The impact of fish predation on invasive rusty crayfish (*Orconectes rusticus*) populations in two northern temperate lakes

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Abstract

Throughout northern Wisconsin and the Upper Peninsula of Michigan, the rusty crayfish (*Orconectes rusticus*) has negatively impacted the lakes it has invaded. However, rusty crayfish do not always reach outbreak densities, and can persist at low levels in some lakes for many years. One example of a vast difference between rusty crayfish establishment success exists at Big Lake and Brown Lake in Vilas County, Wisconsin. I studied these lakes to determine whether a difference in fish predation could be a factor keeping crayfish at low levels in Brown Lake and allowing them to thrive in Big Lake. Higher numbers of fish that eat crayfish were found in Brown Lake, but there was not a significant difference between fish populations that specifically eat adult crayfish. Therefore, a higher level of predation on juvenile crayfish in Brown Lake could be causing rusty crayfish to persist at lower levels than in Big Lake. Lakes with small populations of fish that prey on juvenile crayfish should be closely monitored to prevent invasion by rusty crayfish.

Introduction

The rusty crayfish, *Orconectes rusticus*, is invasive in northern Wisconsin and the Upper Peninsula of Michigan. Many lakes have already been overrun by this invader, with drastic consequences. Rusty crayfish negatively impact lake dynamics in several ways. They alter the vegetation structure by destroying less hardy macrophytes, which can negatively impact certain types of fish and macroinvertebrates that use these plants for refuge (Wilson et al. 2004). Snails and other invertebrates decline sharply after invasion, likely due to predation or competition (Wilson et al. 2004). Fish populations also change since rusty crayfish evict small fish from refuges, making them more susceptible to predation (Rahel and Stein 1988), and crayfish feed on the eggs of small bluegill and pumpkinseed sunfish which are unable to defend their nests (Wilson et al. 2004).

Additionally, rusty crayfish displace other crayfish in the lakes they invade. In the lakes of northern Wisconsin, the native virile crayfish *Orconectes virilis* and the already established invasive northern crayfish *Orconectes propinquus* are outcompeted by rusty crayfish (Hill and Lodge 1994). It appears that rusty crayfish are less susceptible to fish predation because of their relatively large size, high levels of aggression towards fish, and ability to outcompete the other species for shelter (Garvey et al. 1994). Rusty crayfish also forage for food under predation pressure more often than virile crayfish, giving them additional advantage (Hill and Lodge 1994). In addition, *O. propinquus* numbers decrease due to hybridization with *O. rusticus* (Perry et al. 2001).

Since rusty crayfish cause such a wide array of costly disruptions in the lakes they invade, protecting susceptible lakes and restoring invaded lakes is of great importance. In general, the cost of protecting a lake is less than the monetary cost of invasion by rusty crayfish (Keller et al. 2008). Trapping and fish predation have been proposed as methods to remove rusty crayfish from lakes that have already been invaded, and both appear to be effective (Hein et al. 2006). Fish that prey on rusty crayfish include smallmouth bass (*Micropterous dolomieu)*, largemouth bass (*Micropterous salmoides*), yellow perch (*Perca flavescens*), and rock bass (*Ambloplites rupestris*) (Kershner and Lodge 1995). Stocking lakes or enforcing more stringent fishing bag limits are two ways to increase the amount of these predatory fish. It follows that higher numbers of these types of fish would result in lowered crayfish populations.

Rusty crayfish do not always dominate the ecosystems they invade, sometimes existing at low levels for a decade or more (Garvey et al. 2003). Fish predation might be a factor that keeps their populations small (Roth et al. 2007). An ideal location to explore this idea exists at the University of Notre Dame Environmental Research Center (UNDERC) in Vilas County, Wisconsin, where both Brown Lake and Big Lake have been invaded by rusty crayfish. These lakes are located less than 2 kilometers apart, but there are noticeable differences between their crayfish populations. Brown Lake is relatively isolated, with exclusively private access. Rusty crayfish have been present for at least 5 years, but they remain at low levels. Big Lake is a popular fishing lake with multiple public access points. Rusty crayfish were likely introduced by anglers discarding excess bait at least 14 years ago, and they are now present at very high levels (A. Baldridge, personal communication). This study will examine whether this distinct difference between crayfish populations could be caused by a difference in fish populations between the two lakes. I hypothesize that *Orconectes rusticus* are more limited in Brown Lake than in Big Lake due to higher levels of predatory fish in Brown Lake.

