Quetico Provincial Park
Rusty Crayfish Upstream Dispersal Study

By Brigitte Champaigne-Klassen
September 2016

Photos: Hannah Koslowsky

QUETICO FOUNDATION

ONTARIO PARKS

Quetico

Staffing for this project was provided in part by the Quetico Foundation

Executive Summary

In 2016, crayfish populations were monitored by the Quetico Research team in the Basswood Area of Quetico Provincial Park, namely the lakes upstream of Basswood Lake. This area was targeted in order to discern the ability of the invasive rusty crayfish (Oronectes rusticus) to travel upstream of an established population, Basswood Lake. Using baited traps, information was collected on the relative abundance, species distribution and sex and size of all crayfish captured. Stream surveys were conducted on the connective streams between the lakes to understand the types of obstacles relevant to the expanding range of the rusty crayfish. Results indicate that the rusty crayfish are able to spread upstream from the established population of Basswood Lake and is the dominant crayfish species in the Basswood area (100% of crayfish caught). Physical obstacles found in the connective streams seemed to matter very little in hindering their establishment. Future recommendations include 1) collect calcium or conductivity measurements in the sampled lakes; 2) collect quantitative measurements and photo documentation of significant obstacles present in the connective streams; 3) continue use of current monitoring protocols but use fresh cans of catfood as bait when possible.

Table of Contents

Background

Crayfish (Anisinaabemowin – Zhaageshii) play an important role in the aquatic community of lakes, as they make up the majority of the benthic invertebrate population (Keller and Moore, 2000). As omnivores, they eat a variety of aquatic plants, fish eggs and benthic organisms (Edwards and Jackson, 2009) and act as prey to larger fish species (Tetzlaff et al., 2011). Changes to crayfish communities can create significant alterations to the community composition of species in lakes, especially when an invasive crayfish species expands their range into new water bodies (Philip et al., 2009). Yet, the manner in which invasive crayfish species influence their habitat and all other lake organisms are not well understood.

One such species is the aggressive and invasive rusty crayfish (*Oronectes rusticus*), a large aggressive crayfish with an increased rate of food consumption and a higher metabolic rate (Phillip et al., 2009). The introduction and increased abundance of the rusty crayfish in new waterbodies tends to displace native crayfish through competition and reduce the amount of aquatic vegetation in lakes (Olsen et al. 1991; Peters et al. 2013). This reduction limits the habitat and food availability for other species, and is caused by the increased consumptive rate and foraging behaviour of the rusty crayfish (Olsen et al. 1991; Nilsso et al., 2011). O. *virilis*, the most widespread native stream and lake species of crayfish in Ontario, has experienced a shift in population abundance due to the increasing spread and abundance of the rusty crayfish in Ontario lakes (Olsen et al., 1991). While little is known about the range and abundance of O. *virilis* throughout the Park, it has been the only known species of crayfish present in Quetico Provincial Park until recently.

In the early 90`s, the rusty crayfish was first documented in Quetico near Prairie Portage in Basswood Lake, and in 2014 and 2015, it was documented in Basswood Lake, as well as downstream in the Basswood River and the east end of Crooked Lake during scientific surveys (Jackson, 2015a,b). While the movement rates of rusty crayfish within and downstream of Basswood Lake have been fairly well documented, the ability of rusty crayfish to move upstream in a Shield lake ecosystem remains largely unknown (Jackson, 2015b). A factor that is thought to hinder the range expansion of the rusty crayfish are physical natural obstacles and the distance of the connective streams between the lakes where rusty crayfish reside (Philips et al., 2009).

Objective

Using modified minnow traps, the objective of this study was to ascertain the dispersal ability of rusty crayfish upstream of an established population in Quetico Provincial Park, namely Basswood Lake (Jackson, 2015b). The presence/absence of rusty crayfish will be assessed, as well as data on relative abundance (#caught/trap) and size will be collected for all species of crayfish.

Methods

Estimations for the watershed area and flow characteristics for lakes upstream of Basswood Lake were completed using OFATIII (Ontario Flow Assessment Tool) (appendix table 2) (figure 1). Although no surveys have been completed on them to date, these lakes are not known to contain rusty crayfish. It is speculated that these lakes are within the range of potential rusty crayfish invasion, if crayfish move upstream at the same rate as is reported for downstream movement in other shield lake ecosystems, which is 1-3km/year (Jackson 2015b, Jansen et al. 2009). Lakes were selected to vary in flow and distance (appendix table 2), and were selected because of their upstream location from the source population of Basswood Lake (figure 1). Dahlberg, Nest, South and then Burke Lake were sampled in that respective order.

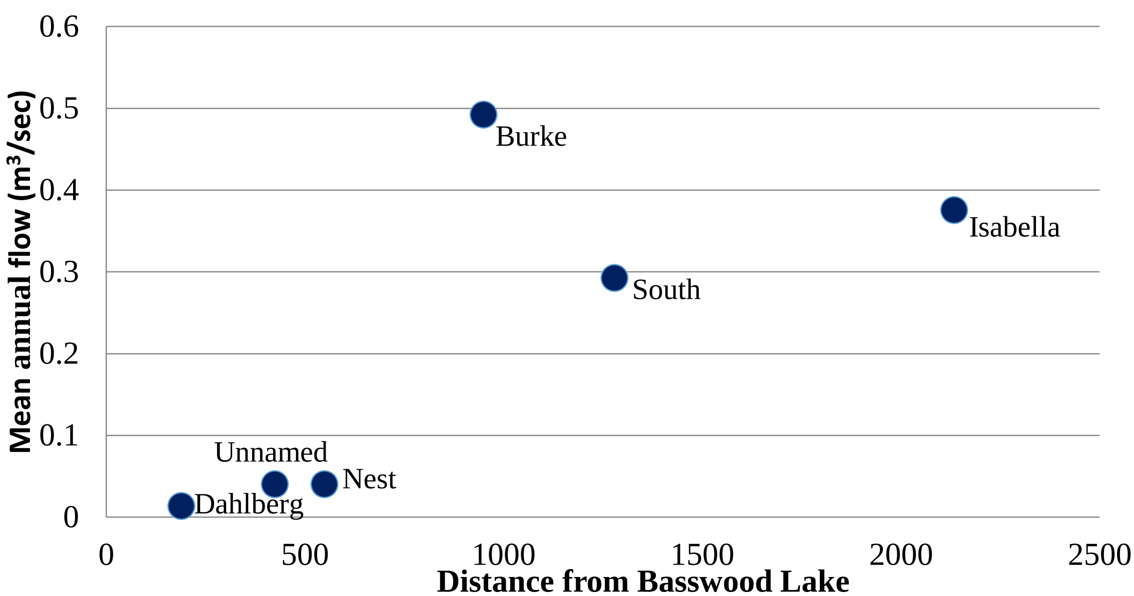


Figure 1. Potential sites for rusty crayfish upstream dispersal study (Jackson, 2015).

In 2016, sampling occurred from July 22nd-30th following the protocol (Jackson, 2015c). Dahlberg Lake was sampled from the 22nd-24th, Nest from 25th-26th, West and South 27th-28th and Burke Lake from 29th-30th. A full species list is only available for Burke Lake on a lake survey conducted in 1968 (Crossman, 1976). Fish species for other lakes are only known from anecdotal observations, or observations and incidental captures from this study (appendix table 1). Dahlberg Lake, an unnamed lake north of Basswood Lake, covers 71 hectares with an estimated mean annual stream flow of 0.013 m^3/sec (OMNR, 2003), with a stream distance from Basswood Lake of 190 meters (m) (figure 1) (appendix table 2). Notable species in Dahlberg include smallmouth bass, rock bass and bluegill sunfish, which are all known to feed on crayfish (Keller and Moore, 2000; Tetzlaff et al., 2011; Jackson, 2015d). Nest Lake has a lake area of 75 hectares with a stream distance of 425m away from Basswood Lake and a mean annual stream outflow of 0.04 m^3/sec. It is devoid of bass, an important crayfish predator, but include lake trout, northern pike, yellow perch and northern longear sunfish as notable fish species. South Lake has a lake area of 60 hectares and is 1280m away from Basswood Lake, with an estimated mean annual stream flow of 0.292m^3/sec (OMNR, 2003). Significant fish species are largemouth bass, smallmouth bass and bluegill. Burke lake, with 268 hectares of lake area, and stream distance from Basswood Lake is 950m and an outflow of 0.492 m^3/sec. Notable species in Burke include bluegill, rock bass, smallmouth and largemouth bass.

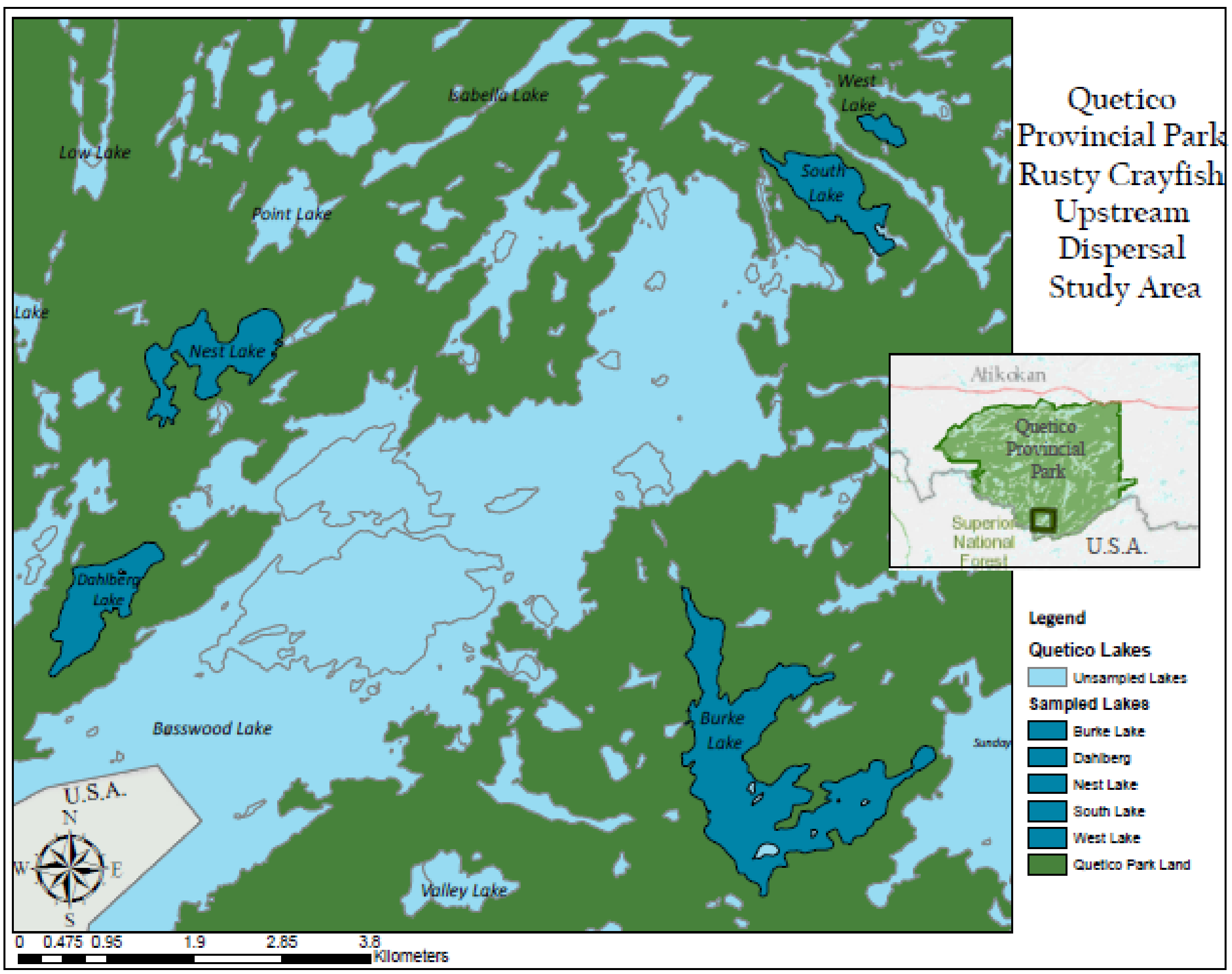


Figure 2. Map of the sampled lakes and general study area in Quetico Provincial Park.

