Relationship of Rainy River Hydrology to the Distribution and Abundance of Freshwater Mussels

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February 2016

Acknowledgments

We thank the following for their assistance with this project: Ian Chisholm for project development and sampling design, Samantha Bump for field sampling, and Dan O'Shea for statistical analysis. We also thank Mark Colosimo, Ryan Maki, and Claire Kissane for helpful edits and comments on this report.

TABLES

FIGURES

Executive Summary

The objective of this study was to quantitatively characterize the mussel assemblages in the Rainy River that encompass the range of physical effects created by implementation of the 2000 rule curve. Three 1-km reaches were selected based on hydrologic models that indicate changes in hydrology along the course of the river, one each within the dam-regulated zone (Reach 2), the nearly unaffected zone (Reach 7), and the zone impounded by Lake of the Woods (Reach 9). Data from a qualitative mussel survey conducted in 2007 were also analyzed. Mussel assemblage metrics that were examined included species distribution, richness, density, catch per unit effort, recruitment, and growth. Mussel species richness and density were not significantly different among the three quantitatively sampled reaches; however, there was a general trend of lower mussel abundance in upstream reaches from both quantitative and timed search samples. Average density ranged between 1.63 to 2.17 mussels/m^2 among the three quantitatively sampled reaches and was used to estimate a total mussel population size of 104,096, 141,289, and 137,750 mussels in Reaches 2, 7, and 9, respectively. Mussels were concentrated nearest to shore in Reaches 7 and 9 but more patchily distributed in Reach 2, and there was no apparent relationship between substrate composition and mussel abundance. *Lampsilis siliquoidea*, the most abundant species, was significantly larger at a given age in Reach 2 than in Reaches 7 and 9. Based on our results, there is no direct evidence that mussels were negatively affected by the implementation of the 2000 rule curves. Lower mussel abundance and recruitment in upstream reaches could be due to hydrologic variability from long-standing dam operations; however, these potential effects on mussel abundance are not greatly pronounced and appear to diminish beyond 20 km from the dam, where mussel assemblages were more comparable to downstream reaches.

Introduction

Rainy River flows are regulated at two hydropower facilities at Fort Frances and International Falls. In 2000, the International Joint Commission (IJC) made changes to their rule curves to better manage reservoir levels in lakes upstream (International Joint Commission 2001), which have affected the hydrology of the Rainy River. Under current operation, Rainy Lake elevation must be maintained between prescribed minimum and maximum elevations. As long as the water level of Rainy Lake is maintained within the limits, the discharge rate into, and the water level of, Rainy River is unrestricted. As such, the Canadian side of the International Falls / Fort Frances Dam (IFD) continues to practice hydro-peaking (i.e., fluctuating rates about the daily mean discharge), whereas, the U.S. dam has not peaked since 2001 (O'Shea 2005). The resulting hydrograph of Rainy River is thought to have lost the natural seasonal flow pattern and has increased short-term variability in discharge due to hydro-peaking (O'Shea 2005). The 2000 rule curve changes are subject to an IJC review in 2015, which will include an evaluation of monitoring information on the possible effects of the flow changes. A Plan of Study (POS) was developed to prioritize the monitoring and analyses required to identify the impacts on the biological and aquatic communities of the adoption of the 2000 Order (Kallemeyn et al. 2009). This information will be used to determine whether to maintain the current rules governing dam operation (2000 Rule Curves) or make changes. Freshwater mussels in the Rainy River are among the biological monitoring components identified in the POS.

The freshwater mussel fauna of the Lake of the Woods Drainage consists of a relatively small set of species compared to the more diverse lower Mississippi River fauna but is similar to the adjacent Mississippi Headwaters and Lake Superior drainages (Graf, 1997). Of the 10 species occurring in the drainage, 9 are known to occur in the Rainy River (Minnesota DNR unpubl. data). Freshwater mussels are a unique and diverse group of benthic, filter-feeding bivalves that provide important ecosystem services in rivers (Vaughn et al. 2007, Vaughn et al. 2008, Spooner et al. 2012). Mussels are also distinguished by having among the highest extinction and imperilment rates of any group of organisms in the world (Haag 2012, Haag and Williams 2014). Their susceptibility to various environmental disturbances and dependence on fish to complete their life cycle and for dispersal, make them useful biological indicators (Grabarkiewicz & Davis, 2008).

In 2013, the International Joint Commission (IJC) contracted with the MNDNR to assess the status of freshwater mussel communities and populations along the gradient of hydrologic effects imposed on the river flows by the 2000 rule curve changes. The objectives of this study were to quantitatively sample mussel assemblages in three reaches of the Rainy River that could be affected differently by the rule curve changes. Specifically, mussel species distribution, richness, density, recruitment, and growth were analyzed. A larger scale qualitative mussel survey from 2007 along the length of Rainy River is also included and compared to the current study.

Methods

Site Selection

We reviewed the IJC Hydrology Report for the Rainy River (Luce and Metcalfe 2014) to assist in identifying sites along the river that would be representative of the changes in hydrology without differing greatly in physical habitat characteristics. Eleven hydrologic reaches were identified in the IJC report (Fig. 1). Reaches 1-5 were most affected by dam regulation and attenuated with distance downstream. These effects were absent below Reach 6. Below Reach 7, the effects of Lake of the Woods were increasingly evident.

As flows are regulated by dam operations, water levels and current velocity vary frequently compared to unregulated zones. As the Rainy River descends into the area effected by Lake of the Woods, current velocity decreases and the aquatic habitat becomes increasingly lentic. We determined that establishing a sampling area within the impounded zone, the relatively unaffected zone, and within the zone clearly effected by the rule curve would allow for comparison of mussel communities and species populations among reaches. After reviewing geomorphology of the channel and depths we decided on 1-km-long sampling areas within Reaches 2, 7, and 9 (Fig. 2). Although it is within the area not affected by impoundment or dam regulation, we avoided sampling within Long Sault Rapids because of its unique physical habitat characteristics.

Sampling Design

We followed recommendations by Pooler and Smith (2005) to implement a systematic pattern of sampling sites at each of the three reach areas. We used ArcMap to establish three randomized starting points for a total of 105 sample units within each study area. Each sample unit had a unique UTM coordinate (Fig. 3).

Two boats with SCUBA divers and sampling gear were employed to collect samples. We navigated to each sample coordinate using a Garmin Montana 650T GPS unit. Five sample target sites that were inadvertently placed on shore were not included. Upon arrival at each sample point, anchors were lowered to hold the dive boat in position. Water depth in meters was recorded. After a ¼ m^2 aluminum quadrat sampler with an attached 6.35 mm mesh bag (Fig. 4) was lowered to the bottom, the diver descended to the sampler and excavated the area within the quadrat to a depth of 10-15 cm, placing all substrate material into the bag. After returning to the dive boat, the sampler was retrieved and fine sediments rinsed through the bag. The remaining bag contents were emptied onto a sorting table, and all live mussels were removed. Mussels were identified, and the shell length in mm and the number of growth arrest lines (annuli) were recorded. At each site, the diver provided an estimate of sediment composition as a percent of the following categories: Clay, Silt, Sand, Gravel, Cobble, Boulder, Bedrock, Shell, Detritus/woody debris, and Vegetation. All live mussels were returned to the river.

We also include data from a mussel survey of the Rainy River in 2007. Mussels were sampled at 26 sites along the length of the river above and below access points on the U.S. - Canada border only. At each sample point, we deployed 1-2 divers using SCUBA to collect all live mussels encountered, recording the total search time for each sample. Mussels were sorted, identified, counted, and returned to the river. Catch per unit effort (number of live mussels per minute) was calculated for each sample.

11 Hydrologic Reaches of the Rainy River
as Identified in the IJC Report

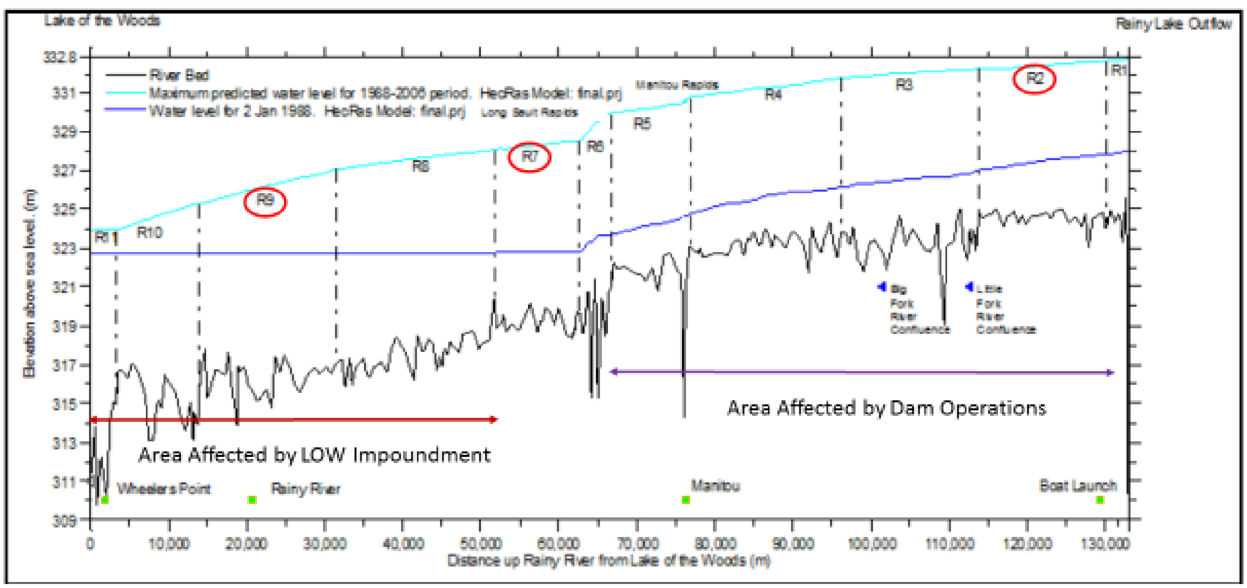

Figure 1. Hydrologic reaches of the Rainy River selected for mussel sampling (from Luce and Metcalfe 2014).

