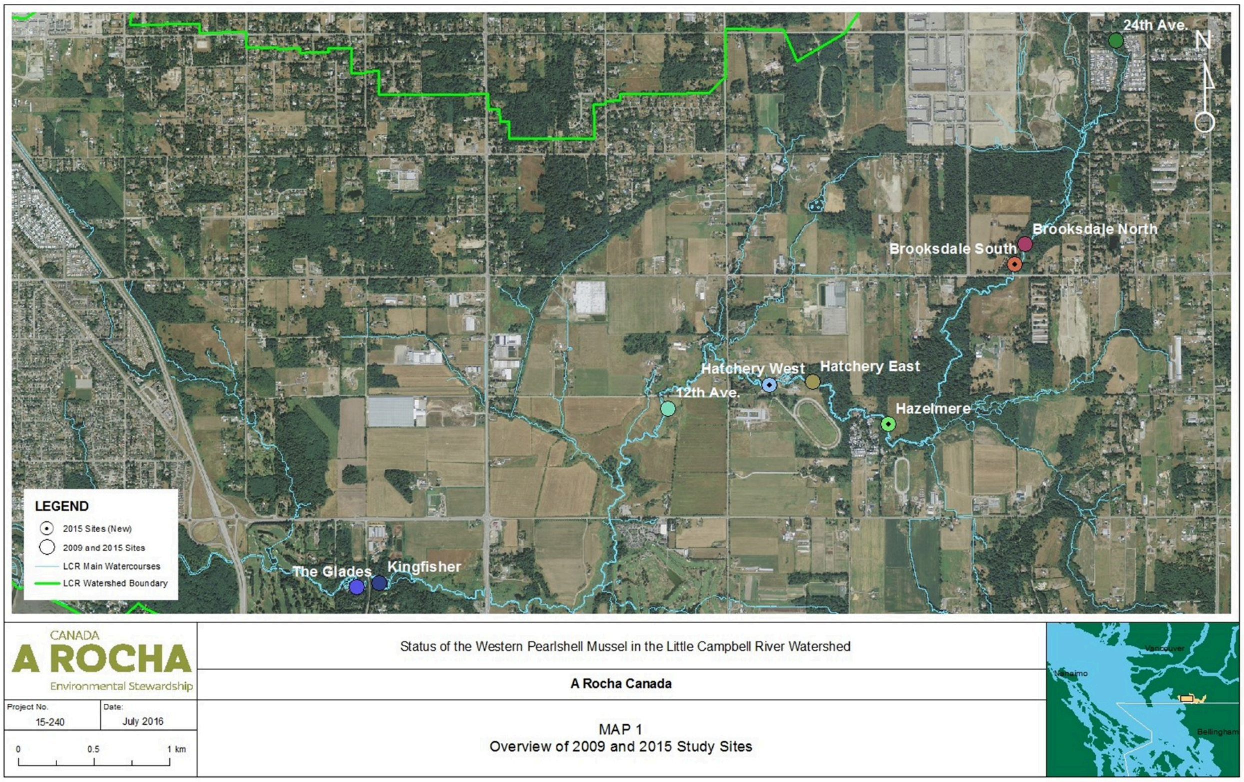

Figure 2. Overview of 2009 and 2015 study sites.

For GPS waypoint and location details for each site, see Table 1 in Appendix A. The figure has been produced using ArcGIS® ArcMap version 10.2.2. (ESRI 2014). Base map source: City of Surrey, British Columbia, Canada.

2015 study

The same sites as used in the 2009 study (Rae 2009) were chosen, to facilitate the comparison of the data on the Western Pearlshell between years. Every effort was made to locate the sites in the same exact position as they were located in 2009. However, due to limitations in the 2009 field notes, 2015 site locations may not exactly match the 2009 site locations, particularly for transect locations. An additional three sites were added to provide a more representative overview of the mussel population in the Little Campbell River (Figure 2).

Generally, the same methodology was followed for the 2015 study as for the 2009 study, although some improvements were made. These improvements primarily related to subsurface sieving for mussels. Such surveying is very important in determining juvenile recruitment in the population, as juvenile mussels are typically buried within the substrate (Larsen 1997, Strayer *et al.* 2004, Jepsen *et al.* 2010, Mageroy 2015). The following paragraphs contain further details on the 2015 methodology and differences between the two methodologies.

Each site was 10 m long. The three transects were placed at the downstream end of the site, in the middle of the site, and the upstream end of the sites, respectively. Photographs of each transect were taken from both banks. Sketches of each site were also made from both banks. The sketches include landmarks and characteristic vegetation. GPS waypoints were also taken at the downstream end of the site. The photographs, sketches, and GPS waypoint will facilitate re-locating the sites for future studies.

At each site, the river channel was designated as a pool, run, or a riffle. The various species of plants, fish, and invertebrates were also recorded for each site. For plants, the vegetative cover was recorded both within the river and along the banks, the latter including percent shade cover. For each transect, habitat measures such as mean green width, mean wetted width, and depth of the river were measured. Green width was measured at the point at which the base of the terrestrial vegetation is growing on the bank. Wetted width was measured at the point at which the surface of the water reaches the bank. Note that for the 2015 study, depth was based on the depth of the river from the green line, while for the 2009 study depth was based on depth of the river from the water surface. This change was made because depth from the green line is less variable and makes comparisons between time points more reliable. The water depth was recorded at five points along each transect: left bank at the wetted width line, left centre, centre, right centre, and right bank at the wetted width line. At each of these points, substrate type was also determined. The substrate was either classified as fine sediment, sand, gravel, cobble, or other. Note that five points were used in the 2015 study, as compared to three in the 2009 study. This change was made to better characterize the river channel at each transect. These abiotic and biotic measures were taken to provide data for long-term trends in environmental factors and to determine whether such trends affect the mussel population.

Each site was also surveyed for mussels. Only live mussels were included in the 2015 study, unlike the 2009 study. The sites were surveyed without any aids in shallow water and with view buckets in deeper or more turbulent water. Unlike in the 2009 study, snorkelling was not found to be necessary at any of the sites. It was also decided to follow a methodology, similar to the methodology used for high density mussel sites in the 2009 study, at all sites (Figure 3):

1. For each transect, two chains spaced 0.25 m apart were laid down to mark out the transect.
2. Three 0.25 m x 0.25 m quadrats were laid down at the ¼ mark, ½ mark, and ¾ mark of the transect. Smaller quadrats were used in the 2015 study, than the 2009 study, due to availability.
3. The number of mussels found at the surface within each transect, but not within the quadrats, were counted, measured, and aged.
4. The number of mussels on the surface within the quadrats were counted, measured, and aged.
5. Larger cobbles, stones, and other objects were removed from the quadrats and the finer substrate was excavated down to a depth of approximately 0.20 m. The excavated sediments were sieved in an effort to located buried mussels. Any mussels found were counted, measured, and aged.
6. All mussels were returned to their original position. The greater surface survey effort in the 2015 study, than in the 2009 study, was undertaken to improve the quality of the mussel data.

The greater subsurface survey effort in the 2015 study, than the 2009 study, was undertaken to improve the ability to evaluate juvenile recruitment, as previously discussed. The counting and measuring of the mussels was undertaken, as described above, to allow for comparison with the 2009 data.