Trap plots

To successfully capture the crayfish, minnow traps were modified, with enlarged entrance holes of 3.5 cm diameter. Even though traps tend to select for large, aggressive male crayfish (Wilson et al., 2004; Hein et al., 2006), traps can provide accurate assessments of species composition and relative abundance (Capelli, 2003). Fish based catfood was used as bait in each trap, and one can was used for two consecutive trap days. Set-up perpendicular to shore, each trap line contained 3 traps, each 3 meters apart. One plot constituted of four traplines, each 5-10m apart, with a total of twelve traps per plot. To select the plots, the shoreline was divided into 50m segments and then randomly selected using a random number generator prior to sampling. The traps were set overnight for a minimum of 12 hours. The depth of each trap was measured and recorded, as well as the set and lift time, bait type, observers, location, habitat, the number, a note of all other organisms caught in the trap and the sex of each crayfish caught. Habitat was classified as cobble, macrophyte (weedy habitat) or detritus (decaying leaf layer and fallen woody debris). All caught crayfish were identified to species and measured with calipers, including the total length (tip of the rostrum to the tip of the central telson measured on the dorsal surface) and the carapace length (tip of the rostrum to the back of the carapace measured on the dorsal surface) (appendix figure 1) (Jackson, 2015c). In total, there were 42 plots as well as a sample plot in West Lake (table 1), constituting of 168 traplines and 497 traps that were set throughout all 5 lakes (figure 3-6).

Table 1. Summary of plot and trap amounts for all the sampled lakes.

Lakes	*Total Plots*	*Total trap amounts*	*Traps/plots*
Burke	12	142	12 (x10), 11 (x2)
Nest	12	142	12 (x10), 11 (x2)
Dalhberg	12	142	12 (10), 11 (x2)
South	6	65	12 (x3), 9 (x2), 11 (x1)
West	*sample (2 traplines)	6	n/a

One trapline only contained 2 traps instead of 3, which reduced the number of traps in some of the plots throughout this study. In South Lake, 6 plots instead of 12 were set up due to a time constraint in the field. The research team prioritised the complete sampling of Burke Lake (i.e. 12 plots) over South Lake. Burke is the furthest lake away from an established rusty crayfish population and thus important to better understand the upstream range of O. *rusticus* from Basswood Lake. In addition, evidence of presence of rusty crayfish in West Lake during a stream survey connecting South into West Lake led the research team to sample West Lake during the same time as South Lake sampling. Only 2 traplines, 3 traps each, were moved from South into West in order to confirm rusty crayfish presence and to better elucidate what types of obstacles rustys' are overcoming (figure 5). For this reason, the crayfish data collected in West Lake is not used during statistical analysis and will only be referred to while discussing the range and type of geographical obstacles relevant to the spread of the rusty crayfish upstream of Basswood Lake.

Stream surveys

In addition to lake sampling, streams of the sampled lakes that connected to Basswood Lake were surveyed. Surveys consisted of mapping the substrate/cover type of the stream and identifying any potential barriers. Crayfish seen throughout the stream were caught and measured when possible.

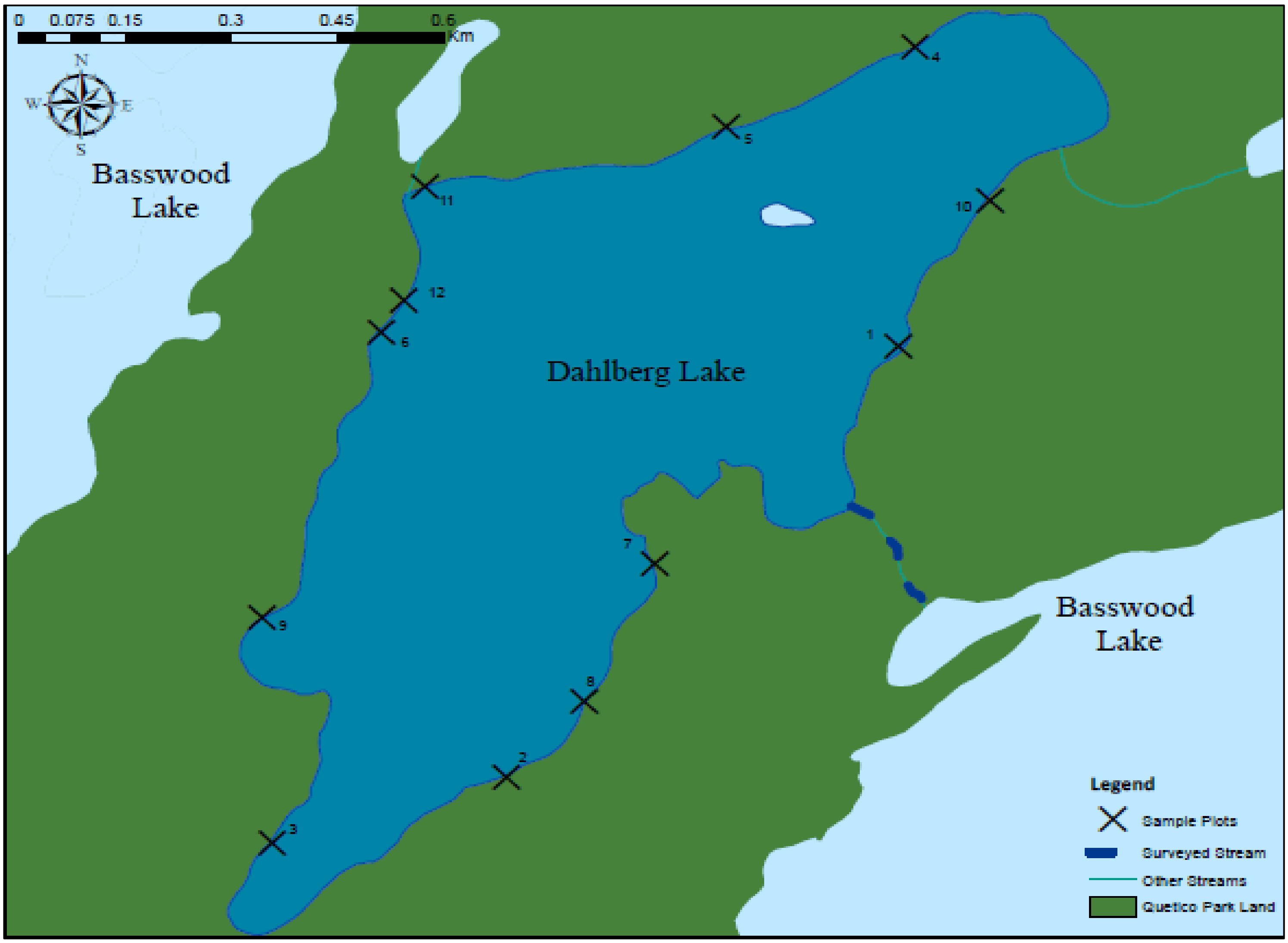


Figure 3. Sample plots and surveyed stream locations of Dahlberg Lake in Quetico Provincial Park area.

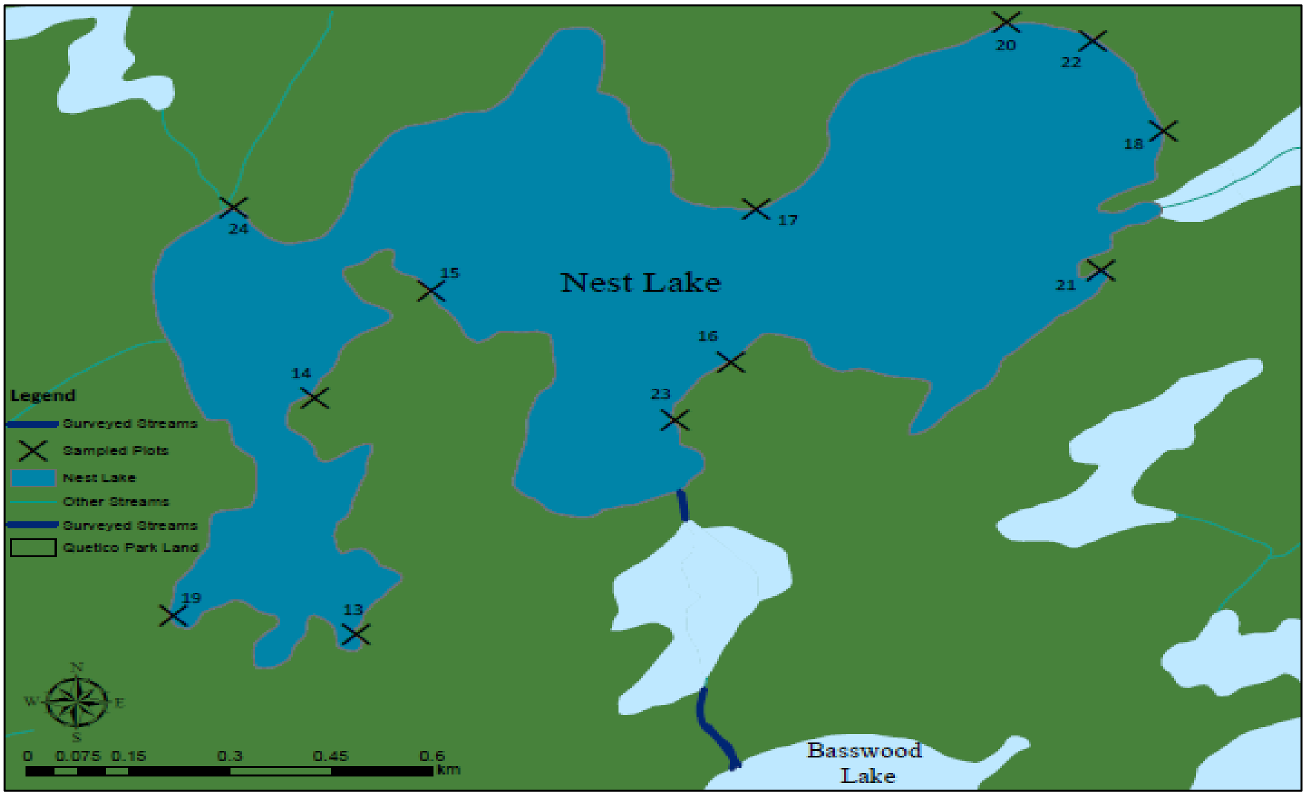


Figure 4. Sample plots and surveyed stream locations of Nest Lake in Quetico Provincial Park area.