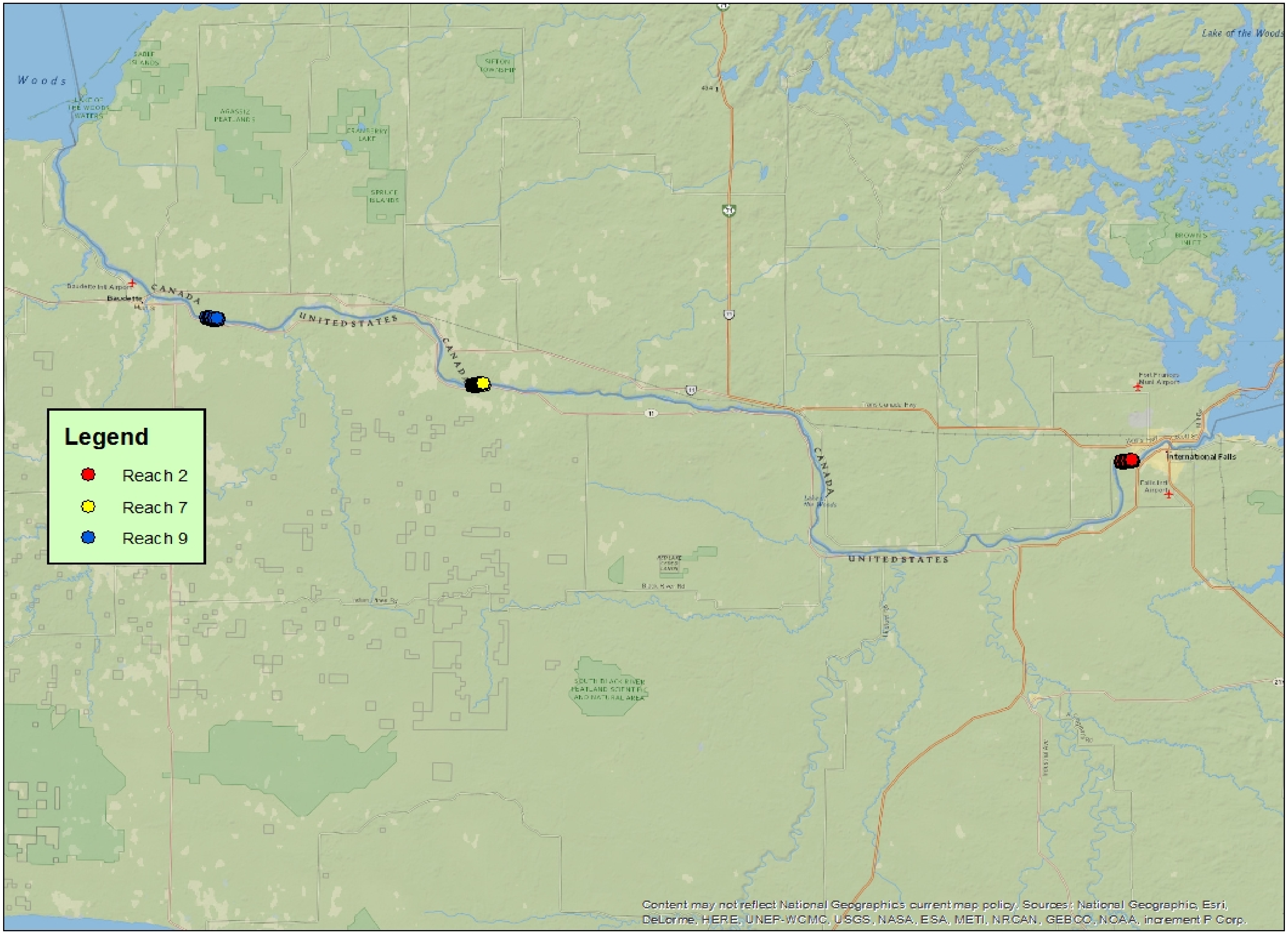

Figure 2. Sampling areas within each selected Rainy River reach.

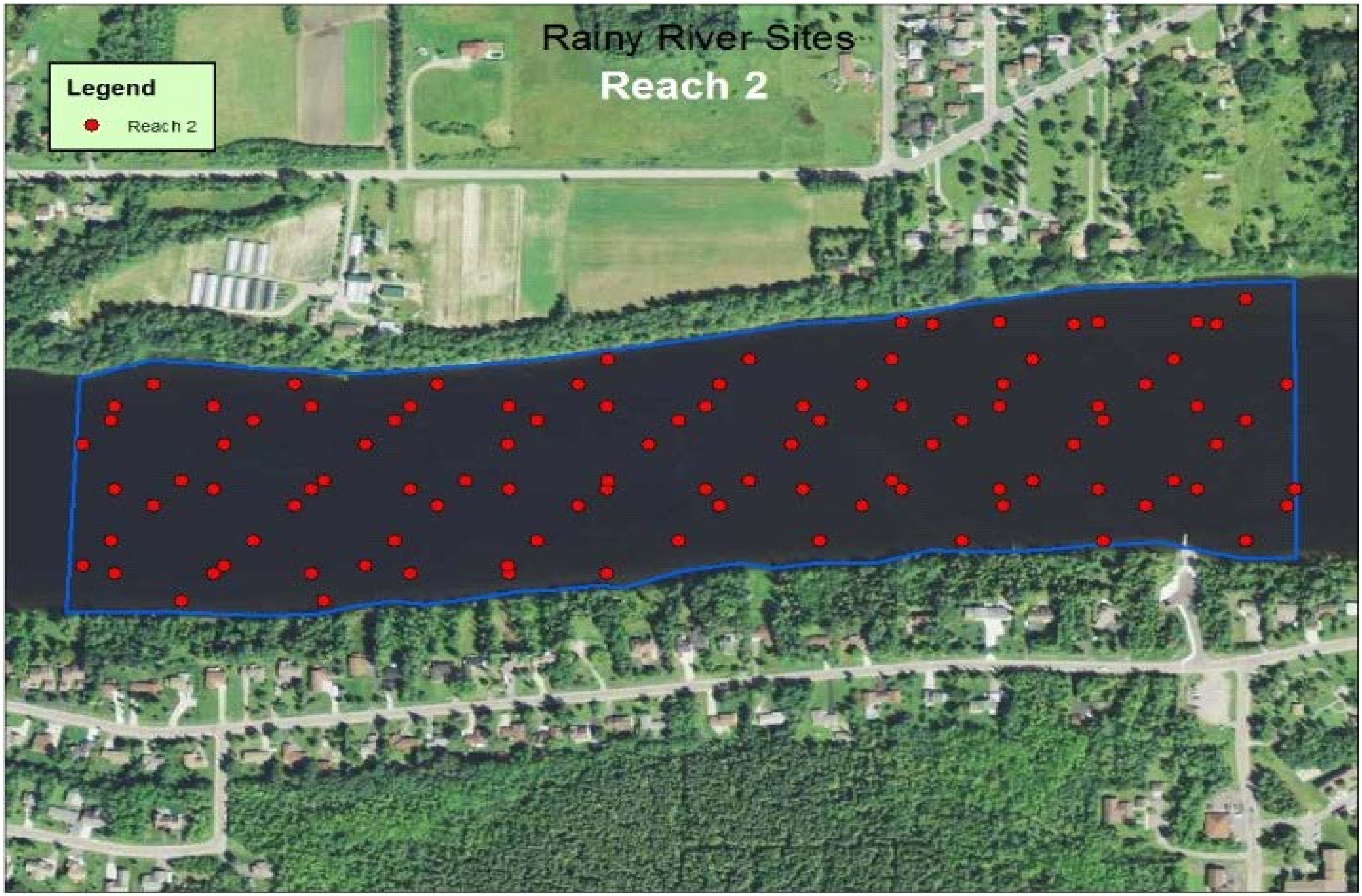

Figure 3. Systematic sampling sites in the Reach 2 study area.

Figure 4. 1/4m^2 sampler used to collect all substrate at each sample site.