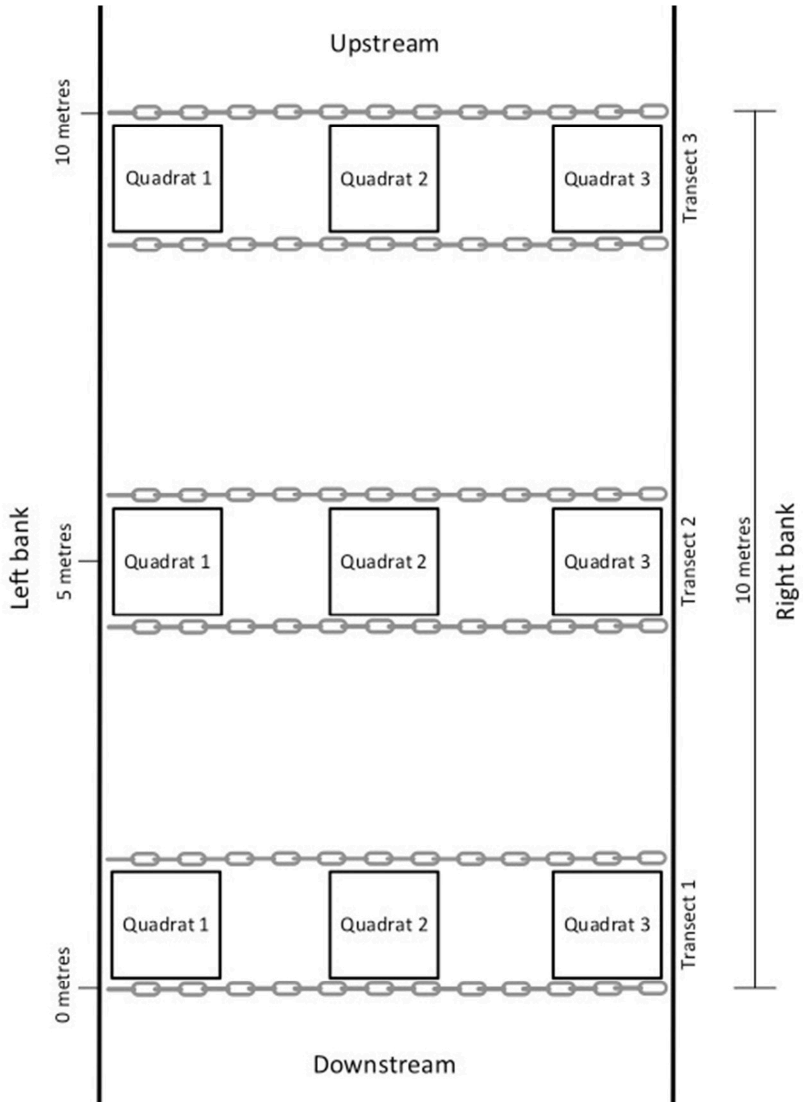

Figure 3. Sketch of a site with transect layout.

All mussels found during the surveying were aged, if possible. The mussels were aged using external growth annuli as used in Larsen 1997, Ruppert *et al.* 2004. Since this method is unreliable at older ages (Neves and Moyer 1988, Downing *et al.* 1991), we only aged mussels with clearly distinguishable growth annuli. Ageing of the mussels was included in the methodology to evaluate the level of juvenile recruitment within the population. From the Eastern Pearlshell (*Margaritifera margaritifera*, Linn. 1758), we know that by comparing the age and length of the mussels it is possible to use a decrease in growth associated with sexual maturation (reviewed in Larsen 1997) to determine the age at which the mussels mature. Using this age, we determined the percentage of juvenile mussels in the population. This percentage can be used to evaluate the population trends over time. Further, percentages of young mussels can be utilized to evaluate whether the juvenile recruitment is sufficient to maintain population numbers, as Young *et al.* (2001) have determined the ideal age distribution for an Eastern Pearlshell population. In such a population, 20 year old or younger mussels should make up 20% of the mussels, and the population should also contain some mussels below 10 years of age. However, the Eastern Pearlshell lives about twice as long as the Western Pearlshell (Young *et al.* 2001, Jepsen *et al.* 2010). Therefore, in an ideal population of the Western Pearlshell 10 year old or younger mussels should make up 20% of the mussels, and the population should also contain some mussels below 5 years of age. We used these criteria to evaluate whether the juvenile recruitment among Western Pearlshells in the Little Campbell River is sufficient to maintain mussel numbers.

Statistical Analyses

Statistical comparisons were only made between years; no statistical comparisons were made between sites within years. All statistical analyses were performed with R Studio, version 3.2.3 (R Core Team 2015).

To evaluate whether there was a change in the density of Western Pearlshells between 2009 and 2015, we used a non-parametric Wilcoxon signed rank test. This test was used instead of a paired *t*-test because the differences between the sites between years were not normally distributed. This was evaluated using graphical model validation techniques as recommended by McDonald (2014). The full R syntax for the Wilcoxon signed rank test was: *wilcox.test(2009, 2015, paired = TRUE, alt = "greater")*. In this model, 2009 and 2015 represents the densities at the sites surveyed in 2009 and 2015, respectively. *paired = TRUE* indicates that each individual site in 2009 are paired with the same site in 2015. *alt = "greater"* was used since graphical inspection of the results indicated that densities were greater in 2009 than in 2015.

Our goal was to evaluate whether there was an overall change in Western Pearlshell length distributions between 2009 and 2015. However, a sufficient number of mussels to statistically test differences in length distributions between these two years was only found for both years at two sites. Therefore, we chose to statistically test whether there was a change in length distributions between years for these two sites, independently. Two identical Welch's two-sample *t*-tests were used for these analyses. The full R syntax for the two sample *t*-test was: *t.test(Length~Year)*. In this model, *Length* is a continuous response variable representing the length of the mussels. *Year* is a categorical predictor variable representing the two years. A

Bonferroni correction was undertaken to correct for multiple analyses, resulting in a new significance value of P=0.025). Model validation was completed according to graphical methods recommended by Zuur *et al.* (2009). The validation showed evidence of heterogeneity, but a Welch's two-sample *t*-test is does not require homogeneity. The validation also showed evidence for non-normality. However, according to McDonald (2014) non-normality is not a problem in a two sample *t*-test if the sample size is greater than 50 and/or the skew in the two distributions are similar. Given that we had large sample sizes and that the skew in the distributions were similar for both years at both sites, we are confident that the Welch's two-sample *t*-test is suitable for analyzing our data.

Results

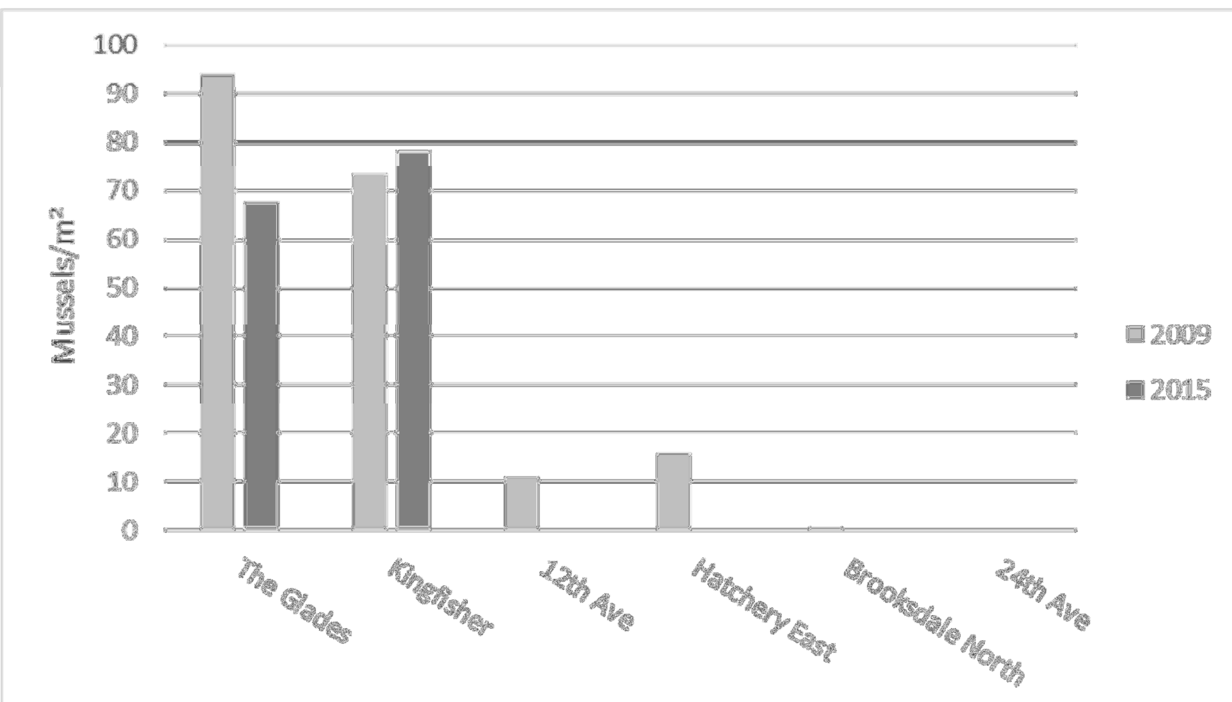

Figure 4. Western Pearlshell density comparison between 2009 and 2015.

The sites are listed in order, from downstream to upstream sites. Note that densities for The Glades, Kingfisher, 12th Ave and Hatchery East are based on quadrat counts and densities for Brooksdale North and 24th Ave are based on transect counts, as these were the counts available from 2009. In addition, the densities for 2015 only reflect mussels found at the surface, to allow for comparison with the 2009 data.

Further the densities for 2009 have been calculated based on the baseline data for that study and were not reported in the original report.