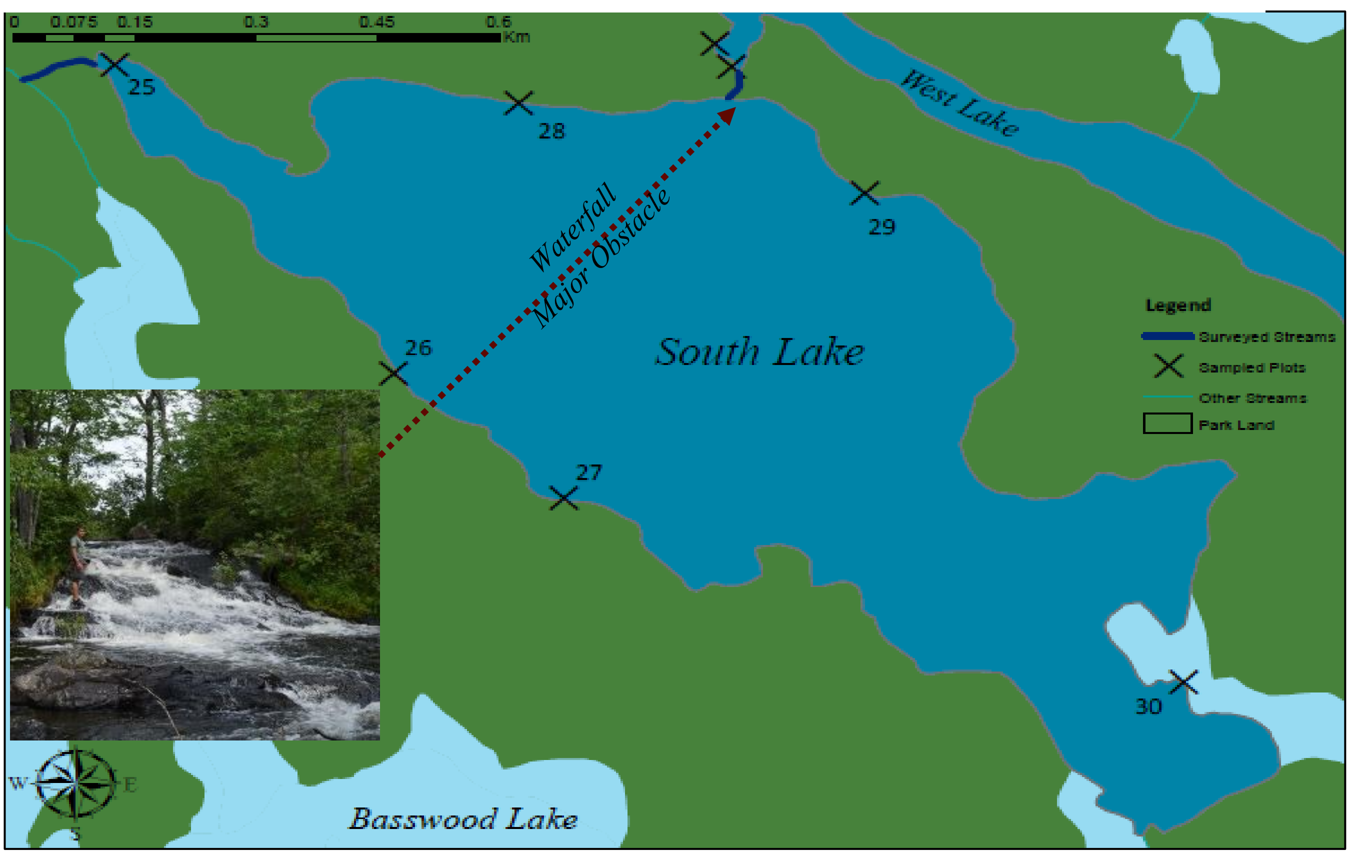


Figure 5. Sample plots and surveyed stream locations depicting a major obstacle to rusty crayfish upstream dispersal found in South Lake in Quetico Provincial Park area.

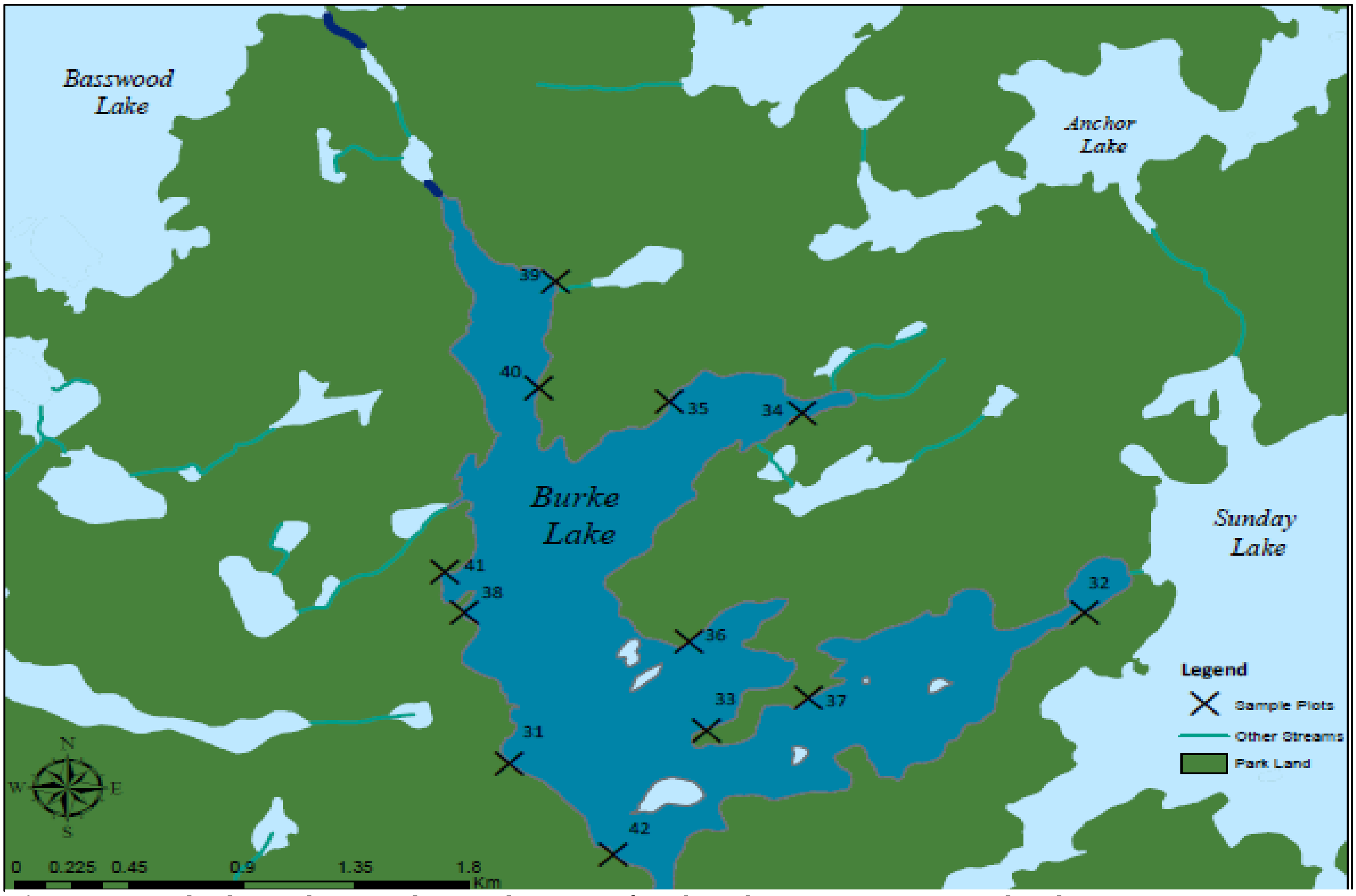


Figure 6. Sample plots and surveyed stream locations of Burke Lake in Quetico Provincial Park area.

Results

Summary

A total of 1392 males and 199 females of O. *rusticus* were caught, with a total of 1591 crayfish sampled. No native crayfish, O. *virilis*, were caught in any of these five lakes; O. *rusticus* was the sole species of crayfish caught and sampled throughout these lakes. Another invasive crayfish species, O. *propinquu*s, has also been reported from Basswood in the past, but was not observed in any study lakes (Jackson, 2015b). Of these crayfish, 136 were sampled in Dahlberg, 1408 in Nest, 25 in South, 6 in West and 16 in Burke Lake. There existed a high degree of variation between the average catch of crayfish per trap for each lake, showing Nest as having the highest average crayfish catch/trap with 9.92 crayfish per trap, which is significantly higher than all of the other sampled lakes: Dahlberg, 0.96; Nest, 9.92; South, 0.38; and Burke, 0.11 (figure 7).