Results

Mussels were present in each of the three quantitatively sampled study reaches, and a total of 152 live mussels representing six species were collected (Table 1). Average density ranged between 1.63 and 2.17 mussels/m^2, and although mussels appeared to be slightly less abundant in Reach 2, overall density of mussels did not differ among the study reaches (F=0.460, df=2, P=0.632). Species richness ranged from four to six species and *Lampsilis cardium*, *Lampsilis siliquoidea*, *Ligumia recta*, and *Pyganodon grandis* were collected at all study reaches. *Lampsilis siliquoidea* was the most abundant and widely distributed species, comprising 50 - 83% of the assemblage within each study reach and occurring in the highest proportion of samples. Relative abundance of mussels was similar among reaches except that *Lasmigona complanta* was more abundant in Reach 2 than other reaches. Figures 5-7 show the abundance of mussels at each sample point within each reach. There was no apparent relationship between substrate composition and mussel abundance in any reach. Mussels were apparently more abundant along the right descending bank of the river in Reach 7 and most abundant along both the right and left descending banks of the river in Reach 9. There was no obvious pattern of abundance in Reach 2. The relationship between substrate composition and mussel abundance does not appear to explain abundance patterns (Figs. 8-10).

Using total area within each study reach, the number of mussels collected in each sample, and variance among them, the density of live mussels/m^2 can be calculated within 95% confidence intervals and used to estimate the population size of mussels within each area (Table 2). Total mussel population size (all species combined) was 104,096, 141,289, and 137,750 mussels in reaches 2, 7, and 9, respectively (Table 2).

Recent recruitment was observed for all species, and overall, there was a higher proportion of individuals ≤5 years old at downstream reaches (14% Reach 2, 30% Reach 7, and 53% in Reach 9). This trend was also evident when using only individuals ≤3 years old, and the most abundant species, *L. siliquoidea* (Fig. 11). However, growth rate of *L. siliquoidea* was significantly greater in Reach 2 than at downstream reaches (Figs. 12-13). Both age ($F=288.84$, $df=1$, $p<0.0001$) and reach ($F=9.51$, $df=2$, $p=0.0002$) had a significant effect on growth. Mussels in Reach 2 were larger for their age than in either Reach 7 ($t=-3.856$, $p=0.0006$) or Reach 9 ($t=-4.183$, $p=0.0002$) (Tukey all-pair comparison on the factor Reach using the general linear hypotheses command (glht) in the multcomp package (Hothorn et al. 2008) R (R Core Team 2014)). The weaker slope of the regression line in Reach 2 compared to reaches 7 and 9 (Fig. 12) is likely due to fewer young individuals represented in Reach 2. No significant differences were observed between Reach 7 and Reach 9 ($t=-0.637$, $p=0.7980$).

A total of nine species were collected during the 2007 survey (Table 3), of which *Anodontoides ferussacianus*, *Strophitus undulatus*, and *Utterbackia imbecillis* were absent during the 2015 study. Similar to the 2015 study, *L. siliquoidea* (77.4%) was by far the most abundant species, followed by *P. grandis* (10.4%) and *L. complanata* (7.6%). There was a weak trend of increasing CPUE from upstream to downstream (Figs. 14-15). This was primarily due to low CPUE (≤ 2 mussels per minute) at several upstream sites within 25km of the IFD (upper Reach 3), and three downstream sites with CPUE of >12 mussels per minute. However, there were also some sites in Reach 2 and upper Reach 3 with CPUE of 2 - 5 and 5 - 8 mussels per minute, respectively (Fig. 15).

Table 1. Summary statistics for mussel species within each study reach of the Rainy River, 2015.

	No. individuals	Density/m2	Relative density (%)	Relative frequency (%)	Importance RD + RF
			Reach 2		
Lampsilis siliquoidea	21	0.82	50.0	56.3	106.3
Lasmigona complanata	16	0.62	38.1	43.8	81.8
Lampsilis cardium	2	0.08	4.8	6.3	11.0
Pyganodon grandis	2	0.08	4.8	6.3	11.0
Ligumia recta	1	0.04	2.4	3.1	5.5
			Reach 7		
Lampsilis siliquoidea	42	1.60	73.7	88.0	161.7
Lasmigona complanata	7	0.27	12.3	24.0	36.3
Lampsilis cardium	2	0.08	3.5	8.0	11.5
Pyganodon grandis	4	0.15	7.0	16.0	23.0
Lasmigona compressa	1	0.04	1.8	4.0	5.8
Ligumia recta	1	0.04	1.8	4.0	5.8
Anodontoides ferussacianus	Dead only				
			Reach 9		
Lampsilis siliquoidea	44	1.69	83.0	84.6	167.6
Ligumia recta	5	0.19	9.4	19.2	28.7
Pyganodon grandis	3	0.12	5.7	11.5	17.2
Lampsilis cardium	1	0.04	1.9	3.8	5.7

Table 1. Estimates of total population statistics for mussels within study areas in the Rainy River.

	Reach 2	Reach 7	Reach 9
Sample Size	103	105	104
Average density (No/m²)	1.63	2.17	2.04
Species richness	5	6	4
Samples without Mussels	70	80	78
Total area (m²)	252,806	260,270	270,302
Mean population Est.	104,096	141,289	137,750
95% UCL	138,579	202,592	199,768
95% LCL	69,613	79,986	75,731
Change in density	Required Sample Size to Detect Change	Required Sample Size to Detect Change	Required Sample Size to Detect Change
10%	1,138	2,011	2,123
20%	284	503	531
25%	182	322	340
30%	126	223	236
35%	93	164	173
40%	71	126	133
50%	46	80	85

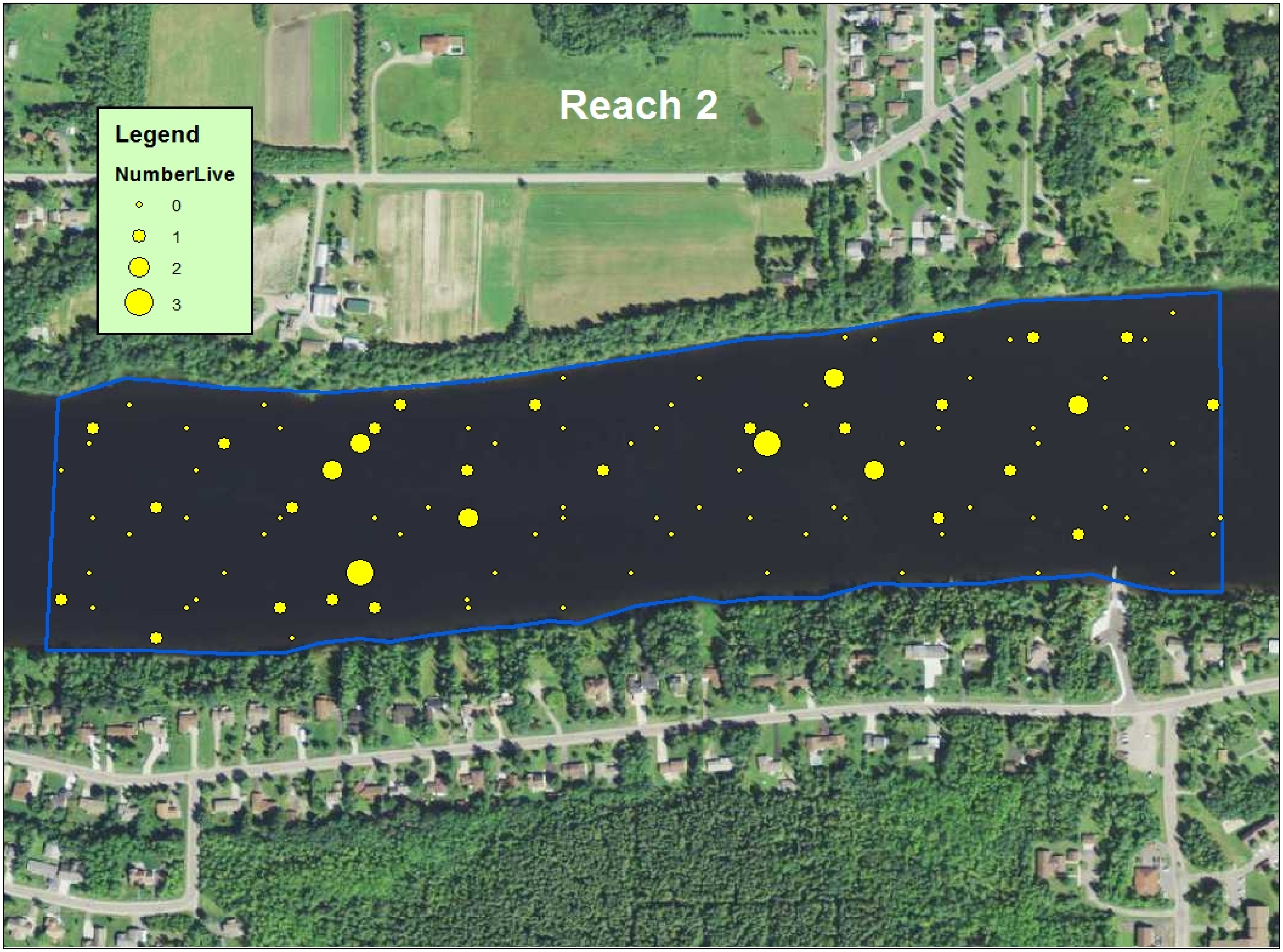

Figure 5. Number of live mussels at each site in Reach 2 of the Rainy River.

