The Effect of Distance, Substrate, Conductivity, and Flow on Crayfish Abundance and Distribution in Northern Wisconsin Creeks

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Abstract

Crayfish can be considered keystone species in aquatic systems as they influence the food web structure in addition to habitats. As omnivores, they feed on organisms like snails, but they also forage for detritus and benthic algae, often altering macrophyte structure in the process. Mainly using lakes for habitat, they also use streams as corridors for movement between lakes. This study attempts to analyze the factors influencing this movement in streams. I looked at a number of factors including distance from the lake, substrate, conductivity, and flow and their role in determining crayfish presence and abundance. It was determined that it is not distance so much that influences crayfish presence in streams, but rather substrate seems to be most important. As long as there is suitable habitat, it seems that crayfish will be present there. It may be the case that crayfish can actually use suitable habitat in the streams as a permanent home and not just as a channel for movement. Culverts and dams, also seem to be playing an important role, acting as barriers which crayfish cannot move across.

Introduction

In aquatic ecosystems, benthic invertebrates, often play a very important role within the ecosystem. Benthic invertebrates are important to aquatic food web dynamics because they facilitate sediment mixing, nutrient cycling, and energy flow in the ecosystem (Covich et al. 1999). Of these invertebrates, perhaps the most important are the many species of crayfish that can be found in lakes, streams, and other bodies of fresh water. Momot (1995) refers to crayfish as a keystone species in the complex food webs of aquatic systems.

Traditionally, many have assigned crayfish a simple functional role in the diet of many fish species. As omnivores, however, crayfish ingest detritus and benthic algae, which helps energy flow through the system, especially when there is low phytoplankton production. This flow of energy can affect a number of species ranging from fish, other benthic invertebrates, and even the periphytic microcommunity (Momot et al. 1978). A more recent paper, however, suggests that the emphasis placed on crayfish as herbivores or detritivores is not entirely accurate and that they actually demonstrate a preference for animal protein promoting rapid growth (Momot 1995). In this search for animal protein, however, they can consume large amounts of detritus, modifying habitats such as macrophyte beds and algal mats (Momot 1995).

Since crayfish play such a key role in aquatic ecosystems, changes in the abundance or species of crayfish can drastically alter the ecosystem. The rusty crayfish (*Orconectes rusticus*) a species native to the Ohio River and its tributaries, was introduced into Northern Wisconsin in the 1960s and has since become a major invasive species in the region (Puth and Allen 2004). Due to its highly aggressive nature, the rusty crayfish is able to outcompete native species of crayfish for both food and shelter (Capelli 1982). Since its invasion, the rusty crayfish has altered native crayfish species composition, the structure of littoral macrophyte communities, and general food web organization. The rusty crayfish seem to have two methods of dispersal aiding in their invasiveness, the first being human activity creating spatially discontinuous corridors.

The second and more traditional corridor for rusty crayfish movement is along streams between lakes (Puth and Allen 2004).

Understanding crayfish distribution within streams as well as understanding what facilitates or hinders their dispersal may be useful in preventing the invasion of rusty crayfish. Although there has only been one reported rusty crayfish at UNDERC, found on Brown Lake in 2003, studying how the native virile crayfish (*Orconectes virilis*) and the introduced northern crayfish (*Orconectes propinquus*) behave and are distributed in the streams could prove to be very useful information. It has been found that the northern crayfish and the rusty crayfish are very similar and have been hybridizing in some places in Northern Wisconsin and would therefore be expected to behave relatively similarly (Perry et al. 2001).