Comparison between 2009 and 2015

The density of Western Pearlshells declined from 32.6 to 24.3 mussels/m^2 between 2009 and 2015, overall. This decline only resulted in a marginal trend towards significance ($p = 0.09$). This was the case, despite that fact that the densities were lower at all sites in 2015 than in 2009 (Figure 4) except for at Kingfisher, which had approximately the same density in both years. When it comes to length distributions, there was no significant difference among the mussels at The Glades between years ($p = 0.14$, 2009 mean = 85.1 mm, 2015 mean = 88.6 mm; see Figure 5 for length distributions). However, at Kingfisher there was a significant decline in length from 2009 to 2015 ($p < 0.001$, 2009 mean = 93.9 mm, 2015 mean = 81.1 mm. See Figure 5 for length distributions.). Note that the significance value for the two tests evaluating length distributions was 0.025 after Bonferroni correction.

Further results from 2015

Juvenile mussel maturation

The overall relationship between growth and age among young Western Pearlshells shows a drop in growth when the mussels turn five years old (Figure 6). This relationship is more easily identified for the individual sites: The Glades, Kingfisher, and Hatchery West. Given that such a drop is an indicator of sexual maturity (Larsen 1997), it seems that the Western Pearlshells are juveniles through year four of their life.

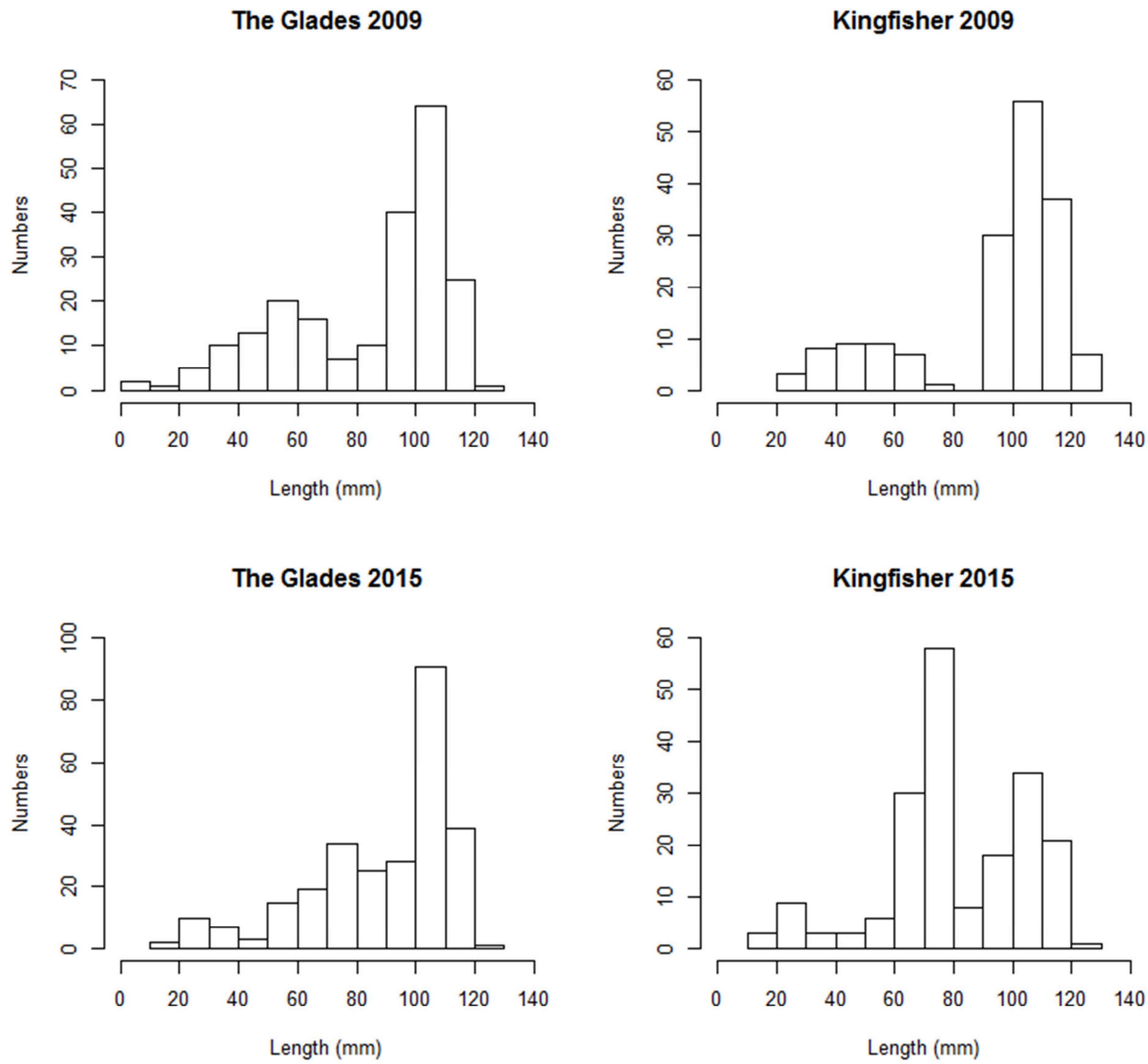

Figure 5. Western Pearlshell length distribution comparison between 2009 and 2015.

Length distributions were only developed for sites that contained high densities of mussels in both years. Note that the length distributions for 2015 only reflect mussels found at the surface, to allow for comparison with the 2009 data. Also, note that the length distributions for 2009 have been developed based on the baseline data for that study and were not reported in the original report.

Details on Western Pearlshell data: Overall and site specific

Overall: A total of 671 live Western Pearlshells were found during this study. They varied from 6 to 127 mm in length (Figures 7 and 8), and from 2 years and up in age. The overall density for the surface of transects was 13.6 mussels/m^2 (Figure 9). A total of 141 mussels were found within the quadrats. The density within the quadrats was 28.2 mussels/m^2 (See Figure 9 for overview of site densities.). Among these mussels, 97 (68.8%) were found at the surface and 44 (31.2%) were buried in the substrate. Twenty of twenty-five juvenile mussels were buried (80%). Among the mussels found in the quadrats 17.9% were juveniles (4 years old or younger) and 42.6% were 10 years old and younger (Figure 10). Given the criteria for an ideal mussel population (20% of mussels 10 years or younger and some mussels 5 years or younger), modified from Young *et al.* (2001), the population has a sufficient percentage of young mussels to maintain mussel numbers. Note that the overall results are primarily determined by the three high-density mussel sites: The Glades, Kingfisher, and Hatchery West. Below follows the data for each of the individual sites. The sites are listed in order, from downstream to upstream sites.

The Glades: A total 272 live Western Pearlshells were found. They varied from 11 to 123 mm in length (Figures 7 and 8), and from 2 years and up in age. The overall density for the surface of transects was 45.6 mussels/m^2 (Figure 9). A total of 41 mussels were found within the quadrats. The density within the quadrats was 78.2 mussels/m^2 (Figure 9). Among these mussels, 38 (92.4%) were found at the surface and 3 (7.6%) were buried in the substrate. 1 of 3 juvenile mussels were buried (33.3%). Further, among the mussels found in the quadrats 7.3% were juveniles and 22.0% were 10 years old and younger (Figure 10). Given the modified criteria for an ideal mussel population, discussed in the previous paragraph, this site has a sufficient percentage of young mussels to maintain mussel numbers.