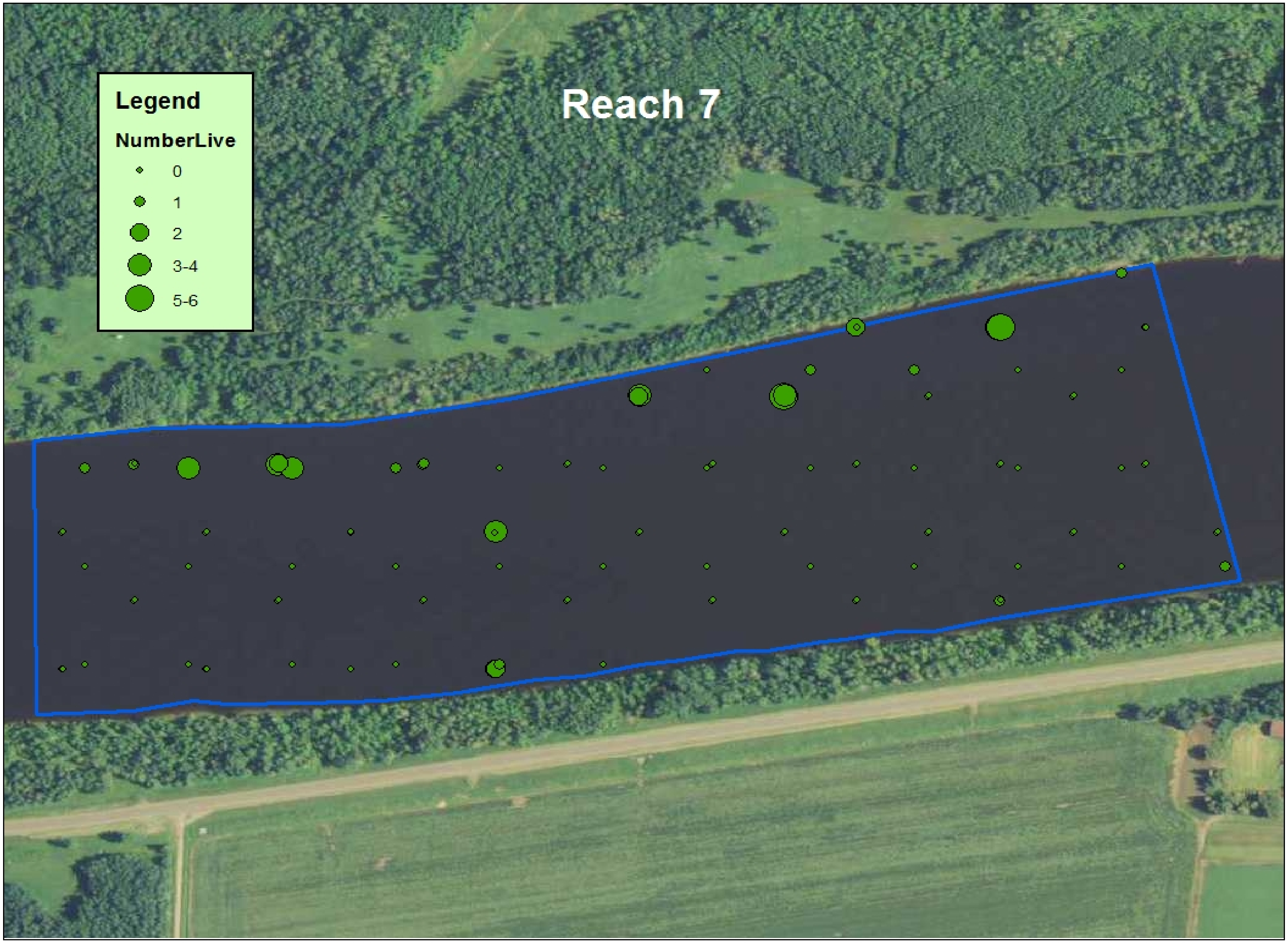

Figure 6. Mussel abundance at sample sites in Reach 7.

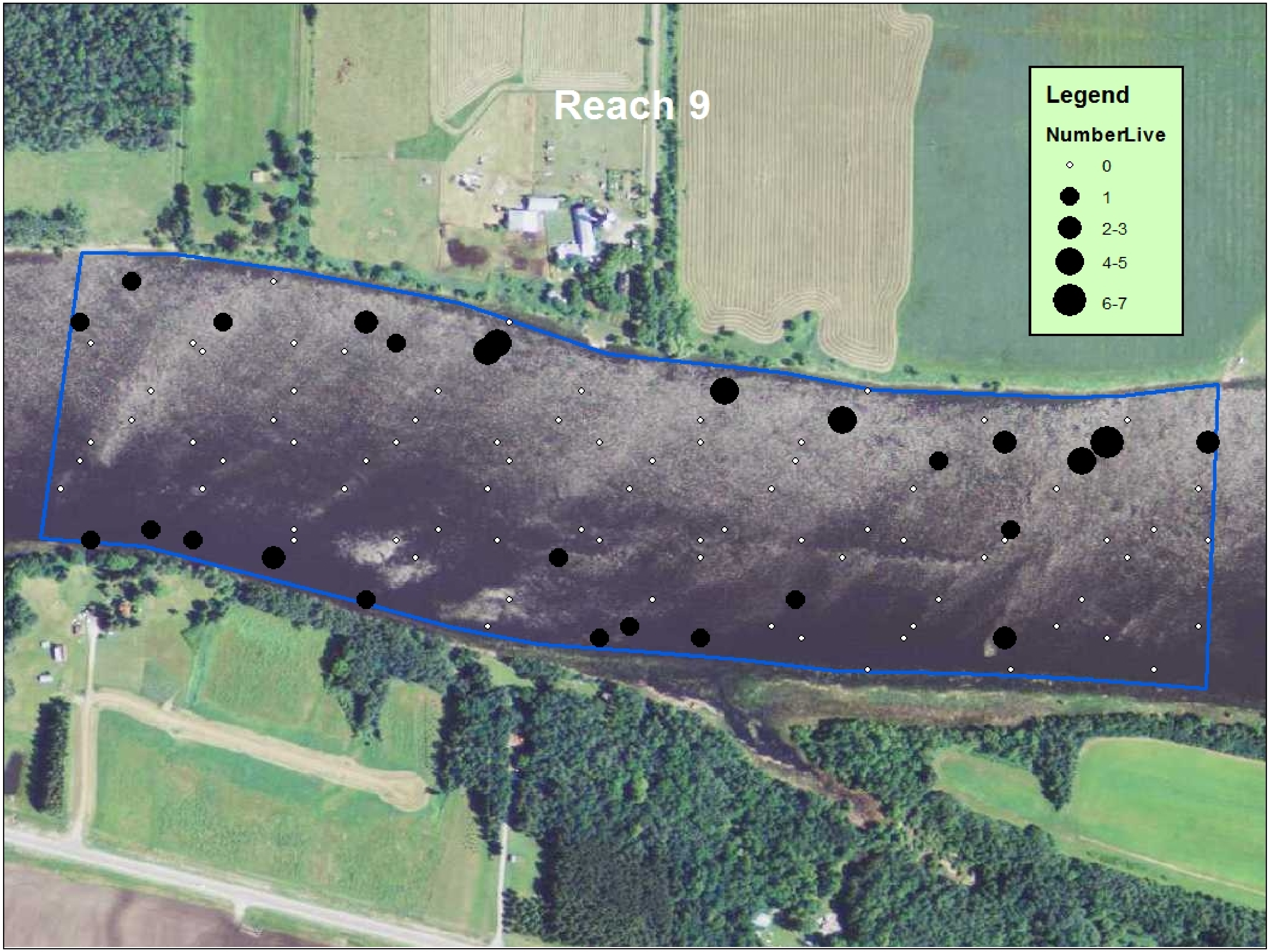

Figure 7. Mussel abundance at sample sites in Reach 9.