In particular, this experiment focuses on a number of variables that may affect crayfish distribution and movement upstream and downstream. Through trapping, I determined the relative abundance of crayfish at various points within the streams connecting Tenderfoot, Palmer, Kickapoo, and Brown Lakes on the UNDERC property. I analyzed the effects of distance from the lake, type of substrate, calcium concentration, and flow of water. The spatial and temporal distributions of the two crayfish species were monitored over three weeks of trapping to determine how crayfish use habitats such as pools and riffles, especially around culverts. This was analyzed to determine if certain habitats facilitates or hinders movement. Puth and Allen (2004) have suggested culverts as a possible barrier for crayfish movement and any other potential barriers that are discovered during the experiment may serve as ways to prevent the spread of the rusty crayfish.

Crayfish were also marked in an attempt to recapture them on later trapping efforts to provide insight into their migratory habits including the distance covered during movements. This is important since lakes with long stream connections may inhibit the spread of the rusty crayfish if they cannot travel great distances. Finally, on Tenderfoot Lake, both native virile crayfish as well as northern crayfish have been reported and I looked at the relationship between the two species in both Tenderfoot Creek and Ontonagon Creek that connects to Palmer Lake. The northern crayfish has been found to be dominant to the virile crayfish and if there is significantly more northern crayfish this may be important since the rusty crayfish has been found to be dominant to both of these species (Capelli 1982).

Materials and Methods

This study was conducted in several streams on the UNDERC property connecting several major lakes. This includes Tenderfoot Creek flowing north from Tenderfoot Lake, Ontonagon Creek which connects Tenderfoot Lake to Palmer Lake, Brown Creek which connects Palmer Lake to Brown and Kickapoo Lakes, and the stream that connects Kickapoo Lake to Plum Lake. Each of the lakes that have these stream connections were also trapped once during the summer to determine relative abundance within the lakes. In the streams, traps were set every 100 meters and were baited with 120g ± 10g of raw beef liver, which has been shown to accurately represent crayfish species composition and abundance (Capelli and Magnuson 1983). Traps were set for 24 hours and then removed for analysis. Upon removal, a kick-sample was also performed to also try to determine relative abundance, another successful method (Light 2003). Crayfish collected were measured for carapace length and were also identified to species. Each crayfish trapped was also marked with a visible implant elastomer (VIE) used for tracking and recapture.

Substrate in each trapping area was classified with regard to shelter potential in a manner similar to Capelli and Magnuson (1983). A ranking of 1 signifies probably unsuitable substrate, consisting of mostly silt or muck, 2 corresponds to poor mostly sand-gravel (<15mm particle size), 3 with sand-gravel mixed with cobble-pebble areas (16-250mm particle size). A ranking of 4 is the most suitable substrate with mostly cobble-pebble substrate (>250mm particle size).

Stream flow was determined using a stopwatch and a ping-pong ball and was measured in meters per second. Stream flow was measured on each trapping date as well to see if the flow changed as the summer progressed. Conductivity measurements were taken at each trapping location using a hydrolab since conductivity as a relative measure of ion concentration is a surrogate for calcium.

To analyze the data I performed analysis of variance (ANOVA) tests to determine whether the four creeks were different in terms of substrate, conductivity, and flow. I also used equality of two proportions tests to determine whether the proportion of captures in one substrate was significantly different than captures in other substrates. Finally, for distance and conductivity, I used logistic regression modeling to analyze the relationship between these factors and crayfish presence.

Results

During the three weeks of trapping, 157 crayfish were caught and marked in the 261 traps that were set throughout the four creeks. The largest percent of these crayfish came from Brown Creek with almost 60%, while Tenderfoot and Ontonagon each had about 20% for the three weeks. The small creek that connects Kickapoo and Plum Lakes accounted for less than 2% of crayfish trapped. On a temporal scale there is a significant difference in crayfish abundance between the three weeks of trapping. On Tenderfoot, there were significantly less crayfish trapped during the second and third week in comparison to the first week ($p=0.0003$ and $p<0.001$ respectively). On the Ontonagon, the same significant decline occurred between the first week and both the second and third weeks ($p=0.0004$ and $p=0.0001$ respectively). On Brown Creek, however, there were significantly less crayfish during the second week in comparison to the first week ($p=0.0056$), and significantly more crayfish trapped in the third week than the first week ($p=0.035$).