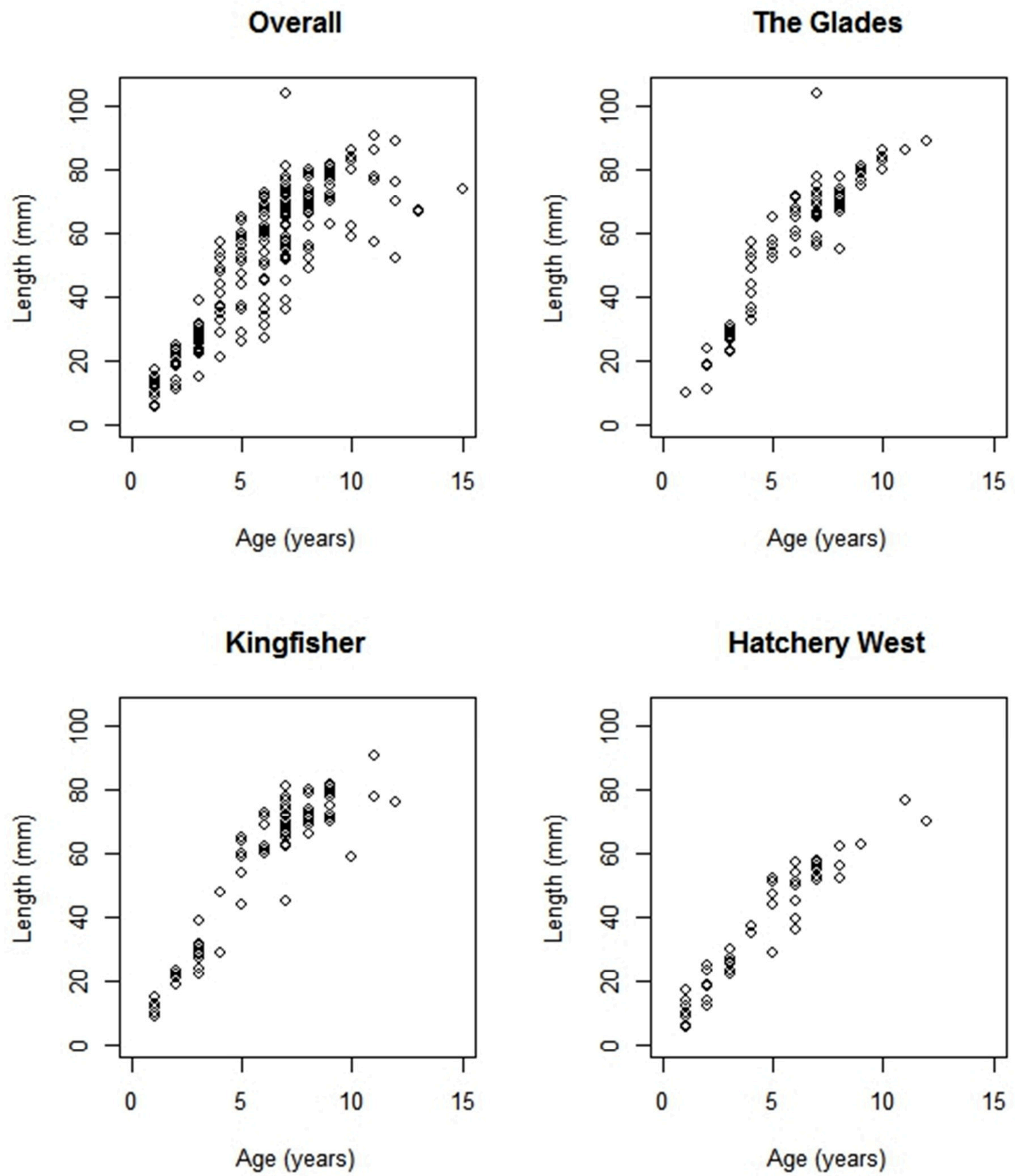

Figure 6. Growth of young Western Pearlshells.

The individual sites are listed in order, from downstream to upstream sites. Note that the length vs. age serves as a proxy for growth among young mussels. Also, note that these figures only include mussels with which it was possible to determine the number of external growth annuli with certainty.

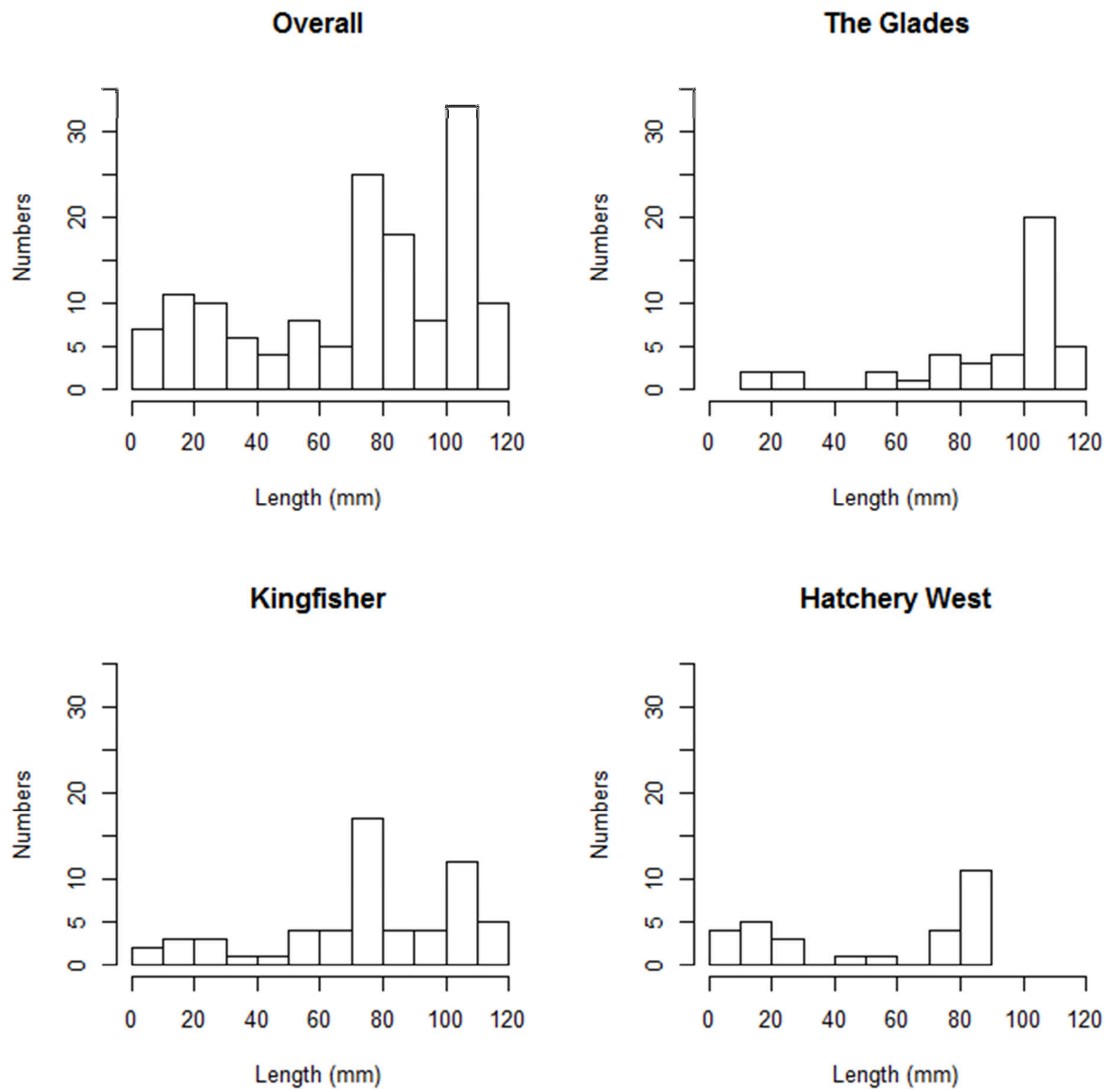

Figure 7. 2015 Western Pearlshell length distributions, overall and at high density sites.

The individual sites are listed in order, from downstream to upstream sites. Note that it is only data from quadrats, which include both mussels found at the surface of and in the substrate, that give true length distributions. Therefore, only distributions for the overall population and the sites with high numbers of mussels within the quadrats are included.

Kingfisher: A total of 210 live Western Pearlshells were found. They varied from 9 to 127 mm in length (Figures 7 and 8), and from 2 years and up in age. The overall density for the surface of transects was 53.9 mussels/m^2 (Figure 9). A total of 60 mussels were found within the quadrats. The density within the quadrats was 103.1 mussels/m^2 (Figure 9). Among these mussels, 44 (73.3%) were found at the surface of and 16 (26.7%) were buried in the substrate. 9 of 9 juvenile mussels were buried (100%). Further, among the mussels found in the quadrats 15.0% were juveniles and 43.3% were 10 years old and younger (Figure 10). Given the modified criteria for an ideal mussel population, discussed in the 'Overall' section, this site has a sufficient percentage of young mussels to maintain mussel numbers.

12th Ave: A total of 8 live Western Pearlshells were found. They varied from 15 to 106 mm in length (Figure 8), and from 3 years and up in age. The overall density for the surface of transects was 0.3 mussels/m^2 (Figure 9). 7 mussels were found within the quadrats. The density within the quadrats was 12.4 mussels/m^2 (Figure 9). All of the mussels found within the quadrats were buried, including 2 juveniles. Due to the low number of mussels found, it is not possible to evaluate the percentage of buried and/or young mussels in any meaningful way.