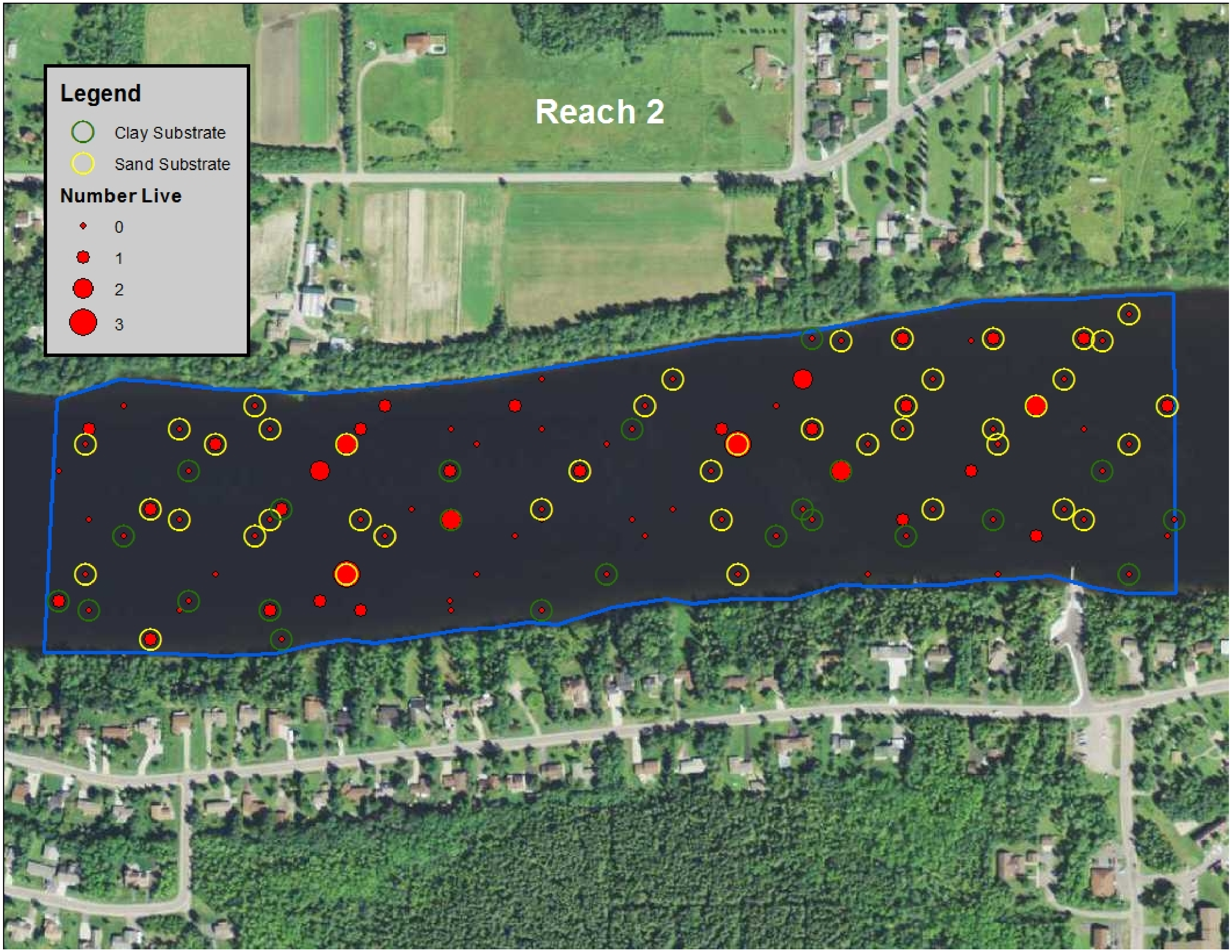

Figure 8. Mussel abundance associated with substrate dominance at sites in Reach 2.

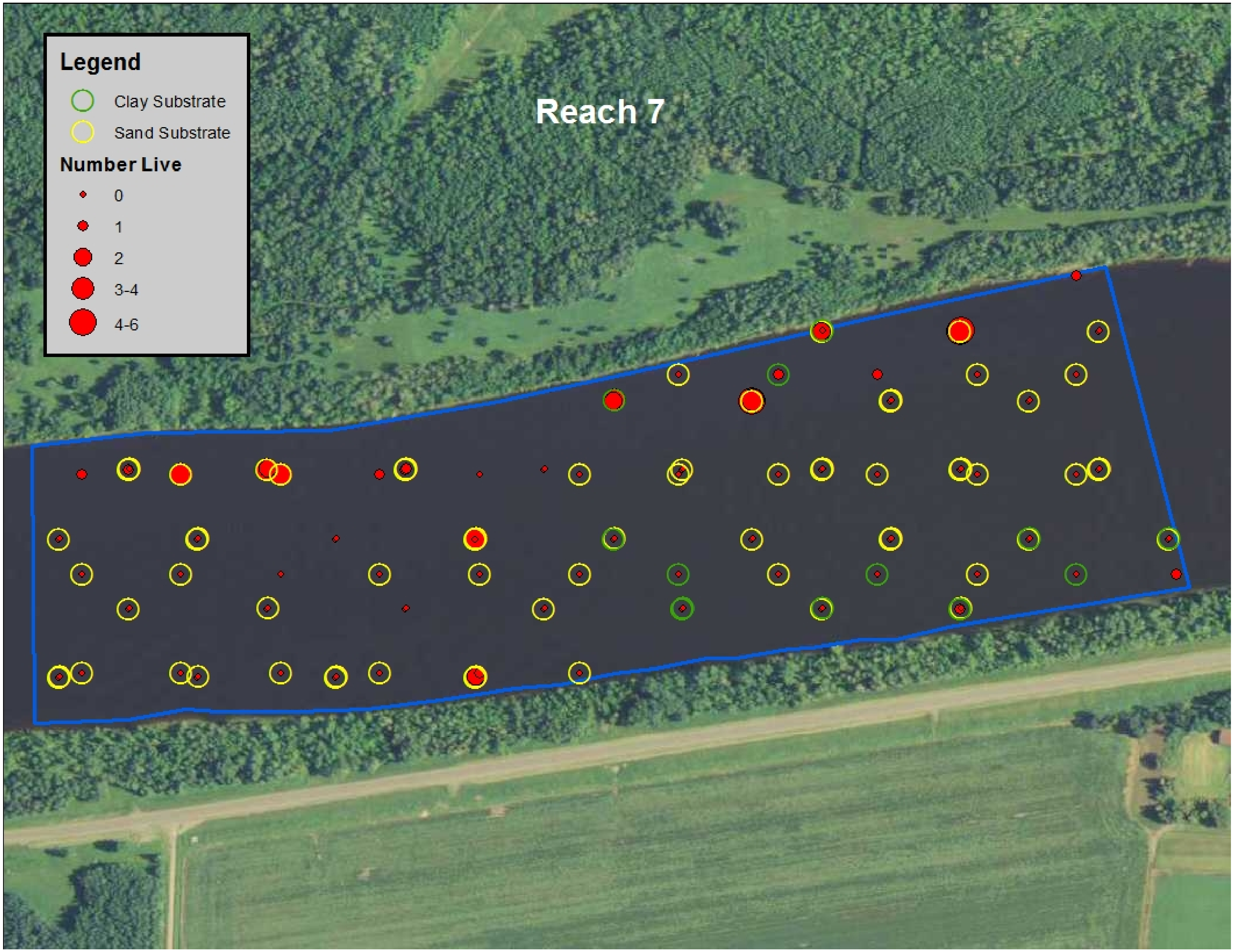

Figure 9. Mussel abundance associated with substrate dominance at sites in Reach 7.