Materials and Methods

Substrate was first mapped in Brown Lake and Big Lake at .75m, ½ Secchi, and ¾ Secchi depths all along the shoreline. Locations with primarily cobble, sand, or vegetation were chosen for fish and crayfish sampling. Three sites per substrate per lake were used for crayfish sampling, and one site per substrate per lake was used for fish sampling. This method was chosen to eliminate bias of crayfish and fish captures in different substrate types.

Random crayfish sampling with .25 m^2 quadrats was performed at 1 m depths, with 4 quadrats in each of the 9 crayfish sampling sites for a total of 36 quadrats per lake. Quadrats were left overnight to minimize disruption of the crayfish in each location. Each crayfish in the quadrats was hand collected by snorkeling, identified to species, sexed, and the carapace length measured. Since traps and hand collection target different sexes and sizes of crayfish, trapping was also performed. Two modified Gee minnow traps were each baited with 120g beef liver (as described in Wilson et al 2004) and placed at each of the 9 sites used for quadrat sampling. After being left overnight, traps were collected and the crayfish were identified to species, sexed, and the carapace length measured.

Fish surveys using fyke nets were performed on each lake by setting one fyke net in each of the three substrate types overnight. Seine netting was performed in the same locations, with 3 seine passes per location. Fish collected were identified to species, their total length was measured, and they were immediately released on site.

Data Analysis

Fish data from fyke and seine netting at each location was combined into whole lake totals to minimize bias between capture method and substrate type. The fish data was organized based on species and size into groups of fish that eat crayfish, and more specifically, fish that eat adult crayfish. Northern pike, walleye, and tiger muskellunge of all sizes eat adult crayfish (Roth and Kitchell 2005). Rock bass and yellow perch eat crayfish; however, only individuals larger than 15 cm in length eat adult crayfish (Stein 1977). Bluegill and pumpkinseed eat only juvenile crayfish (Roth et al. 2007). Black crappie, golden shiners, and fathead minnows do not generally eat crayfish.

A regression between average crayfish captured in quadrats and traps at each site showed no correlation, so quadrat data was not used (R^2= 0.078, p= 0.262). The quadrats probably did not accurately reflect crayfish numbers due to difficulties in locating crayfish in dense vegetation and debris, and from human disturbance at the site.

Data was analyzed using SYSTAT 12. Friedman and chi-square tests were performed to determine whether there was a significant difference between predatory fish populations of the two lakes, and whether fish populations were dependent on source lake. The crayfish data was analyzed graphically, as the large number of zeroes obtained made statistical analysis impractical. Graphs were created using Microsoft Excel.

Results

There was a large discrepancy between the total numbers of crayfish found on each lake (Figure 1). Crayfish levels in Brown Lake are low overall, with a total of 1 *O. virilis* and no *O. rusticus*, for an average of 0.55556 *O. virilis* per trap. Big Lake showed much higher numbers of crayfish, with 493 *O. rusticus*, or an average of 27.38889 per trap. However, no *O. virilis* were found in Big Lake.

Overall, more fish were caught on Brown Lake than on Big Lake. The only species of fish that were more abundant in Big Lake was the rock bass, *Ambloplites rupestris* (Figure 2). Other species captured include the black crappie (*Pomoxis nigromaculatus*), bluegill (*Lepomis macrochirus*), fathead minnow (*Pimephales promelas*), golden shiner (*Notemigonus crysoleucas*), northern pike (*Esox Lucius*), pumpkinseed (*Lepomis gibbosus*), tiger muskellunge (*Esox Lucius x Esox masquinongy*), walleye (*Stizostedion vitreum*), and yellow perch (*Perca flavescens*).

The group of fish that are able to eat crayfish of any size includes all bluegills, northern pike, pumpkinseed, tiger muskellunge, walleye, yellow perch, and rock bass. A Shapiro-Wilk test of normality showed that this data was not normally distributed (*Shapiro-Wilk test statistic*= 0.674, p<0.001). Therefore, non-parametric chi-square and Friedman tests were performed. At an alpha p-value of 0.05, the Friedman test showed a marginally non-significant difference between the populations of predatory fish in Brown and Big Lakes, when blocked by fish species (*Friedman test statistic*= 3.571, p= 0.059). The chi-square test showed that the number of predatory fish is dependent on the source lake (χ^2= 41.688, df= 1, p< 0.001).