Hatchery West: A total of 169 live Western Pearlshells were found. They varied from 6 to 109 mm in length (Figures 7 and 8), and from 2 years and up in age. The overall density for the surface of transects was 20.6 mussels/m^2 (Figure 9). A total of 27 mussels were found within the quadrats. The density within the quadrats was 49.8 mussels/m^2 (Figure 9). Among these mussels, 15 (66.0%) were found at the surface and 12 (44.0%) were buried in the substrate. 8 of 11 of juvenile mussels were buried (72.7%). Further, among the mussels found in the quadrats 40.7% were juveniles and 46.4% were 10 years old and younger (Figure 10). Given the modified criteria for an ideal mussel population, discussed in the 'Overall' paragraph above, this site has a sufficient number of young mussels to maintain mussel numbers.

Hatchery East: A total of 5 live Western Pearlshells were found. They varied from 27 to 74 mm in length (Figure 8) and from 7 to 14 years in age. The overall density for the surface of transects was 1.2 mussels/m^2 (Figure 9). These mussels were found at the surface of the substrate, and no mussels were found within the quadrats (Figure 9). No juvenile mussels were found. Due to the low number of mussels found, it is not possible to evaluate the percentage of young mussels in any meaningful way.

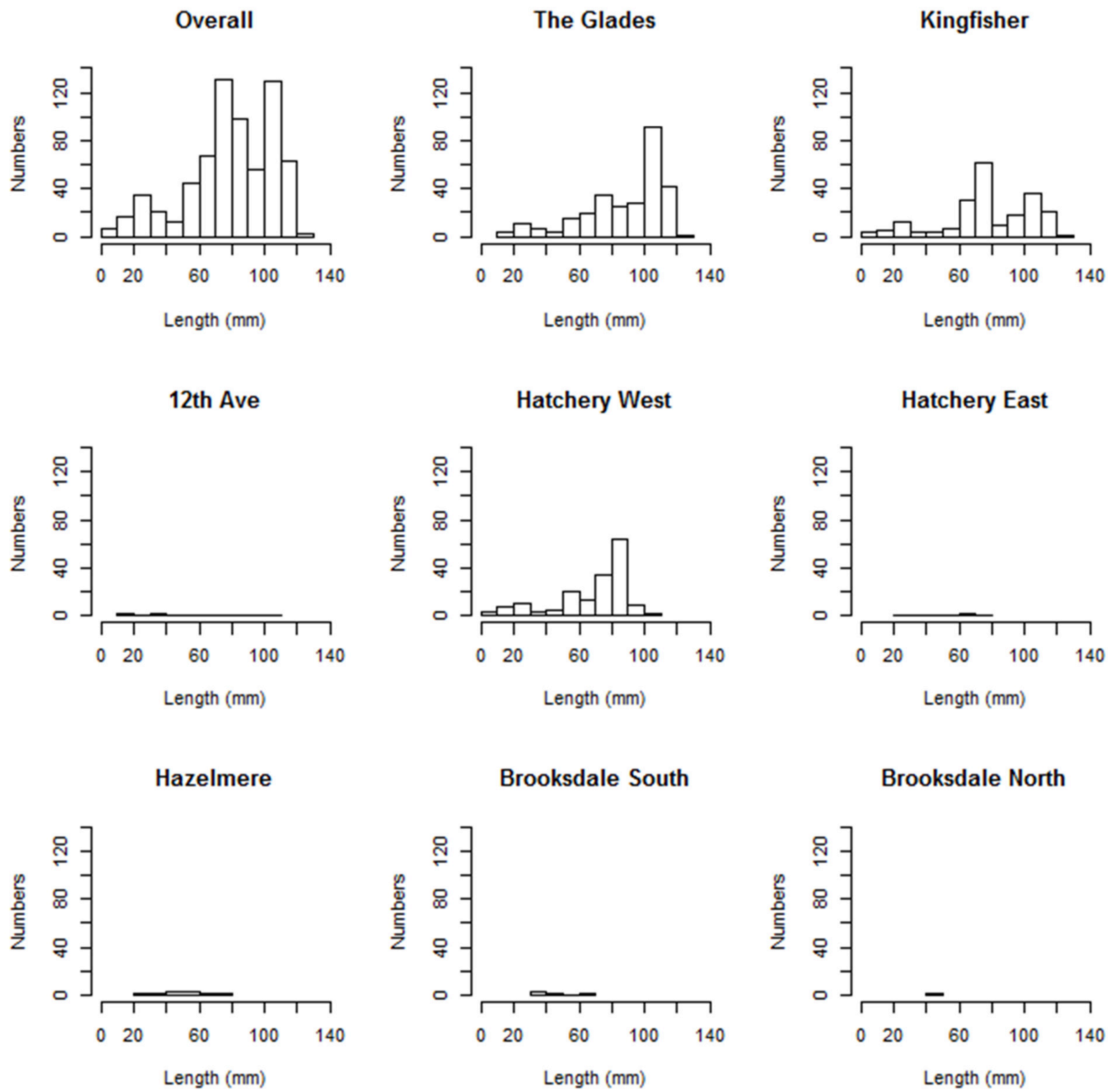

Figure 8. 2015 Western Pearlshell length distributions, overall and all sites.

The individual sites are listed in order, from downstream to upstream sites. Note that these distributions are based on all the mussels measured. Therefore, it underestimates the number of buried and young mussels.

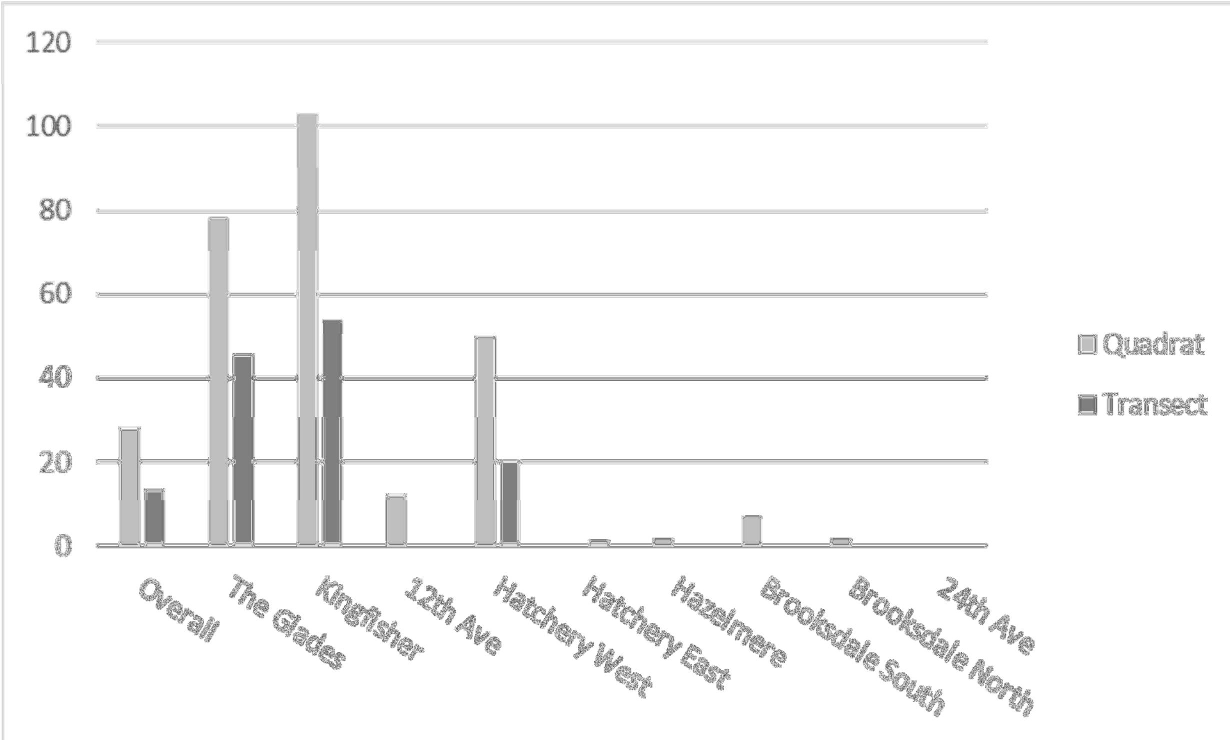

Figure 9. 2015 Western Pearlshell densities.

The individual sites are listed in order, from downstream to upstream sites. Densities from both Quadrat and Transect surveys are included. Quadrat surveys include both mussels found on the surface of and in the substrate, giving true densities from small areas. Transect surveys only include mussels found on the surface of the substrate, but give densities for larger areas.