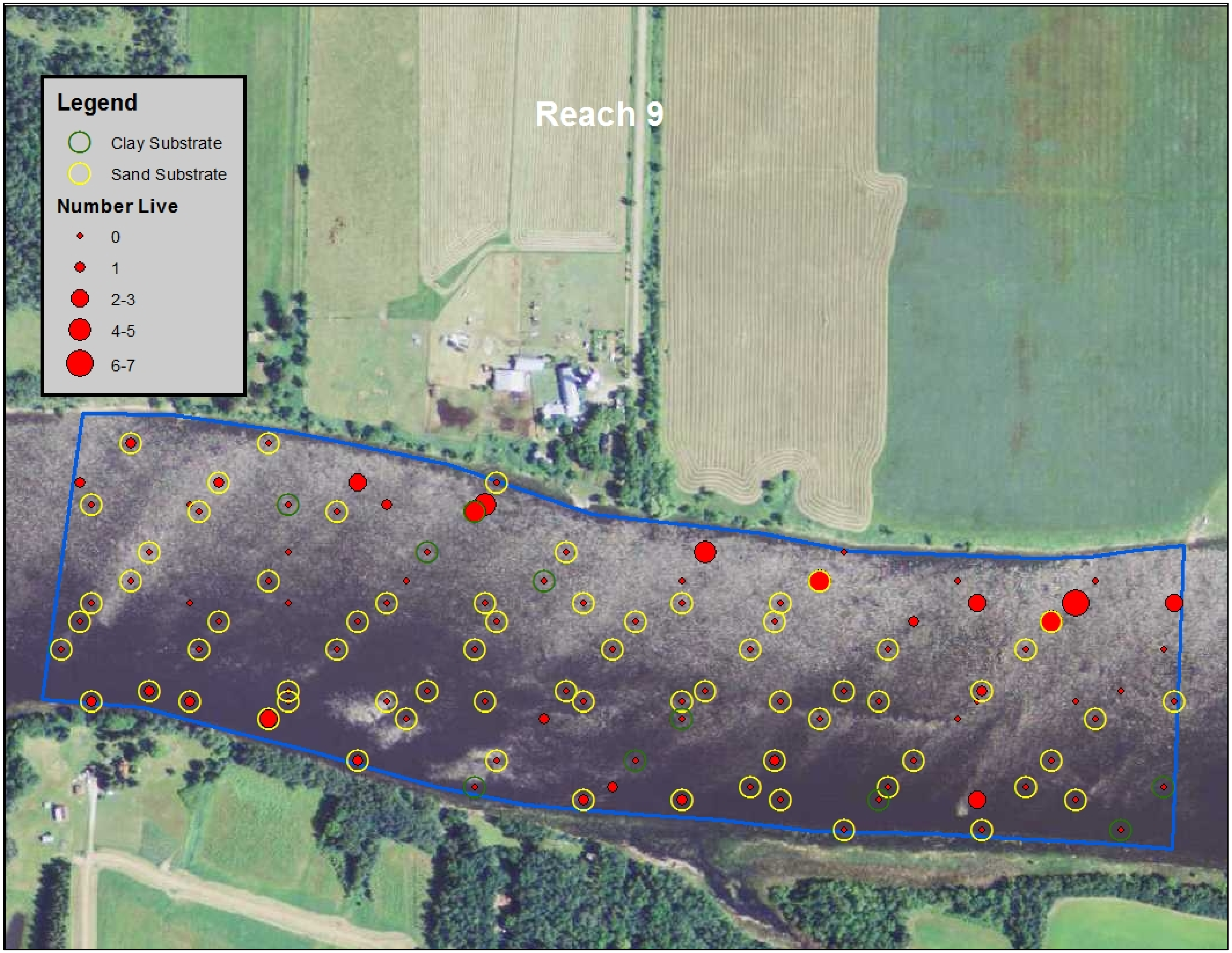

Figure 10. Mussel abundance associated with substrate dominance at sites in Reach 9.

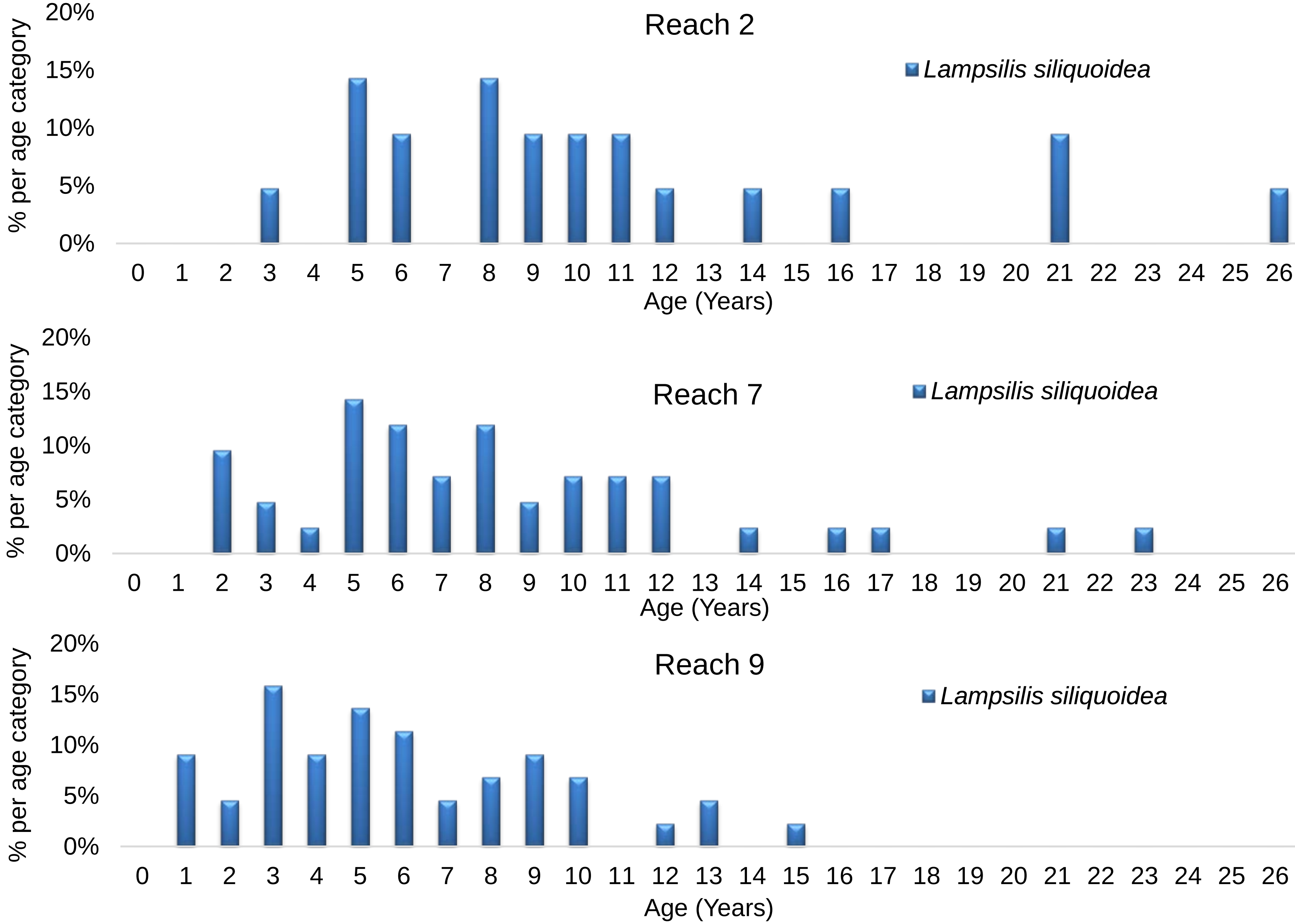

Figure 11. Age distribution of *Lampsilis siliquoidea* in each sampling area.

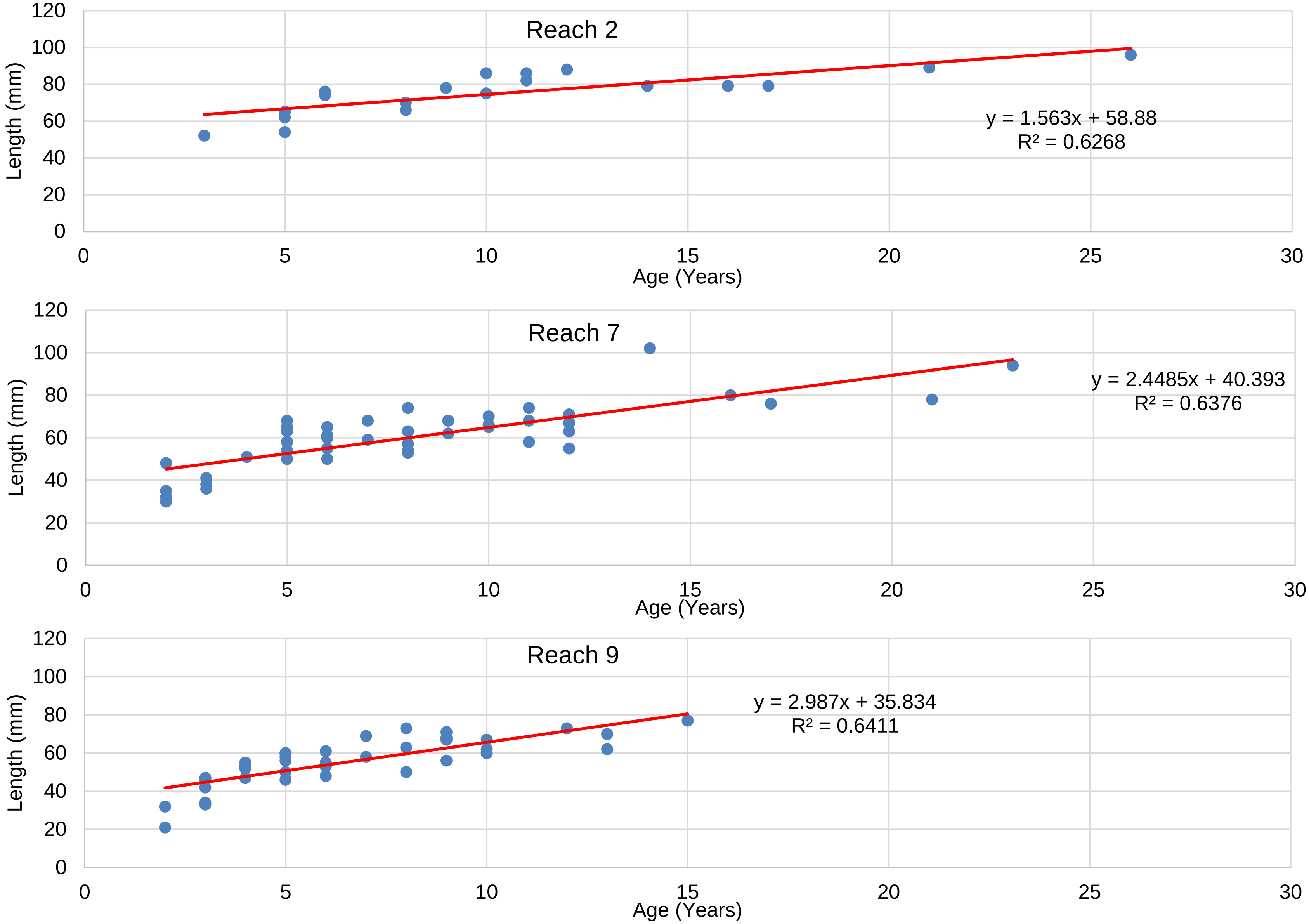

Figure 12. Growth of *Lampsilis siliquoidea* in each sampling area. Individuals ≤ 1 year old were removed because they were only present in Reach 9.