The group of fish that are able to eat adult crayfish includes all northern pike, tiger muskellunge, and walleye as well as yellow perch and rock bass greater than or equal to 15cm total length. A Shapiro-Wilk test of normality showed that this data was not normally distributed (*Shapiro-Wilk test statistic*= 0.649, p<0.001). Therefore, another Friedman test was performed. There was not a statistically significant difference between the populations of fish that eat adult crayfish in the two lakes when blocked by fish species (*Friedman test statistic*= 1.800 , p= 0.180). The chi-square test showed that the number of fish that prey on adult crayfish is independent of source lake (χ^2= 1.089, df= 1, p= 0.297).

Discussion

Crayfish numbers, and more specifically rusty crayfish numbers, were noticeably higher in Big Lake than in Brown Lake as expected. The fact that only rusty crayfish were found in Big Lake, which used to be dominated by virile crayfish (Capelli and Magnuson 1983), demonstrates that the lake has been completely overtaken by rusty crayfish. In a crayfish survey of other lakes in the area performed after this study, a rusty crayfish was found in Brown Lake, confirming its presence. During the study, however, only 2 virile crayfish were captured. This indicates that there is an aspect of Brown Lake that is preventing the rusty crayfish from overtaking the lake and keeping total crayfish numbers low.

Predation by fish could be the difference between the lakes that is causing the discrepancy in crayfish numbers. According to the Friedman and chi-square tests, there is a significant difference between lakes in the numbers of fish that eat crayfish of any size, but not in the numbers of fish that are able to eat adult crayfish. This suggests that what is causing crayfish levels to be lower in Brown Lake is a higher number of fish that eat juvenile crayfish, not adults. In fact, there were much higher levels of bluegill, pumpkinseed, and yellow perch in Brown Lake than in Big Lake. A study by Roth et al. (2007) also found that high levels of predation on juveniles by bluegill and pumpkinseed can keep crayfish populations small. Also, intense predation on juveniles over a short period of time could have a larger impact on the crayfish population than eating only a few adults over a longer period of time (Hein et al. 2006).

Low levels of fish that prey on juvenile crayfish, possibly due to overfishing of pan fish, could have been a factor that allowed the rusty crayfish to establish in Big Lake. Now that rusty crayfish are present in high densities, they are probably keeping levels of pan fish low by eating their eggs and destroying the macrophyte habitat they need to feed and reproduce (Roth et al. 2007). This reciprocal cycle of low levels of predation on juveniles leading to higher crayfish populations, which suppresses the number of predators further, is likely enabling rusty crayfish to persist at such high densities in Big Lake.

Past studies have determined exactly what the fish have consumed by using gastric lavage to examine the contents of their stomachs (Stein 1977, Roth and Kitchell 2005, Garvey et al. 2003). Since time did not permit me to use this technique, I can only speculate that the higher numbers of predatory fish in Brown Lake are eating more juvenile crayfish than those in Big Lake. Further studies of the two lakes in which the stomach contents of the fish are examined would be necessary to determine whether this is the case. However, the difference in numbers of fish in the lakes should be great enough to impact the crayfish populations to some degree.

Future studies of Big and Brown Lakes should examine other aspects of the lakes to determine whether there are other factors impacting the crayfish populations. Habitat has already been shown to differ between the two lakes (S.D. Pecoraro, unpublished data). Other environmental factors such as temperature, dissolved oxygen content, water turbidity, and pH could differ between the lakes, causing a more favorable environment for crayfish in Big Lake.

Additionally, other lakes on the UNDERC property should be surveyed to determine the composition of their fish populations. Lakes with low levels of predatory fish should be closely monitored and protected to ensure that they are not invaded by rusty crayfish. When predatory fish are not present at high enough levels to suppress crayfish populations, rusty crayfish can quickly establish and reach outbreak densities in the lakes they invade.