Hazelmere: A total of 4 live Western Pearlshells were found. They varied from 21 to 74 mm in length (Figure 8) and from 5 to 16 years in age. The overall density for the surface of transects was 0.6 mussels/m^2 (Figure 9). One mussel was found in a quadrat and this mussel was buried in the substrate. The density within the quadrats was 1.8 mussels/m^2 (Figure 9). No juvenile mussels were found. Due to the low number of mussels found, it is not possible to evaluate the percentage of buried and/or young mussels in any meaningful way.

Brooksdale South: A total of 4 live Western Pearlshells were found. They varied from 31 to 46 mm in length (Figure 8) and from 7 to 8 years in age. All mussels were found buried in the substrate within the quadrats. The density within the quadrats was 7.1 mussels/m^2 (Figure 9). No juvenile mussels were found. Due to the low number of mussels found, it is not possible to evaluate the percentage of buried and/or young mussels in any meaningful way.

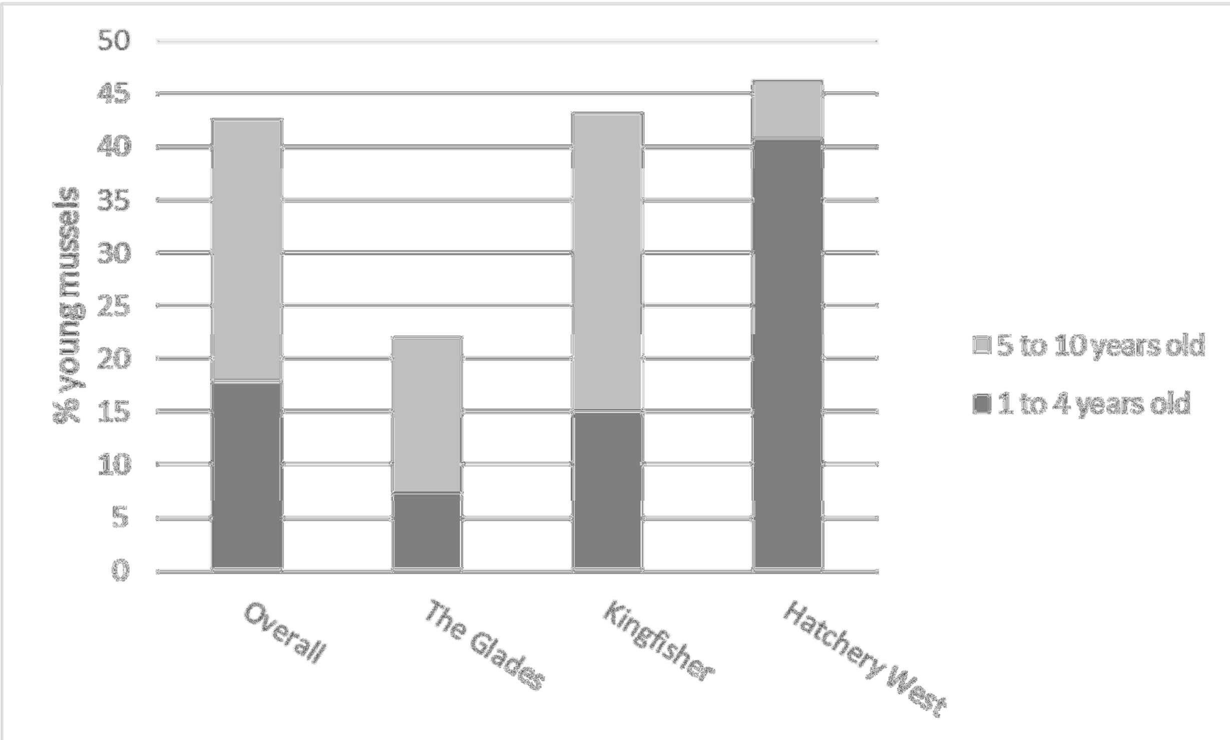

Figure 10. Percentages of young Western Pearlshells.

Each bar represents the cumulative percentages of young mussels overall and at each survey site, i.e. the two bars combined represent the percentage of mussels 10 years old and younger. The individual sites are listed in order, from downstream to upstream sites. Note that it is only data from quadrats, which include both mussels found at the surface of and in the substrate, that give true percentages of young mussels. Therefore, only distributions for the overall population and the sites with high numbers of mussels within the quadrats are included. However, even within quadrats the percentages of young mussels are likely to be underestimated, as their small size makes them difficult to find (Larsen and Hartvigsen 1997, Stanton et al. 2012).

Brooksdale North: A total of 1 live Western Pearlshell was found. This mussel was 49 mm long and 9 years old (Figure 8). It was found buried in the substrate within one of the quadrats. The density within the quadrats was 1.8 mussels/m^2 (Figure 9). Due to the low number of mussels found, it is not possible to evaluate the percentage of buried and/or young mussels in any meaningful way.

24th Ave: A total of 0 live Western Pearlshells were found (Figure 9).

For further details on data on biotic factors and channel characteristics, at the various sites, see Appendix B.

Discussion

Overall

We found that the densities of Western Pearlshell were substantially greater in 2009 than in 2015 at all sites, except for at Kingfisher (Figure 4). However, there was only a marginal trend towards a significant decline in overall density. The fact that we only found a trend towards significance is likely explained by our limited number of sites and the great variation in density between sites. Despite our best efforts to locate the sites in the exact same position both years, there might be slight differences in the location of the sites. Since freshwater mussel densities are known to vary greatly over short distances within systems (Downing and Downing 1992, Downing *et al.* 1993, Hastie *et al.* 2000), this may explain the differences in densities between years. However, one should expect random changes in the location of sites to result in both increases and decreases in densities. Therefore, the fact that the density declined substantially suggests that there has been a decline in the mussel population in the Little Campbell River (LCR).

Investigating the length distributions of Western Pearlshells and percentages of young mussels gave a more positive outlook. The comparison of length distributions showed that Kingfisher contains mussels of significantly shorter length in 2015 than it did in 2009 (Figure 5), indicating rejuvenation among the mussels at this site. In addition, Hatchery West, which was only surveyed in 2015, contains many mussels in the smaller and middle length classes, and no mussels in the greater length classes (Figures 7 and 8). This indicates that this site has been colonized or re-colonized recently, relative to the overall lifespan of the Western Pearlshell (approximately 60 years according to Jepsen *et al.* (2010)). Further, given the criteria for an ideal mussel population, modified from Young *et al.* (2001), all the 2015 high-density sites had percentages of young mussels (Figure 10) sufficient to maintain mussel numbers. For the low-density sites, it was impossible to evaluate the young mussel percentages using these criteria. However, these criteria cannot be trusted completely, since the maximum age of the Western Pearlshell in the Little Campbell River is not known with certainty. Many of the length distributions (Figures 5, 7, and 8) also have several peaks, which indicate that the recruitment in the river is very variable. This makes it more difficult to evaluate long-term trends in the LCR. Even so, the data seem to indicate that the numbers of the mussel should be maintained, at least at the high-density sites in the river.

As freshwater mussels are important indicators of ecosystem health (Larsen 1997, Nedeau *et al.* 2009, Jepsen *et al.* 2010), our findings on the status of the Western Pearlshell population can also be used as an indicator of the health of the Little Campbell River. The decline in density between 2009 and 2015 (Figure 4) suggests that environmental conditions have been too bad to result in sufficient recruitment among the mussels. Note that this reflects the environmental conditions prior to 2009, as there is a time lag between a decline in recruitment and a decline in population numbers among freshwater mussel (Larsen 1997, Jepsen 2010). Therefore, it is safe to assume that general health of the LCR has been reduced prior to 2009, and that this reduced health would have affected other organisms within the ecosystem. These findings are not surprising since the river is known to have problems associated with low flow, high temperatures, low dissolved oxygen, high nutrient input, high fecal coliform bacteria, and high turbidity (Swain and Holms 1988, Drever and Brown 1999, Hay & Company Consultants Inc. 2003, British Columbia Ministry of Water, Land, and Air Protection 2003, Fleming and Quilty 2006, Juteau 2008, Zevit *et al.* 2008, Kerr Wood Leidal Ass. Ltd. 2011). The fact that there has been a rejuvenation of the population (Figures 5, 7, and 8) and that there is sufficient juvenile recruitment at some of the sites (Figure 10) indicates that there has been an improvement in the health of LCR during later years. However, the peaks in many of the length distributions (Figures 5, 7, and 8) indicate that the recruitment in the LCR is very variable. This indicates that the health of the river also varies. Therefore, one can question whether the improved health of the river is a short-term fluctuation or a long-term trend.