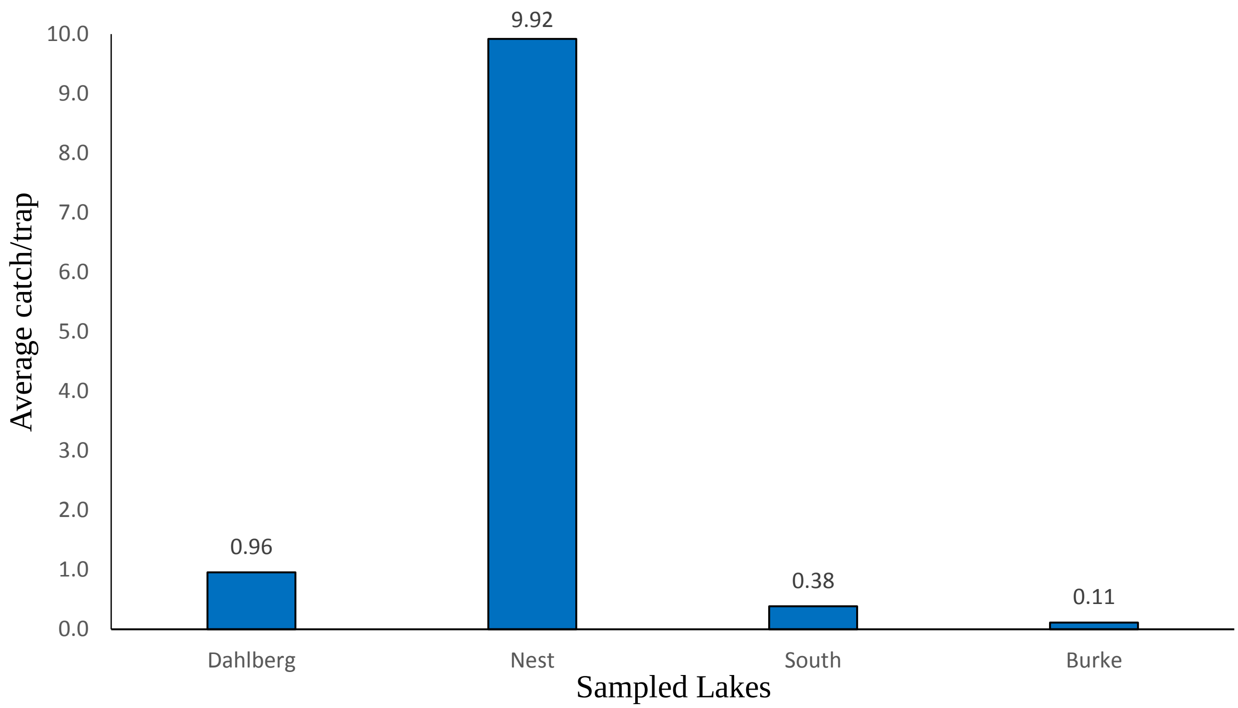


Figure 7. Average catch/trap for O. *rusticus* caught in Dahlberg, Nest, South and Burke Lake.

Size relationships

Carapace length vs. total length - The total length and carapace length of O. *rusticus* are significantly related for all sampled lakes including Dahlberg, South and Burke and Nest Lake (regression analysis, p value <0.05). Nest had a slightly less significant relationship than the other three, likely caused by measurement error from a high incidence of sampling (figure 8). These results are consistent with surveys of O. *rusticus* completed in 2015 (Jackson, 2015). As such, once the regression was calculated for each lake, it was applied to all carapace lengths of the crayfish in order to attain a more accurate total length (figure 9). The total average carapace length of all females and males respectively across all four lakes is 26.5 and 32.1mm. Dahlberg Lake had the smallest average size female and male among all four lakes (23.52 mm and 30.7mm) while Burke has the largest female and male size average (27.82mm and 32.75mm).

Size between lakes – Statistical tests were performed between the carapace length of all male rusty crayfish caught in Dahlberg, Nest, South and Burke in order to discover if there was a significant difference in crayfish size between the sampled lakes. A significant size difference was found between the male crayfish in Dahlberg and Nest Lake, with a p value of 0.015 (appendix table 3) ($p<0.05$). The mean carapace length for male crayfish in Dahlberg is 30.69mm and in Nest it is 32.24mm, showing that Nest Lake harbour larger crayfish than Burke Lake. It is possible that the sample size of male crayfish was too small for the other lakes to show significant results, as the sample size for South and Burke Lake was only 20 and 11 male crayfish respectively.

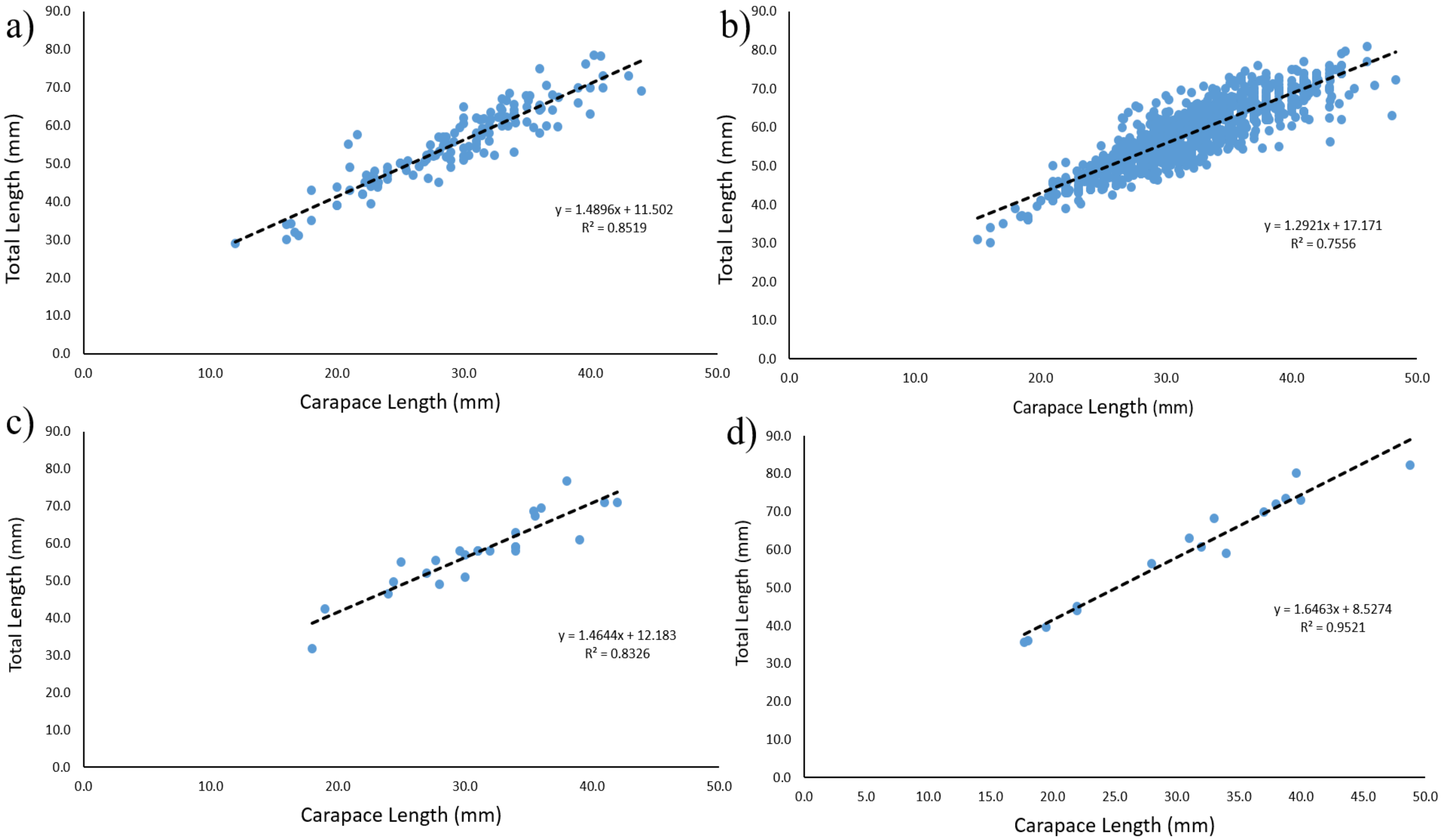


Figure 8. Illustration of total length vs. carapace length and calculated regression of O. *rusticus* collected from a) Dahlberg, b) Nest, c) South and d) Burke Lake.