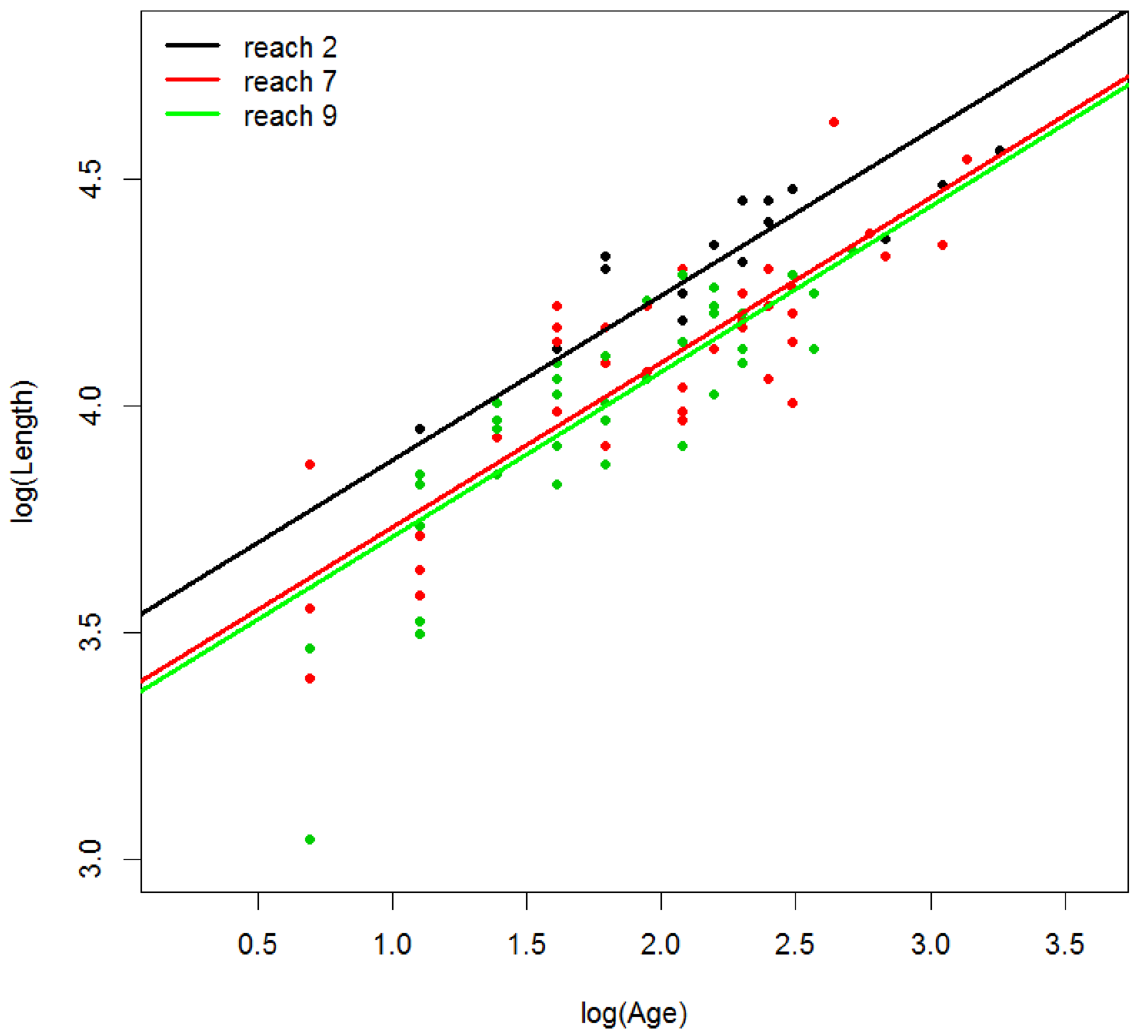

Figure 13. Linear regression of *Lampsilis siliquoidea* growth in each sampling area. Individuals ≤ 1 year old were removed because they were only present in Reach 9.

Table 2. Relative abundance of mussels collected during the 2007 Rainy River Survey.

	No. of individuals	%
Anodontoides ferussacianus	7	0.2
Lampsilis cardium	36	0.8
Lampsilis siliquoidea	3557	77.4
Lasmigona complanata	347	7.6
Lasmigona compressa	60	1.3
Ligumia recta	51	1.1
Pyganodon grandis	480	10.4
Strophitus undulatus	53	1.2
Utterbackia imbecillis	4	0.1
Total	4595	

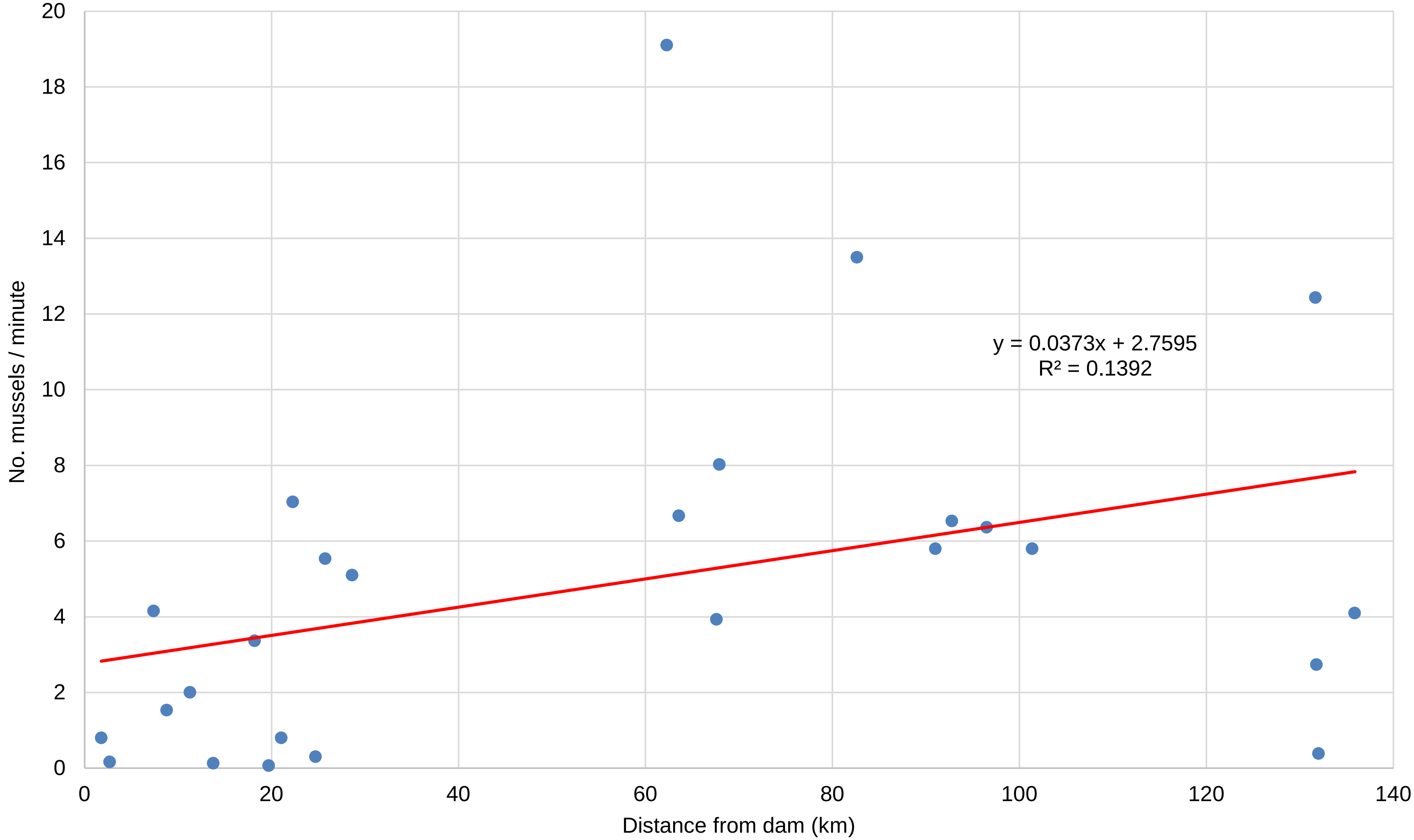

Figure 14. Relationship between CPUE (No. of mussels per minute) and distance from the dam.