Site specific

We found great variation between the sites. For the sites surveyed in both 2009 and 2015, there was quite substantial variation in how much the density changed between the two years (Figure 4). For 2015, the sites vary greatly in length distribution (Figures 7 and 8), density (Figure 9), and percentages of young mussels (Figure 10). Therefore, the sites also vary greatly in their conservation value for the Western Pearlshell population in the Little Campbell River. Below follows an overview for each of the high-density sites. Subsequently, the low-density sites are considered together.

The Glades: The comparison between the densities of Western Pearlshell in 2009 and 2015 (Figure 4) strongly suggest that there has been a decline in mussel numbers. There seems to have been a minimal change in the length distribution at this site (Figure 5). However, this site is still the second densest in the LCR (Figure 9). In addition, the percentage of young mussels (Figure 10) is just about sufficient to maintain mussel numbers, based on the criteria previously discussed. Therefore, the site maintains a high conservation value for the Western Pearlshell population in the Little Campbell River.

Kingfisher: The comparison between the densities of Western Pearlshell in 2009 and 2015 (Figure 4) shows that the mussel numbers have not changed much at this site. Despite the lack of change in number, there seems to have been a rejuvenation among the mussels at this site, as the length distribution shows that the site contains mussels of smaller length in 2015 than in 2009. In addition, this site is the densest in the LCR. The percentage of young mussels (Figure 10) is also about twofold the percentage needed to maintain mussel numbers. Therefore, the site maintains a high conservation value for the Western Pearlshell population in the Little Campbell River.

Hatchery West: This site was only surveyed in 2015. Its length distribution (Figures 7 and 8) shows that the site contains many smaller and medium sized mussels, but did not contain mussels in the greater length classes (Figures 7 and 8). This indicates that this site has been colonized or re-colonized recently. In addition, this site is the third densest in the LCR. The percentage of young mussels (Figure 10) is also more than twofold the percentage needed to maintain mussel numbers. Therefore, the site is of high conservation value for the Western Pearlshell population in the Little Campbell River.

12th Ave, Hatchery East, Hazelmere, Brooksdale South, Brooksdale North, and 24th Ave: For the sites that were surveyed in 2009, the comparison between the densities of Western Pearlshell in 2009 and 2015 (Figure 4) strongly suggest that there has been more than a tenfold decline in mussel numbers. The only exception is 24th Ave, which did not contain mussels in either year. Further, all of these sites currently have very low mussel densities (Figure 9). However, the 2015 length distributions (Figure 8) reveal that all of these sites contain some relatively small mussels. Therefore, these sites are not remnant populations of old mussels without any recruitment. Instead, they are likely to be marginal habitat that allow for a very limited recruitment. Alternatively, the mussels at these sights might have dispersed from locations with better recruitment upstream, but only the 12th Ave site is known to be downstream from a high-density site (Figure 2). One note should be made with respect to the two sites at Brooksdale, as signs of North American river otter (*Lontra canadensis*) presence were seen there. This may explain the decrease in density at Brooksdale North between 2009 and 2015, and the low densities at both sites in 2015. Based on the findings described above, these sites have a limited conservation value within the Western Pearlshell population in the Little Campbell River.

Overall, Kingfisher and Hatchery West have the highest conservation value within the Western Pearlshell population in the Little Campbell River, due to their relatively high densities and high percentages of young mussels. The Glades also has a high conservation value due to its high density and relatively high percentage of young mussels. The remaining sites have a very limited conservation value. Their main value might be in keeping the population genetically connected, by allowing some reproductive connectivity between high-density locations. Further, they also provide re-colonization potential to the upper reaches of the LCR, if environmental factors should improve.

Conclusions

Overall, this study suggests that there has been a decline in the densities of Western Pearlshell in the Little Campbell River between 2009 and 2015. However, there is evidence that there has been a rejuvenation of the population at some of the sites. The evaluation of the percentages of young mussels in the system also shows that several of the sites have sufficient recruitment of juveniles to maintain mussel numbers. For the other sites the future is more uncertain, as there is very limited data on recruitment due to the low number of mussels at these sites. Based on these findings, there should be concern that the population has declined since 2009. There should also be optimism that the population should be maintained at its current size for the future, unless there are changes in environmental conditions in the LCR. Finally, our findings on the status of the Western Pearlshell population show that the LCR has suffered from reduced health before 2009, but that there has been an improvement in ecosystem health in more recent years.

Recommendations

First of all, we recommend continuing the monitoring of the Western Pearlshell population in the Little Campbell River. One reason for this is the decline in the population observed between 2009 and 2015. Despite the rejuvenation and high percentages of juvenile mussels in the population, suggesting that mussel numbers are likely to be maintained in the immediate future, it is important to confirm whether this is going to be the case. Another reason is the lack of knowledge about the mussel in British Columbia (B.C.). As far as we know, this is the first study to evaluate Western Pearlshell population trends and thoroughly investigate juvenile recruitment in B.C.. By continuing the monitoring, it would only add to the value of this study. A third reason is the importance of freshwater mussels as indicators of ecosystem health (Larsen 1997, Nedeau *et al.* 2009, Jepsen *et al.* 2010). Continuing the monitoring of the mussel will also be a continued monitoring of the ecosystem health of the LCR.

Second, we recommend making some changes to the monitoring program, including additional sites. Many of the sites surveyed in 2015 have little conservation value to the Western Pearlshell population in the Little Campbell River. Some reaches of the river are also not well represented by the current network of sites. Therefore, we recommend adding two sites between Kingfisher and 12th Ave, one site between Hazelmere and Brooksdale South, and one site between Brooksdale North and 24th Ave. The two sites between Kingfisher and 12th Ave are of the greatest importance, as this reach of the LCR contains the highest number of mussels. We recommend surveying these sites in 2016, as that would further increase the value of subsequent studies. Further, we recommend maintaining the low-density sites as a part of the monitoring program. If the workload associated with adding the new sites is restrictive, we recommend only doing mussel counts at the low-density sites. At these sites, it will also be beneficial to survey the entire sites and not only the transects, due to the low mussel density. It is important to undertake these counts in such a way that the data is comparable to data from 2009 and 2015.

Third, we recommend establishing which fish species the Western Pearlshell uses as hosts in the Little Campbell River. Like almost all our native freshwater mussels, Western Pearlshell glochidia (larvae) are obligate parasites on fish (Nedeau *et al.* 2009, Jepsen *et al.* 2010). Therefore, the maintenance of population numbers is dependent on the availability of host fish. From previous studies it is known that it uses salmonids (Nedeau *et al.* 2009, Jepsen *et al.* 2010). However, the host is not known for the LCR population. Determining the host usage, of the population, is a necessary first step in determining if host availability is a threat to the mussel. Field data on glochidial infections can be used to determine the likely fish hosts (for methodology, see e.g. Spring Rivers 2007, O’Brien *et al.* 2013, Mageroy 2015). To confirm fish host usage laboratory studies are necessary (for methodology, see e.g. Spring Rivers 2007, O’Brien *et al.* 2013). We recommend completing the field studies as a first step.

Fourth, we recommend a twofold approach to the conservation of the Western Pearlshell population in the Little Campbell River. First, it is important to protect the sites with high conservation value. To protect these sites, it is important to inform and involve the local landowners. Second, due to the dependency of the Western Pearlshell on salmonid host fish and the susceptibility of both the mussels and fish to water quality changes, it is necessary to protect the mussel through an ecosystem and watershed approach. The improvement and maintenance of good water quality within the LCR is dependent on a high level of cooperation between all stakeholders, including the general public, private landowners, municipal and provincial agencies, federal agencies, conservation organizations, and private corporations. Therefore, the conservation of the Western Pearlshell in the LCR is dependent on support from a wide variety of people.

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Appendices

Appendix A: Site location details

See Table 1.

Table 1. GPS waypoints and location details for sites. The sites are listed in order, from downstream to upstream sites.