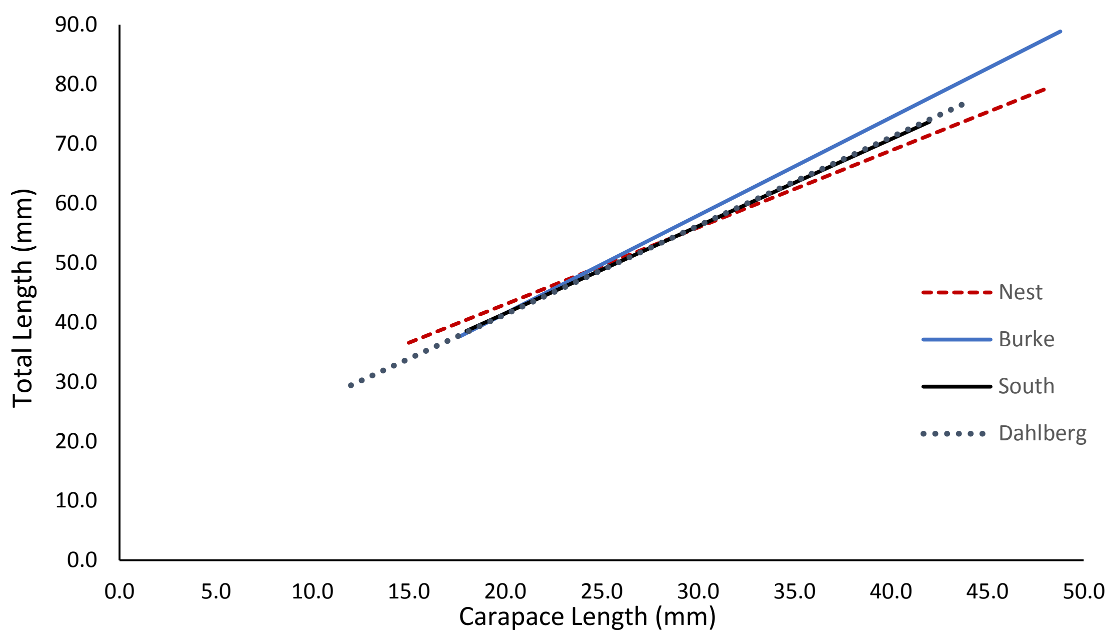
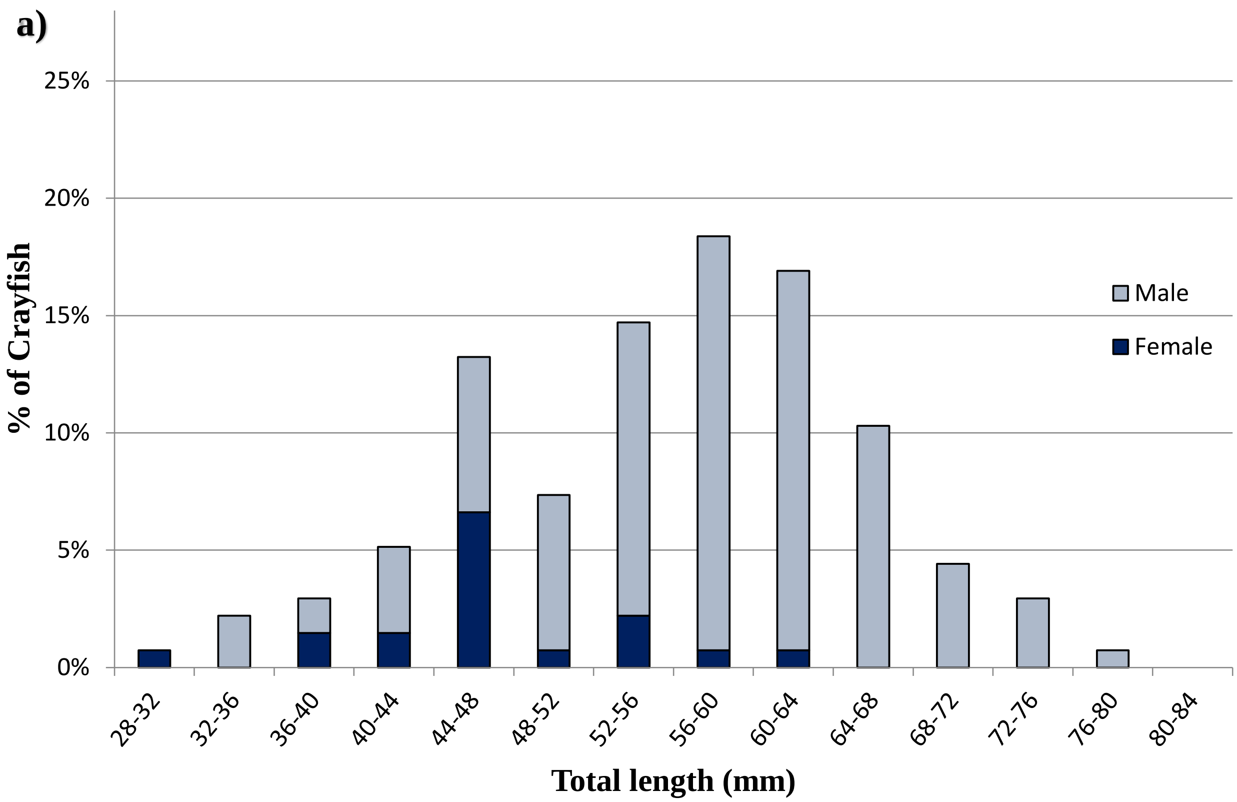
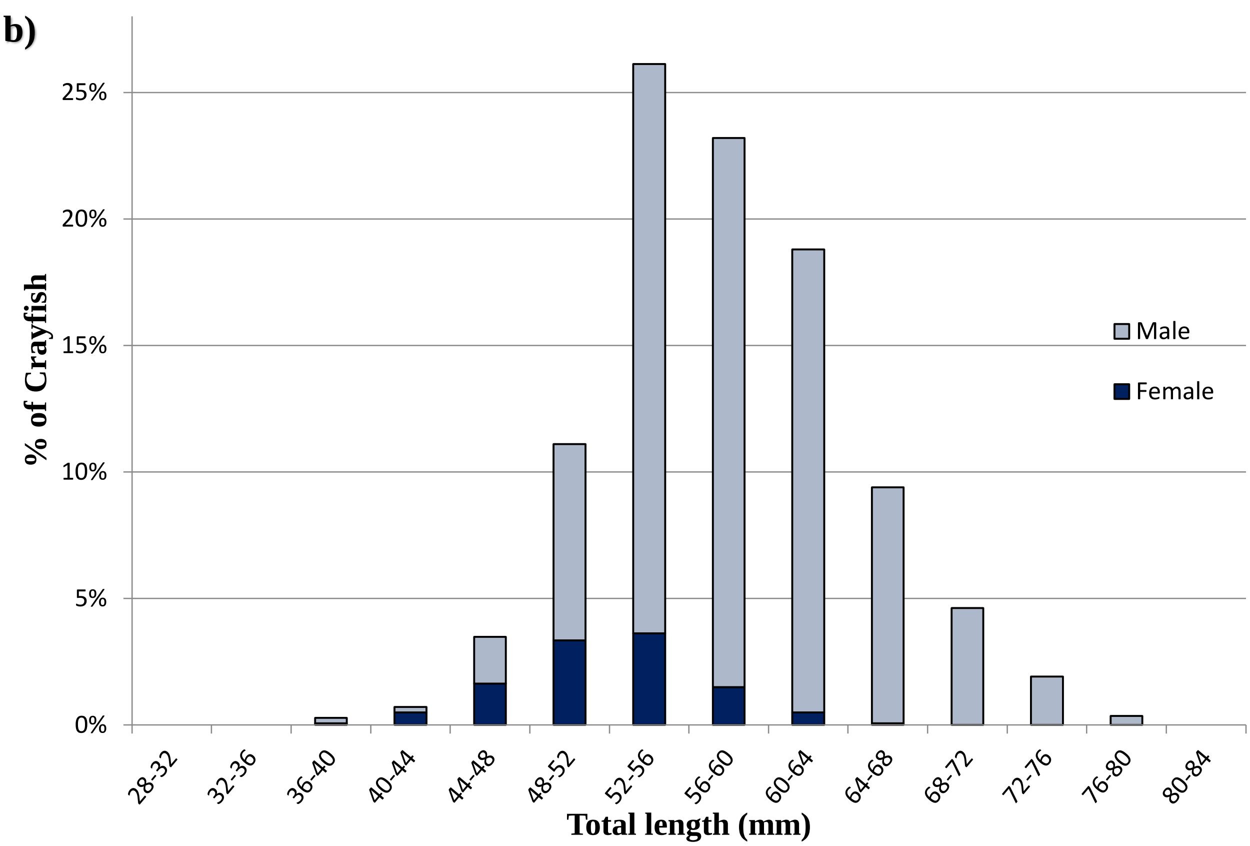
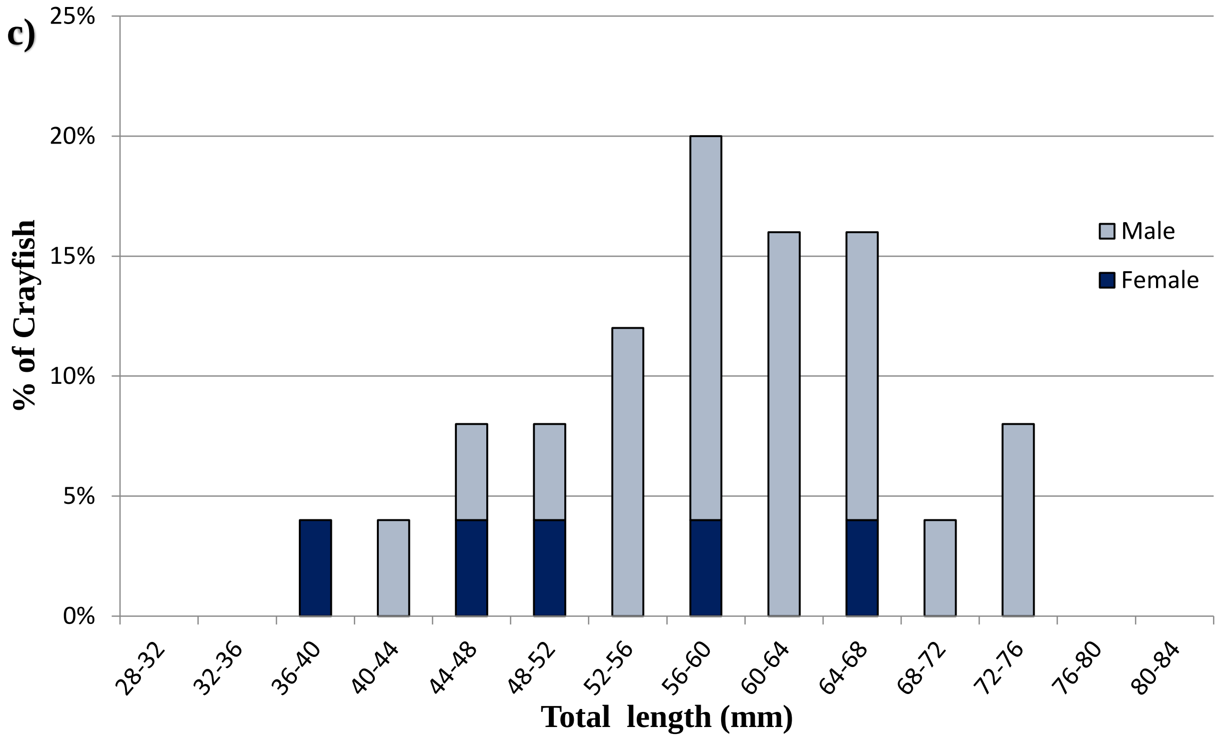


Figure 9. Regression line of all four lakes illustrating carapace length (mm) and total length (mm).


a)
25%
20%
15%
10%
5%
0%
% of Crayfish
Male
Female
28-32
32-36
36-40
40-44
44-48
48-52
52-56
56-60
60-64
64-68
68-72
72-76
76-80
80-84
Total length (mm)


b)
25%
20%
15%
10%
5%
0%
% of Crayfish
Male
Female
28-32
32-36
36-40
40-44
44-48
48-52
52-56
56-60
60-64
64-68
68-72
72-76
76-80
80-84
Total length (mm)



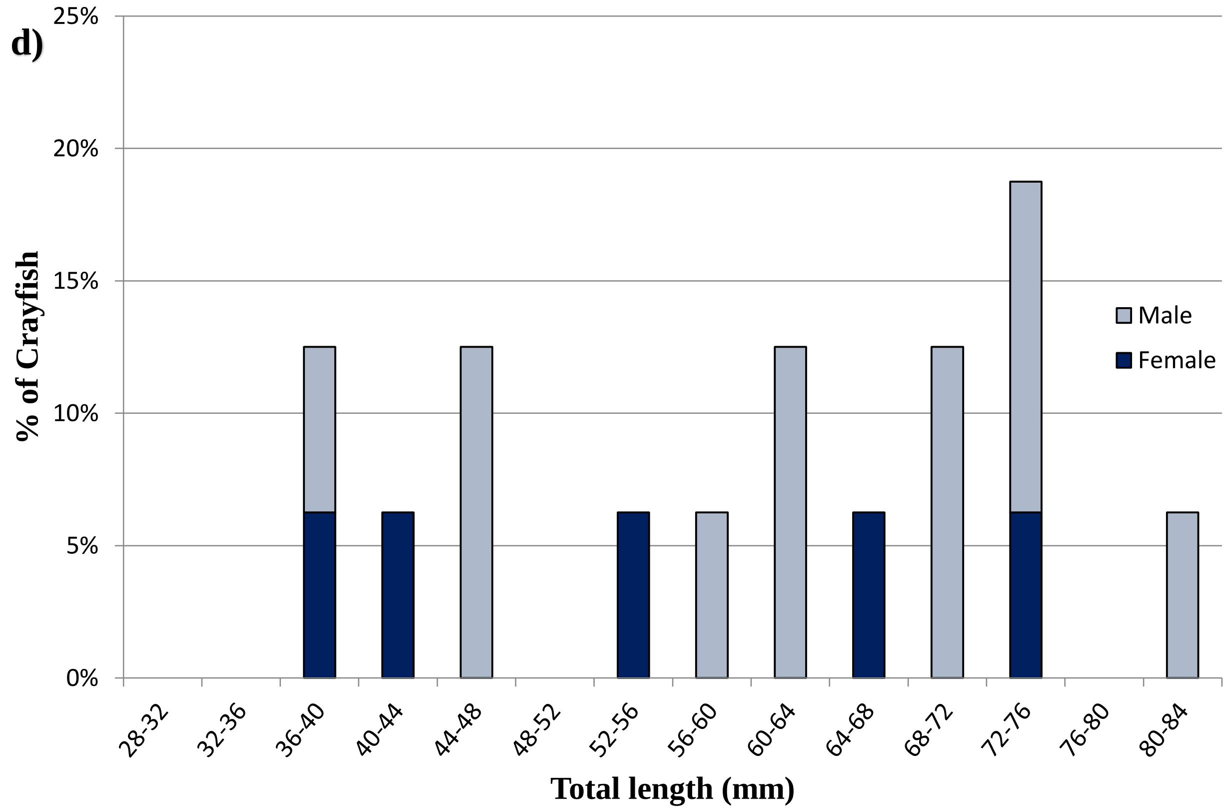


Figure 10. Total length distribution for O. *rusticus* collected from a) Dahlberg (n=136), b) Nest Lake (n=1405), c) South Lake (n=25) and d) Burke Lake (n=16). Total lengths were calculated from carapace lengths using lake specific total length to carapace length regressions.