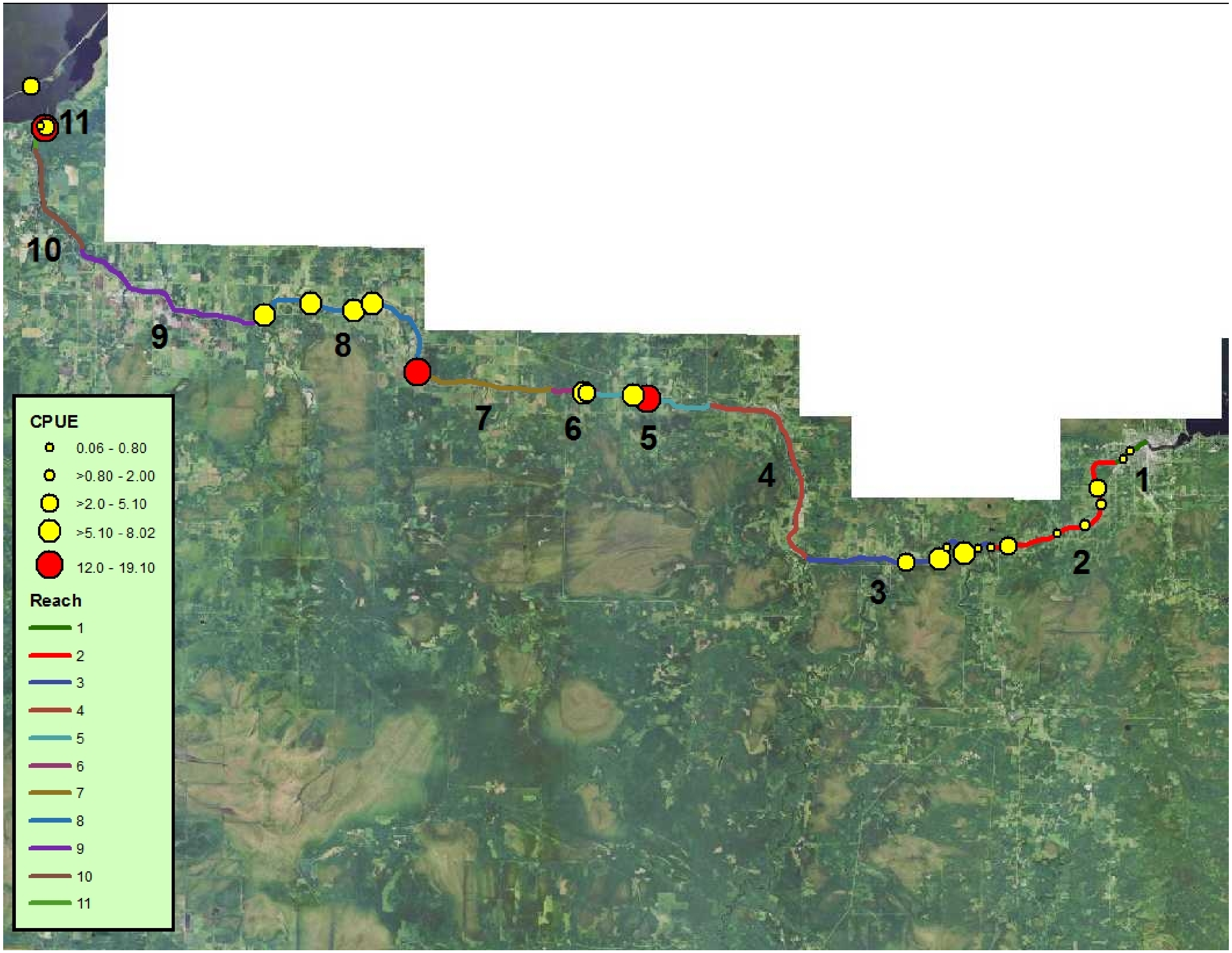

Figure 15. CPUE (No. of mussels per minute) at sample sites from the 2007 survey along the U.S. - Canada border of the Rainy River.

Discussion

Our study showed a modest increase in relative mussel abundance from upstream to downstream in the Rainy River, as well as significantly greater length at age for *L. siliquoidea* in Reach 2 and relatively greater recruitment in reaches 7 and 9. However, average density of mussels in the three study reaches was not significantly different, and species richness was relatively similar among reaches. The pattern of increasing mussel abundance with distance downstream of the IFD was also evident from our 2007 survey, only two years after the 2000 rule curves were implemented, and we found no indication of a recent decline in abundance, such as large numbers of empty shells in upstream reaches. Therefore, there is no direct evidence from our study that mussels were negatively affected by the implementation of the 2000 rule curves.

Several studies have documented decreased mussel abundance below dams (Miller et al. 1984, Layzer et al. 1993, Vaughn and Taylor 1999, Garner and McGregor 2001, Hardison and Layzer 2001), although this is not always the case (Miller et al. 1992, Haag 2012). Similar to our study, Vaughn and Taylor (1999) found that mussel abundance was suppressed for approximately 20 km downstream from a reservoir dam. They suggested that hydrologic variability from regulated flows and release of colder water, which attenuate with distance downstream, likely affect mussels directly through physical stress and indirectly through changes in habitat, food, and fish-host availability. For example, high water velocities can displace juvenile mussels, and variable flows that alter natural flow regimes can subdue seasonal cues that affect host fish movements that are not coincident with mussel brooding periods and release of juveniles from fish (Vaughn and Taylor 1999). As expected, the flow regime at IFD has an altered flow pattern in both the pre- and post-2000 rule-curve periods. However, flows at IFD were outside the range of variability of the natural rivers for the pre- period but not for the post- period (Luce and Metcalfe 2014). Although a measurable effect is not yet evident, over time, mussels in upstream reaches may respond positively to flows that remain within the range of natural variability.

Mussel distribution and abundance is often defined by extremes exerted by events such as floods and droughts (Haag 2012). Because variation in the wetted perimeter area below the dam was narrowed by the 2000 rule curve change for Reaches 1-6, with a diminishing effect going downstream (Luce and Metcalfe 2014), habitat for mussels along shoreline areas should be more stable in the upper reaches now than before because they are less likely to be stranded by falling water levels. In rivers dominated by finer sediments, the aquatic area along river shorelines is often more stable compared to the channel thalweg, where bedload transport of sediment creates unstable habitat conditions for mussels (Haag 2012). This likely explains the greater abundance of mussels along the shorelines of

Reaches 7 and 9 that are influenced by flood pulses from tributaries, and the lack of this pattern in Reach 2 where the dam's regulated flows and sediment trapping effect of the reservoir likely delivers less bed load sediment that can bury or entrain mussels.

Mussel species assemblages were similar among reaches, by and large, except that relative abundance of *Lampsilis siliquoidea* increased downstream and relative abundance of *Lasmigona complanata* decreased. In most rivers, mussel assemblages change in a predictable manner in relation to stream size (Haag 2012); however, this is most evident over the course of multiple changes in stream order. The gradient of stream size and flow along the length of the Rainy River is less pronounced, but this could account, at least in part, for the moderate differences we observed among reaches. A possible reason for differences in species relative abundance is the adaptability of *L. siliquoidea* to lacustrine habitat compared to *L. complanata*, a species limited to streams and rivers. Therefore, the more constant flow conditions found upstream should be more conducive to *L. complanata*, whereas the slower, more lacustrine conditions downstream are more favorable to *L. siliquoidea*.

Lampsilis siliquoidea were larger at a given age in Reach 2 than in the lower reaches of the Rainy River, and although they are now growing more slowly, their larger size indicates a higher rate of growth when they were young compared to the other reaches. Growth of freshwater mussels is rapid during the first few years of life, but slows with the onset of sexual maturity as resources are diverted to reproduction and maintenance (Haag 2012). Mussels grow faster in nutrient-enriched rivers and lakes than in less productive systems (Morris and Corkum 1999, Valdovinos and Pedreros 2007). It is possible that the water flowing from Rainy Lake provides food subsidies that promote more rapid growth of juvenile mussels below the dam, or that the more stable physical habitat there allows for more constant food intake than lower river reaches where tributary flood pulses can disrupt feeding behavior. The comparatively slower growth in downstream reaches could be due to increased suspended sediments from tributaries such as the Big Fork and Little Fork rivers released during flood-pulse events. The smaller sample size for *L. siliquoidea* in Reach 2 (due to lower relative abundance) may have influenced our growth estimates, although this is uncertain.

Conclusions and Recommendations

The lack of pre-existing quantitative mussel data before implementation of the 2000 rule curves makes it difficult to draw a direct association between measured parameters of current mussel assemblages and hydrologic changes from implementing the 2000 rule curves. Although mussel density was not statistically different among the three quantitatively sampled reaches, there was a general trend of lower mussel abundance in upstream reaches from both quantitative and timed search samples. This pattern appears to diminish beyond 20 km from the dam, where mussel assemblages were more comparable to downstream reaches. This suggests that factors, including hydrologic variability from IFD operations that have been in practice for many decades, may be suppressing mussel recruitment and survival. However, this pattern of abundance was evident in 2007, only two years after the 2000 rule curves were implemented, and we found no evidence of a recent mussel decline based on empty shells. Therefore, it is unlikely that lower mussel abundance in upstream reaches is due to implementing the 2000 rule curves, and over time, mussels in upstream reaches may respond positively to flows that remain within the range of natural variability.

Recommendations

Continued monitoring: This study establishes a baseline for future monitoring of mussel assemblages in the Rainy River. Periodic monitoring of mussel assemblages through a combination of quantitative sampling at the established sites in Reach 2, 7, and 9, and timed (qualitative) searches over a broader area of the Rainy River would establish trends for mussel abundance, species assemblages, and recruitment.

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