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Figures

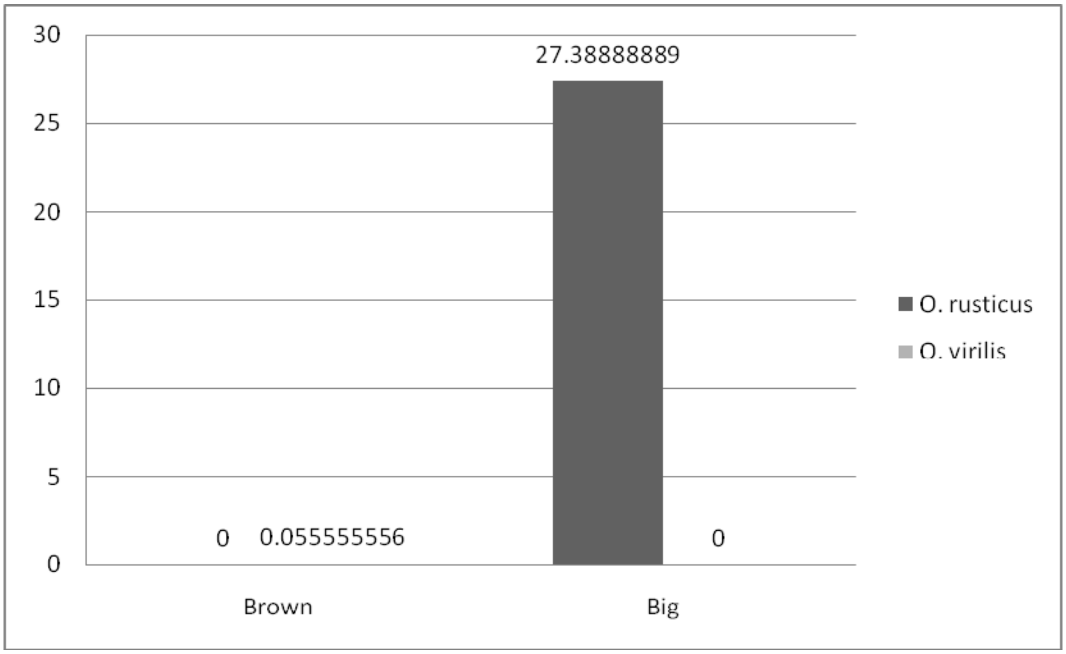

Figure 1: Average crayfish/trap. Shown here are the average numbers of crayfish trapped per trap for Big and Brown Lakes, separated by species. 18 traps were set on each lake.

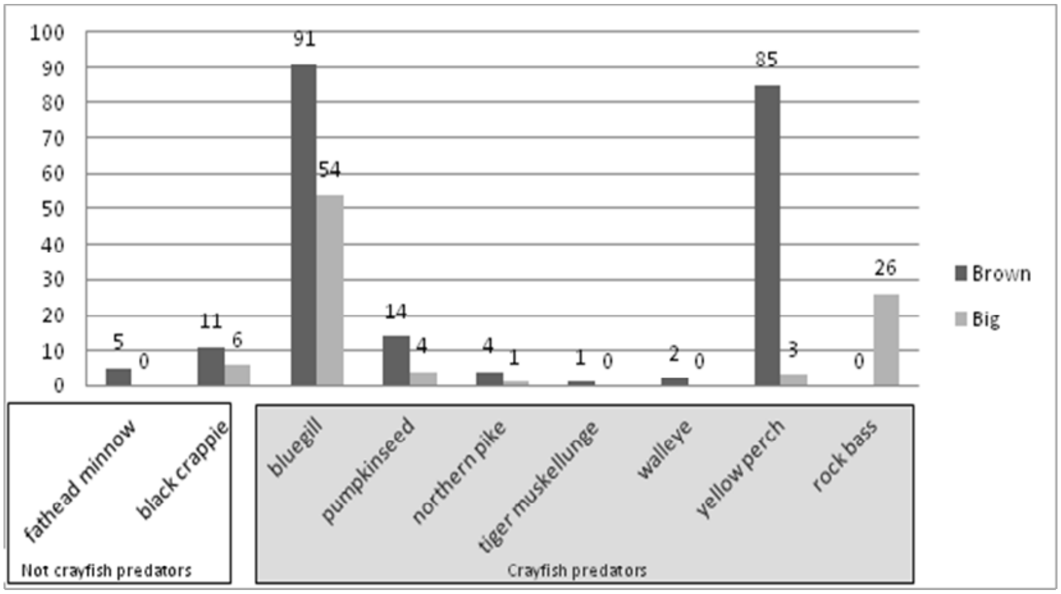

Figure 2: Total number of fish caught on Brown and Big Lakes. Shown here are the combined total data for fyke and seine net fish catches on each lake, separated by species. Not shown are the 238 golden shiners captured on Brown Lake, with 0 captured on Big Lake. Golden shiners, fathead minnows, and black crappies do not prey on crayfish. All other species represented will eat crayfish.