Site	UTM	Location details
The Glades	11 U 0518488 5428882	At The Glades garden
Kingfisher	11 U 0518239 5428912	At Kingfisher Farm: North of farm buildings, between 8^{th} and 4^{th} Ave, east of 172^{nd} St
12^{th} Ave	11 U 0520558 5430074	70 m downriver from the 11^{th} Ave bridge
Hatchery West	11 U 0521233 5430234	At Semiahmoo Fish and Game Club: Downriver from the salmon fence
Hatchery East	11 U 0521522 5430253	At Semiahmoo Fish and Game Club: Between the Little Campbell Hatchery and the archery range
Hazelmere	11 U 0522027 5429970	At Hazelmere RV Park: Upriver from the RV parking area.
Brooksdale South	11 U 0522865 5431033	At A Rocha Brooksdale Environmental Centre: Upriver from 16^{th} Ave bridge
Brooksdale North	11 U 0522934 5431168	At A Rocha Brooksdale Environmental Centre: North of footbridge
24^{th} Ave	11 U 0523537 5432520	Downriver from the 24^{th} Ave bridge and culvert

Appendix B: Data on biotic factors and channel characteristics

Below follows an overview of data on biotic factors and channel characteristics at each site. The sites are listed in order, from downstream to upstream sites.

The Glades: The site is a part of a pool and log dam complex. Along the banks the vegetation is extensive and the canopy cover is app. 60%. Plant species observed include Bracken Fern (*Pteridium* sp.), Indian Plum (*Oemleria cerasiformis*), Pacific Ninebark (*Physocarpus capitatus*), Red Alder (*Alnus rubra*), Red Elderberry (*Sambucus racemosa*), Reed Canary Grass (*Phalaris arundinacea*), Stinging Nettle (*Urtica dioica*), Thimbleberry (*Rubus parviflorus*), Western Hemlock (*Tsuga heterophylla*), and Western Red Cedar (*Thuja plicata*). Animals observed include the Great Blue Heron (*Ardea herodias*) and Pacific Chorus Frog (*Pseudacris regilla*). The site itself is a run, with a clay slope making up the right bank and undercut left bank. Its mean wetted width is 7.86 m (7.00 to 8.38 m), and its mean green line width is 8.32 m (7.25 to 9.40 m). The mean depth of the river, from the green line, is 0.29 m (0.08 to 0.55 m). Lots of small woody debris cover the substrate, which consists of app. 20% clay, 30% fine sediments, and 50% sand.

Kingfisher: The site is surrounded by large woody debris. Along the banks the vegetation is extensive and the canopy cover is app. 25%. Plant species observed include Black Twinberry (*Lonicera involucrata*), Ocean Spray (*Holodiscus discolor*), Pacific Ninebark, Smartweed (*Polygonum* sp.), Spiny Woodfern (*Dryopteris expansa*), Stinging Nettle, Red Alder, Red Elderberry, Reed Canary Grass, and Vine Maple (*Acer circinatum*). Animals and animal signs observed include Blacktail Deer tracks (*Odocoileus hemionus*), caddisfly carapaces (Trichoptera), and Northern Red-Legged Frog (*Rana aurora*). The site itself is a run, with a mean wetted width of 4.82 m (4.35 to 5.20 m) and a mean green line width of 6.04 m (5.18 to 6.90 m). Its mean depth, from the green line, is 0.26 m (0.10 to 0.51 m). The substrate consists of app. 25% clay, 70% sand, and 5% gravel.

12th Ave: The site is surrounded by pastures. Grazing has reduced the vegetation along the bank to almost nothing and the canopy cover to app. 10%. The little vegetation there is include Himalayan Blackberry (*Rubus armeniacus*), Purple Nightshade (*Solanum xanti*), Reed Canary Grass, and Yellow Flag Iris (*Iris pseudacorus*). Animals observed include Northern Red-Legged Frog. The site itself is a run, with sandy and steep banks. Its mean wetted width is 3.91 m (3.35 to 4.45 m), and its mean green line width is 4.04 m (3.40 to 4.66 m). The mean depth of the river, from the green line, is 0.31 m (0.07 to 0.59 m). Its substrate consists of app. 45% sand, 45% gravel, and 10% cobble.

Hatchery West: The site is surrounded by large woody debris. Its canopy cover is app. 80%. Plant species observed include Bittersweet Nightshade (*Solanum dulcamara*), Himalayan Balsam (*Impatiens glandulifera*), Himalayan Blackberry, Red Alder, and Reed Canary Grass. Animals observed include caddisfly larvae and salmon fry (*Oncorhynchus* sp.). The site itself is a run, with a mean wetted width of 6.93 m (6.90 to 7.80 m) and a mean green line width of 7.49 m (6.38 to 8.08 m). Its mean depth, from the green line, is 0.49 m (0.17 to 1.00 m). The substrate consists of app. 20% fine sediments, 30% sand, and 50% gravel.

Hatchery East: The site is part of a riffle and pool complex. Its canopy cover is app. 25%. Plant species observed include Himalayan Blackberry, Red Alder, Red Elderberry, Reed Canary Grass, and Salmon Berry (*Rubus spectabilis*). Animals observed include caddisfly larvae, Coho Salmon fry (*Oncorhynchus kisutch*), lamprey (*Lampetra* sp.), and Northern Red-Legged Frog. The site itself is a run, with a mean wetted width of 5.58 m (5.05 to 6.20 m) and a mean green line width of 5.96 m (5.76 to 6.30 m). Its mean depth, from the green line, is 0.21 m (0.05 to 0.43 m). The substrate consists of app. 5% fine sediments, 25% sand, and 70% cobble.

Hazelmere: The canopy cover at the sites is app. 60%. Plant species observed include Field Bindweed (*Convolvulus arvensis*), geranium (*Geranium* sp.), Hedge Nettle (*Stachys palustris*), Himalayan Balsam, Himalayan Blackberry, Indian Plum, Pacific Ninebark, Purple Nightshade, Red Alder, Reed Canary Grass, Salmon Berry, Stinging Nettle, Western Red Cedar, and Western Swordfern (*Polystichum munitum*). Animals observed include caddisfly larvae, Coho Salmon fry, and crayfish (Astacoidea). The site itself is a run, which is divided in two by a gravel bar. Its mean wetted width is 7.07 m (4.20 to 9.30 m), and its mean green line width is 11.10 m (10.60 to 11.80 m). The mean depth of the river, from the green line, is 0.43 m (0.22 to 1.26 m). Woody debris cover the substrate, which consists of app. 10% clay, 5% fine sediments, 15% sand, 60% gravel, and 10% cobble.

Brooksdale South: The canopy cover at the sites is app. 50%. Plant species observed include geranium, Himalayan Blackberry, impatiens (*Impatiens* sp.), Red Alder, Reed Canary Grass, and Western Red Cedar. Animal signs observed include signs of North American River Otter presence (*Lontra canadensis*). The site itself is a run, with an undercut right bank. A cobble bar divides the river channel in two at the lower end of the site. Its mean wetted width is 4.60 m (2.30 to 6.80 m), and its mean green line width is 5.66 m (4.27 to 7.50 m). The mean depth of the river, from the green line, is 0.37 m (0.22 to 0.60 m). Woody debris cover some of the substrate, which consists of app. 5% fine sediments, 25% sand, 45% gravel, and 25% cobble.

Brooksdale North: The site is part of a riffle complex. Along the banks the vegetation is extensive and the canopy cover is app. 40%. Plant species observed include Common Holly (*Ilex aquifolium*), Himalayan Blackberry, Indian Plum, Pacific Ninebark, Red Alder, Reed Canary Grass, Salmon Berry, and Sitka Spruce (*Picea sitchensis*). Animals and animal signs observed include amphipods (Amphipoda), caddisfly larvae, dragonfly nymphs (Anispotera), Northern Red-Legged Frog, North American River Otter den, and salmon fry. The site itself is a riffle, which is divided in two by a gravel bar in the middle of the site. Its mean wetted width is 5.73 m (5.50 to 5.90 m), and its mean green line width is 7.17 m (5.50 to 9.40 m). The mean depth of the river, from the green line, is 0.32 m (0.10 to 0.74 m). Large woody debris cover some of the substrate, which consists of app. 25% sand, 45% gravel, and 30% cobble.

24th Ave: The site is in a residential area and is part of a riffle and pool complex. Along the banks the vegetation is extensive and the canopy cover is app. 80%. Plant species observed include Pacific Ninebark, Red Alder, Reed Canary Grass, Western Skunk Cabbage (*Lysichiton americanus*). Animals observed include caddisfly larvae, crayfish, and Mallard Duck (*Anas platyrhynchos*). The site itself is a pool, with a mean wetted width of 6.08 m (4.80 to 7.20 m) and a mean green line width of 7.49 m (5.90 to 8.97 m). Its mean depth, from the green line, is 0.29 m (0.07 to 0.73 m). Woody debris covers the substrate, which consists of app. 30% sand, 35% gravel, and 35% cobble.