Stream surveys

Data was collected through qualitative observation, which is summarised below, from the streams connecting each lake (figure 2-6) to better understand the present obstacles potentially hindering the geographic range expansion of O. *rusticus*, as well as collect evidence of O. *rusticus* and/or O. *virilis* presence in the streams. During these surveys, evidence of O. *rusticus* was found in every stream with no sign of O. *virilis*. In many streams, significant obstacles were present including rapids with varying velocities, significant water flow, beaver dams, bedrock cascades and waterfalls of varying heights, as discussed below.

Survey 1: Dahlberg to Basswood

- Gradient drop of stream from 10cm-50cm. Light-moderate water flow, series of small rapids throughout creek. Habitat mainly cobble with mucky swamp/detritus habitat closer to Dahlberg entrance. Two live O. *rusticus* caught and measured.

Survey 2: Nest Creek – pond

- Significant bedrock cascade and beaver dam as obstacles in the creek. Significant amount (~10) of baby crayfish found at the mouth of Nest Creek into the pond. Four live O. *rusticus* caught and measured.

Survey 3: Nest Creek – Basswood Lake

- 3-4m gradient drop from pond creek entrance into Basswood Lake. Major obstacles: beaverdam, bedrock cascade (first bedrock cascade drop of ~50cm, second large cascade ~1m drop, with gradual 50cm decline like 'steps' four times over) and minor rapids. Dead O. *rusticus* carcass; 2 live caught and measured.

Survey 4: South – Basswood Lake

- Rusty crayfish sighted, one collected and measured. Old beaver dam, bedrock shelf with 1 foot drop, huge boulders, rapids with varying levels of velocity from changes in creek width, and a big waterfall.

Survey 5: West – South Lake

- Caught and measured 2 live rusty crayfish. Stream was along portage. Fast moving water throughout, old beaver dam side stream with cobble and slower moving water, small rapids and large waterfall with significant water velocity at South Lake entrance (figure 5).

Survey 6: Burke-Basswood

- No crayfish caught and measured, 3 dead crayfish found. Near Basswood, small rapids with ~10cm drop. Side stream with rocks, boulders, small rapids. Significant number of boulders, downed trees with small rapids with ~10-20cm drop.

Trapping biases

The average number of crayfish per trap, including males and females, was compared between those caught on the first and second day (figure 11) in order to discern differences of crayfish catch based on the freshness of the catfood used as bait. Dahlberg, Nest and Burke Lake were the only lakes during the study where catfood was used for two consecutive days in the traps. All three of these lakes showed a higher incidence of crayfish caught on Day 1 compared to Day 2. Dahlberg Lake has an average of 1.24 and 0.65 crayfish caught on Day 1 and Day 2, while Nest has an average of 11.22 and 8.32 crayfish on Day 1 and Day 2 respectively. However, the data collected from Burke showed no statistically significant results during analysis, while Dahlberg and Nest Lake did show a significant relationship (i.e. p value below 0.05) (appendix table 4). The p values of the relationship between Day 1 and Day 2 for Dahlberg, Nest and Burke Lake are 0.03, 0.01 and 0.4 respectively. It is likely that there were insufficient rusty crayfish caught in Burke to show a significant statistical result for this difference (n=16).

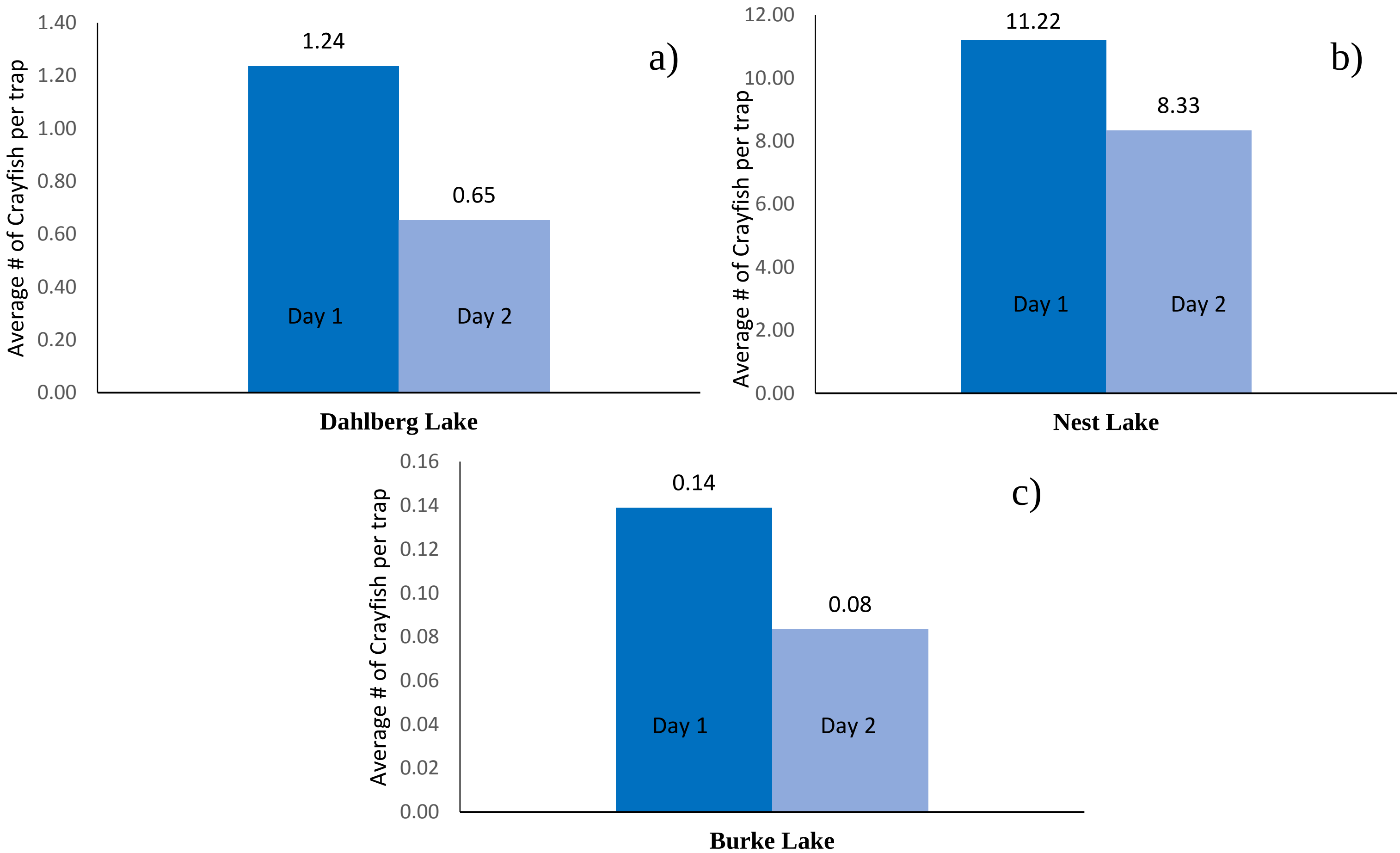
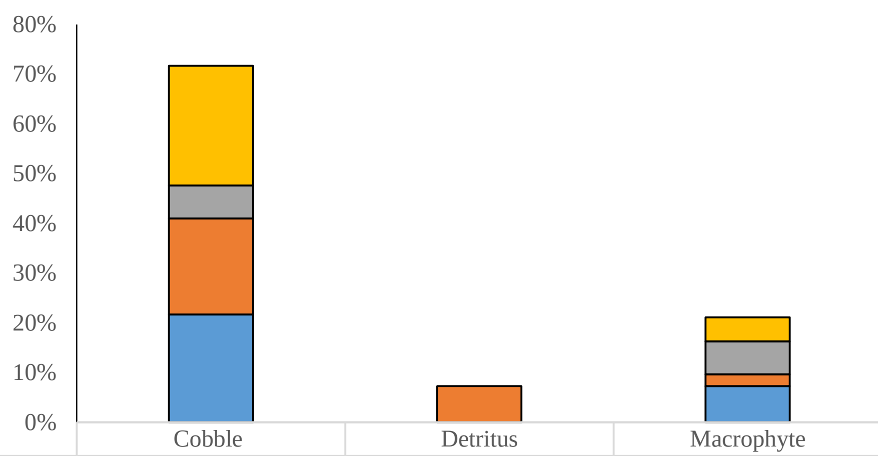


Figure 11. Average number of O. *rusticus* caught per trap on the first and second day of trap bait used in a) Dahlberg, b) Nest and c) Burke.

Habitat

A significant relationship was found between the difference of crayfish abundance depending on habitat type in Dahlberg, Nest and Burke Lake (i.e. $p<0.05$) (appendix table 6). Throughout all habitat types where traps were set in all four sampled lakes, 72% consisted of cobble, 7% detritus and 21% macrophyte (weedy) habitat (figure 12). Overall, the data suggest a preference for macrophyte (weedy) habitat over cobble in Dahlberg and Burke Lake, yet a preference for coble and detritus over weedy habitat in Nest Lake. In Dahlberg, a higher average of crayfish was caught in weedy over cobble habitat, with a p value of 0.0014 showing significance. The average number of crayfish caught per trap for cobble was 0.694, while in weedy habitat it was 1.694. In Burke, an average of 0.5 crayfish per trap was caught in weedy habitat and an average of 0.033 per trap in cobble habitat. In Nest, a significant difference between cobble and weedy habitat and detritus and weedy habitat existed, with a p value of 0.011 and 0.012 respectively. While comparing detritus and weedy habitat, the average catch of crayfish per trap was 10.639 in detritus and 4.83 in weedy habitat. The average number crayfish caught per trap in cobble was 10.07 and in weedy habitat it was 4.83. It is important that limited detritus habitat was sampled throughout the sampled lakes, as only Nest lake had detritus habitat that was sampled. Hence a comparison of preference for detritus is impossible to verify in other lakes.



	Cobble	Detritus	Macrophyte
Burke	24%	0%	5%
South	7%	0%	7%
Nest	19%	7%	2%
Dahlberg	22%	0%	7%

Figure 12. Percentage of sampling effort per habitat type by proportion of total crayfish traps.

Discussion

Crayfish predators, particularly smallmouth and largemouth bass, have been shown to effectively reduce crayfish numbers through predation on small and young crayfish (Hein et al., 2006). Rock bass is also an efficient predator, and is known to feed on a wide size range of crayfish but especially larger crayfish (Keller and Moore, 2000; Tetzlaff et al., 2011). Bluegill sunfish have also been known to consume young-of-year rusty crayfish, but to a lesser degree than bass (Tetzlaff et al., 2011). Nest Lake is devoid of any bass and bluegill fish. This lack of rusty crayfish predation is likely the reason for the higher average catch of rusty crayfish per trap in Nest Lake in comparison to the other sampled lakes (figure 7). Dahlberg, South and Burke Lake all contain some of the aforementioned rusty crayfish predators (appendix table 1) and exhibit smaller population sizes and smaller sized rusty crayfish. Moreover, it was found that Nest also contained a higher average of larger crayfish than other lakes, particularly in comparison to Dahlberg Lake. The mean carapace length for male crayfish in Dahlberg is 30.69mm and in Nest it is 32.25mm, showing that Nest Lake harbour larger crayfish than Dahlberg Lake (appendix table 3). Hence, it is likely that rusty crayfish have greater opportunity to establish a larger abundance and a larger size distribution of the rusty crayfish in lakes (figure 10) when no predators are present, especially since they experience greater survival rates as juveniles and grow larger (Tetzlaff et al., 2011). The other sampled lakes seemed to experience smaller crayfish and lessened abundance, as more predation controls the size and population abundance. This finding is consistent with the thesis by Tetzlaff et al. (2011), whom discuss that fish predation can be an efficient mechanism in limiting rusty crayfish density. Hence, it is likely that the most vulnerable lakes in Quetico Provincial Park to rusty crayfish invasion are those with few or no rusty crayfish predators.

Further, research has shown that rusty crayfish prefer cobble habitat because it offers more cover from predators (Hill and Lodge, 1994; Keller and Moore, 2000). However, data collected from Nest, Burke and Dahlberg Lake provides convoluted results. In Dahlberg and Burke, there were higher rates of habitation of rusty crayfish in weedy habitat over cobble habitat. However, in Nest Lake we also noticed an almost equal habitat preference for detritus and cobble over weedy habitat. According to Hill and

Lodge (1994), crayfish select their habitat based on the presence of predators. When predation is high, they choose their habitat on the basis of shelter availability in order to reduce the risk of becoming prey (Hill and Lodge, 1994). When predation is low, they chose habitat based on food availability, as can be seen in Nest Lake. The preference for both detritus and weedy habitat of rusty crayfish instead of just cobble is likely due to the lack of crayfish predators in Nest Lake. The high use of detritus in Nest, where there are no crayfish specialist predators, may support the hypothesis that rusty crayfish use a broader range of habitat when they don't need to rely on escape habitat as much and can focus on food foraging. However, it remains unclear why rusty crayfish prefer weedy habitat over cobble in Burke and Dahlberg.

Another factor important to the expanding upstream range of the rusty crayfish is calcium, as it is essential for the growth and maintenance of the exoskeleton and overall success of crustaceans. According to Edwards and colleagues (2013), it is likely that calcium plays a limiting factor for crayfish growth and survival, particularly in the Canadian Shield. It is shown that a large number of lakes in Ontario across the Shield have calcium ranges from 1.5 mg/L - 2mg/L (Jeziorski et al., 2008). While the optimal limiting requirement for O. *rusticus* survival is suggested as 7.2 mg/L (Capelli and Magnuson, 1983), Edwards et al., suggest that Ca levels in the Shield are lower than in the native range of rusty crayfish and, in consequence, might limit the expansion of the invasive species beyond their current range (2013). However, the observed range and abundance of O. *rusticus* in the lakes sampled in this study suggest that calcium limitation is less likely to be significant in Quetico. Further, the Northwestern Region of Ontario including Quetico seems to have higher Ca levels than what is suggested in the literature for Shield lakes (Edwards et al., 2013; Jackson, 2016). A study using collected data from twenty Quetico Provincial Park Lakes in 2010 looked at the influence of bedrock geology on water chemistry. It was found that only 10% of the lakes contained less than 2 mg/L of calcium, while 65% had calcium levels greater than 2.5 mg/L, with all the lakes less than 2 mg/L located on granitic soils (Jackson, 2016).

Further, Jackson (2016) suggests that the bedrock type found in lakes might limit and/or increase the amount of available calcium, thus potentially influencing crayfish abundance and survivability. In Quetico, there exists 3 basic bedrock types: sedimentary, granitic and volcanic, each of which influence the water chemistry of the lakes differently. However, calcium concentrations seem only to be high in volcanic bedrock types in Quetico Provincial Park, which was the only area with greater than 7 mg/L of calcium, but not in sedimentary and granitic bedrock types. All of the 5 sampled lakes were found in granitic bedrock lakes (Jackson, 2016), making it unlikely that calcium has limited the abundance and range increase in O. *rusticus*, as Edwards et al. suggests (2013). This is particularly true since we have seen various levels of abundance and sizes of crayfish in this study, further asserting the hypothesis that predators are the most influential factor to rusty crayfish population establishment.

Further, the expansion of O. *rusticus* from Basswood Lake into Dahlberg, Nest, South, West and Burke suggest that geography and physical obstacles of the connecting streams between lakes play a less significant role in the dispersal of rusty crayfish than previously suggested (Philips et al., 2009). A major finding during this study was that all sampled upstream lakes contained O. *rusticus*, with no presence of O. *virilis*, no matter the mean annual flow of the lake, distance from source lake, the types of obstacles, or gradient of the stream. Although the date of movement of rusty crayfish into these lakes is not known, based on the understanding of crayfish presence and movement within Basswood Lake, it is within the last 20 years and possibly within the last 10 years for some lakes. Within that relatively short time, it appears that rusty crayfish have completely replaced O. *virilis* in all the lakes surveyed. Of particular significance was the connecting stream from South to West Lake, where a large cascading waterfall with a slope gradient above 3 meters and significant velocity was present (figure 5).

Finally, the size ratio of O. *rusticus* in the sampled lakes in this study is similar to the 2015 survey of Basswood Lake, as the relationship between carapace length and total length is consistent with the findings of Jackson (2015b). This suggests that the total length of the sampled rusty crayfish can be reliably extrapolated from the measured carapace length, which is easier and faster, while collecting measurements from live crayfish in the field.

Future Recommendations

Water samples taken at the sample sites would be helpful in understanding how water chemistry might be influencing rusty crayfish size and population abundance in Quetico Provincial Park. It would also provide a supplement to what we understand about calcium levels in Quetico based on the bedrock of each lake (Jackson, 2016). Conductivity measurements can be taken instead of calcium concentrations if desired, as calcium concentrations in Quetico lakes have been found to be highly correlated with conductivity (Jackson, 2016).

Further, measuring the stream width of the connective streams between sampled lakes during the stream surveys would be useful to further understand what types of physical obstacles rusty crayfish can overcome. Further, more complete documentation including photos and quantitative measurements of the obstacles present in the streams would be useful, especially since little is known on the limiting range of these factors on the rusty crayfish.

The statistically significant reduction of the average number of crayfish caught on Day 2 versus Day 1 in Dahlberg and Nest Lake suggests that fresh catfood should be used every time a new plot is set (figure 11). However, using fresh catfood every time a trap is set can be more time consuming and prove to be more expensive and heavy in the field. Overall, the use of current monitoring protocols should be continued in order to further understand the potential range of the invasive rusty crayfish in Quetico Provincial Park, but the use of fresh cans of catfood as bait when possible is recommended. Further, if the catch/trap density results of this survey are compared with other surveys that use fresh bait each day, it is recommended to only use the data of day 1 catch/trap numbers of this data.

Acknowledgements

Thank you to the Quetico Foundation research team; Kiara Gannon, Ty Colvin, Hannah Koslowsky and Brigitte Champaigne-Klassen for data collection and Glenda McLachlan, the Foundation's Executive director. Thank you also to Brian Jackson, the Quetico Provincial Park Biologist, for designing and overseeing this project as well as Quetico Provincial Park staff for all that they do.

Works Cited

Capelli, G. M. (1982). Displacement of northern Wisconsin crayfish by *Orconectes rusticus*. *Limnology and Oceanography*, 27 (4), *741-745*.

Crossman, E.J. 1976 Quetico Fishes. Life Sci. Misc. Pub., R. Ont. Mus. 85p

Edwards, B.S., Jackson, D.A., & Somers, K.M. (2009). Multispecies crayfish declines in lakes: implications for species distributions and richness. *Journal of the North American Benthological Society*, *28 (3)*, 719-732. http://doi.org/10.1899/08-148.1

Edwards, B.W., Lewis, V.R.E., Rodds, F.H., & Jackson, D.A. (2013). Interactive effects of calcium decline and predation risk on the potential for a continuing northward range expainsion of the rusty crayfish (*Oronectes rusticus). Canadian Journal of Zoology, 91*, 328-337.

Hein, C. L., Rother, B.M., Ives, A.R., & Zanden, M. J. V. (2006). Fish predation and trapping for rusty crayfish (*Oronectes rusticus*) control: a whole-lake experiment. *Canadian Journal of Fisheries and Aquatic Sciences, 63(2),* 383-393. http:doi.org/10,1139/f05-229

Hill, A. M., & Lodge, D. M. (1994). Diel changes in resource demand: competition and predation in species replacement among crayfishes.*Ecology*, *75*(7), 2118-2126.

Jackson, B. 2015a. Crayfish (Zhaageshii) in Quetico Park – Known Status and Distribution as of 2014 *Quetico Provincial Park. 2p + appendices*

Jackson, B. 2015b. Crayfish (Zhaageshii) monitoring of Basswood Lake and Crooked Lake, Quetico Provincial Park: Results of 2014/15 surveys. *Quetico Provincial Park. 18p + appendices*

Jackson, B. 2015c Quetico Park Crayfish/Zhaageshii Monitoring Protocol *Quetico Provincial Park.. 8p*

Jackson, B. 2015d. Use of crayfish as food by selected fish species based on stomach sample analysis with assessment of impact of introduced smallmouth bass. *Quetico Provincial Park. 9p*

Jackson, 2016. Influence of Bedrock Geology on Water Chemistry of Quetico Park Lakes, Ontario Provincial Park.

Keller, T.A., & Moore, P.A. (2000). Context-specific behaviour: crayfish size influences crayfish-fish interactions. *Journal of the North American Benthological Society, 19*(2), 344-351.

Tetzlaff, J.C., Roth, B.M., Weidel, B.C., & Kitchell, J.F. (2011). Predation by native sunfishes (Centrarchidae) on the invasive crayfish *Orconectes rusticus* in four northern Wisconsin etc.

Appendix

Figure 1. Identification of crayfish species found in Quetico Provincial Park (http://pinicola.ca/crayfishontario/index.htm).

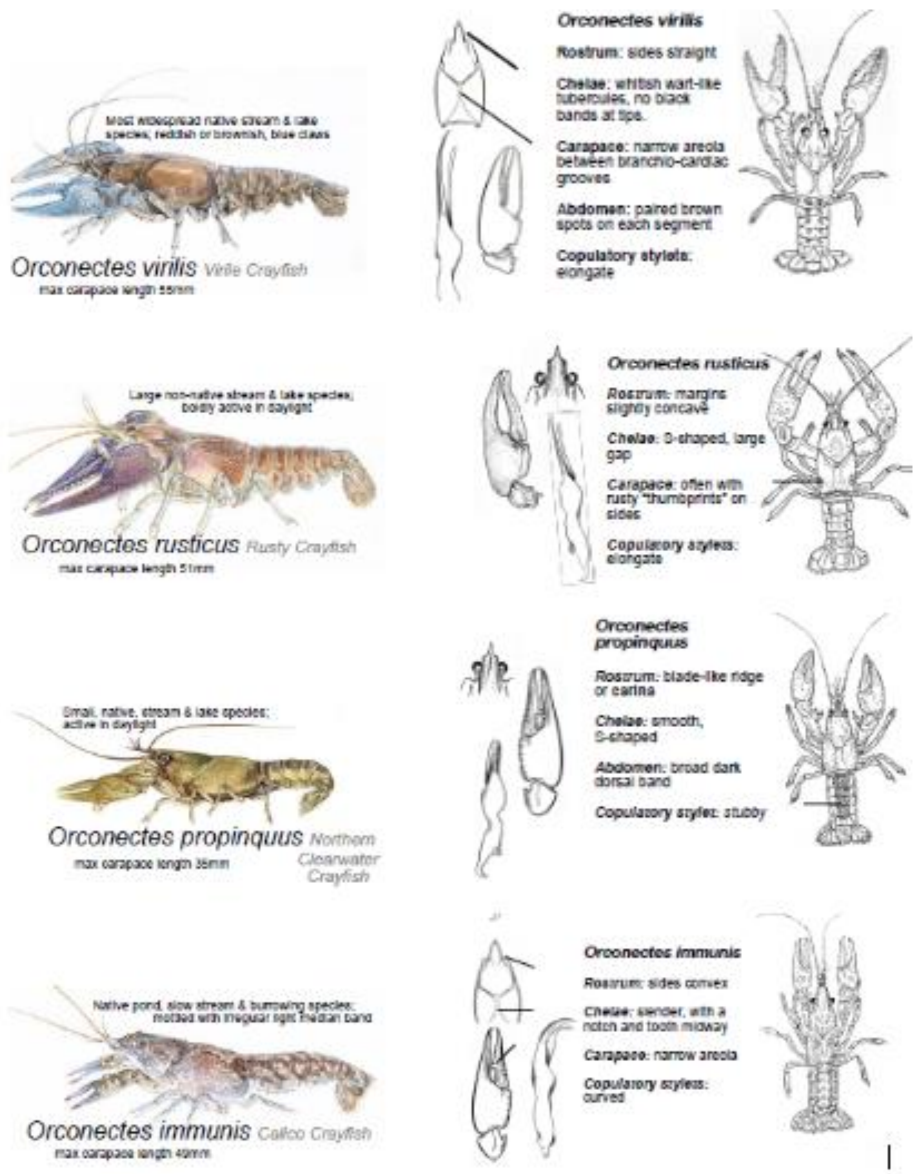


Table 1. Known fish species presence in the five lakes sampled from this study and from the OMNR 2003 data.

Legend: *=OMNR (2003) data, no *= fish sampled during study, **=fish identified in both.

Dahlberg	***Nest***	***South***	***West***	***Burke***
Bluegill	Bluntnose minnow	Largemouth bass	Northern pike*	Bluegill
Rockbass	Yellow perch	Smallmouth bass**	White sucker*	Lake herring*
Smallmouth bass**	Green sunfish	Bluegill	Smallmouth bass*	Walleye*
Blacknose shiner	Longear sunfish		Largemouth bass*	Rock bass**
	Lake trout*		Walleye*	Smallmouth bass**
	Northern pike*			Largemouth bass*
				Lake trout*
				Lake whitefish*
				Northern pike*

Table 2. Rusty crayfish dispersal study data collected from OFATIII (Jackson, 2016).

Potential Monitoring Lake	Lake Area (ha)	Stream distance from Basswood Lake (m)	Estimated mean annual stream flow (m^3/sec) (OMNR 2003)	Watershed Area (km^2)	Total Lake Area in Watershed (km^2)	Total Wetland Area in Watershed (km^2)
"Dahlberg" Lake	71	190	0.013	1.5	0.71	0.01
Unnamed Lake (Ranger Bay)	*~20*	*425*	*0.04*	*4.63*	*0.36*	*0.5*
Nest Lake	75	550	0.04	4.65	1	0.3
South Lake	60	1280	0.292	34.05	7.1	2.6
Isabella Lake	52	2135	0.375	43.76	6.4	2.2
Burke Lake	268	950	0.492	57.5	11.7	4.4

Table 3. Results of statistical data analysis demonstrating the difference of male crayfish size between lakes using *Anova single factor* and *t-test assuming equal variances* statistical tests. Dahlberg vs. Nest Lake are the only lakes showing statistically significant results.

ANOVA (single factor summary)				
Groups	*Count*	*Sum*	*Average*	*Variance*
Dahlberg	116	3560.1	30.69	36.12
Nest	1241	40016.4	32.25	22.93
South	20	644.2	32.21	33.39
Burke	11	360.3	32.76	85.37

ANOVA						
Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	261.11	3	87.04	3.54	0.014	2.61
Within Groups	34069.28	1384	24.62			
Total	34330.39	1387				
T-TEST (assuming equal variance)						
	Dahlberg vs. Nest		*Dahlberg vs. Burke*		*Nest vs. Burke*	
Mean	30.69052	32.24529	30.69052	32.75455	32.24529	32.75455
Variance	36.11808	22.9255	36.11808	85.37073	22.9255	85.37073
Observations	116	1241	116	11	1241	11
Pooled Variance	24.04516		40.05829		23.42506	
Hypothesized Mean Difference	0		0		0	
df	1355		125		1250	
t Stat	-3.2657		-1.0337		-0.34744	
P(T<=t) one-tail	0.00056		0.151637		0.36416	
t Critical one-tail	1.645979		1.657135		1.646074	
P(T<=t) two-tail	0.001119		0.303274		0.72832	
t Critical two-tail	1.961716		1.979124		1.961864	
	Dahlberg vs. South		*Nest vs. South*		*South vs. Burke*	
Mean	30.69052	32.21	32.24529	32.21	32.21	32.75455
Variance	36.11808	33.38832	22.9255	33.38832	33.38832	85.37073
Observations	116	20	1241	20	20	11
Pooled Variance	35.73103		23.08339		51.31329	
Hypothesized Mean Difference	0		0		0	
df	134		1259		29	
t Stat	-1.0499		0.032583		-0.20251	
P(T<=t) one-tail	0.147827		0.487006		0.420465	
t Critical one-tail	1.656305		1.646065		1.699127	
P(T<=t) two-tail	0.295654		0.974012		0.840931	
t Critical two-tail	1.977826		1.96185		2.04523	

Table 4. Summary values from the t-test analysis for Dahlberg, Nest and Burke Lake between the difference of crayfish caught on Day 1 vs. Day 2 (i.e. fresh can of catfood vs. day old can of catfood used as bait in the trap).

		Mean	
Lake	**P(T<=t) two-tail**	**Day 1**	**Day 2**
Dahlberg	1.24	0.65	0.03
Nest	11.22	8.32	0.01
Burke	0.14	0.08	0.40

Table 5. Average Length of Carapace (mm) of female and male crayfish and the overall average in all sampled lakes, other than West Lake.

Average of Carapace Length (mm)	Sex		
Lakes	**Female**	**Male**	**Total**
Burke	28	33	31
Dahlberg	24	31	30
Nest	27	32	32
South	27	32	31
Grand Total	27	32	31

Table 6. Summary of Anova and t-test results between all of the habitats in each lake. Found significant results (p<0.05) in Anova test for Dahlberg, Nest and Burke so t-tests were performed to find the difference between habitats. Found statistical significance in Dahlberg, Burke and Nest Lake in t-test results.

	Anova Results Summary							
	Dahlberg		**Nest**		**South**		**Burke**	
	Sum	*P value*	*Sum*	*P value*	*Sum*	*P value*	*Sum*	*P value*
Cobble	75	0.006	967	0.032	7	0.207	4	2.09E-07
Detritus	0		383		0		0	
Macrophyte	61		58		18		12	

T-test results					
Dahlberg	Cobble vs. Macrophyte		**Burke**	Cobble vs. Macrophyte	
Mean	0.694	1.694	Mean	0.033	0.5
P(T<=t) two-tail	0.001		P(T<=t) two-tail	2.76E-08	
Nest	Cobble vs. Macrophyte		**Nest**	Detritus vs. Macrophyte	
Mean	10.073	4.8333	Mean	10.639	4.833
P(T<=t) two-tail	0.011		P(T<=t) two-tail	0.012	
Nest	Cobble vs. Detritus				
Mean	10.073	10.639			
P(T<=t) two-tail	0.678				

Table 7. T-test results (two sample assuming equal variances) of total crayfish (female and male) in Dahlberg, Nest and Burke Lake demonstrating the difference between Day 1 and Day 2 of catfood can use.

	**Dahlberg*		**Nest*		*Burke*	
	Day 1	*Day 2*	*Day 1*	*Day 2*	*Day1*	*Day2*
Mean	**1.24**	**0.65**	**11.22**	**8.32**	0.14	0.08
Variance	3.51	1.78	50.68	42.28	0.21	0.11
Observations	72.00	72.00	72.00	71.00	72.00	72.00
Pooled Variance	2.64		46.51		0.16	
Hypothesized Mean Difference	0.00		0.00		0.00	
df	142.00		141.00		142.00	
t Stat	2.15		2.54		0.84	
P(T<=t) one-tail	0.02		0.01		0.20	
t Critical one-tail	1.66		1.66		1.66	
P(T<=t) two-tail	**0.03**		**0.01**		0.40	
t Critical two-tail	1.98		1.98		1.98	
*significant (p value<0.05)			*significant		not significant (p value>0.05)	