On a spatial scale, scatterplots of the data show that abundance is increasing as distance from lake increases for Brown Creek and Tenderfoot Creek, though the abundance of crayfish is fairly evenly distributed for the Ontonagon, while Plum Creek only had two traps total that had crayfish (Fig. 1). Since the trap catches were so low, rather than looking at abundances, I also analyzed the data simply by whether crayfish were presence or absent with regards to distance. Coding the data so that an empty trap was given a value of 0, while traps with crayfish were valued at 1, a logistic model fit the data fairly well (Fig. 2). This model was significant for both Brown Creek ($p=0.0003$)

and Tenderfoot Creek (p=0.00056), and both models predicted increased presence of crayfish as distance from lake increased.

The three other factors that were thought to be potentially important for crayfish abundance and dispersal in streams were conductivity, substrate, and flow. After running an analysis of variance (ANOVA) for the creeks and doing a Tukey's Post-hoc analysis, it was found that conductivity was significantly lower for Ontonagon in comparison to Tenderfoot (p<0.001) and it is also lower in comparison to Brown Creek (p<0.001). Tenderfoot and Brown, however, have similar conductivities. A similar coding process was used to show presence or absence of crayfish and then a logistic model regression was fit to the data (Fig. 3). This model was significant for Tenderfoot Creek (p=0.0002) and almost significant for Brown Creek (p=0.0597). Both models had a positive slope indicating that as conductivity increased, crayfish were more likely to be present.

The ANOVA that compared substrate across the four streams said that there was a significant difference, however after a Tukey's Post-hoc analysis, none of the streams were significantly different. The closest was between Brown and Tenderfoot, with the latter having a slightly higher average substrate (p=0.066). Since the streams are not significantly different, I was able to group the data for all of the streams when comparing substrate for the presence or absence of crayfish. Using the equality of two proportions test, it was determined that type 1 substrate had significantly less crayfish present than type 2 (p=0.0022) or type 4 (p<0.001). Furthermore, type 4 substrate had significantly more crayfish than type 2 (p=0.013) and type 3 (p=0.0069) in addition to type 1 as determined above.

Flow was the last factor analyzed, and an ANOVA showed that there was no significant difference in flow between the creeks (p=0.516). Flow was also analyzed using an equality of two proportions test, to see of there was a difference in presence or absence in sites with flow and without flow. The only creek to show a significant difference in presence of crayfish was Tenderfoot, which had significantly more captures at sites with flow than without (p=0.0019).

I also trapped in Tenderfoot, Palmer, Kickapoo, and Brown Lakes in order to determine relative abundances of crayfish in the lakes themselves. Brown and Kickapoo Lakes each had a total of one crayfish, while Palmer Lake had 2 crayfish total both of which were *O. virilis*. These lakes therefore had an average of 0.05 to 0.1 crayfish per trap in comparison to Brown Creek which had 0.843 crayfish per trap over the three weeks, most of which were also *O. virilis.* Tenderfoot Lake had 15 crayfish total, most of which were *O. propinquus*, for an average of 0.75 crayfish per trap. Ontonagon Creek, which is between Palmer and Tenderfoot Lakes had 0.833 crayfish per trap. Finally on Tenderfoot Creek, there was an average of 0.314 crayfish per trap for the three weeks.

During this study, I was marking all crayfish using a visible implant elastomer in order to determine recaptures. Of all the crayfish marked, however, there was only one instance of a recapture. This occurred in Brown Creek and the individual was a large male of the species *Cambarus diogenes*, commonly known as the devil crayfish.

Discussion

Based on the data, I must reject the hypothesis that distance from the nearest lake is an important factor in determining crayfish distribution in streams. I expected that there would be an inverse relationship between distance and abundance or presence of crayfish, however, for Tenderfoot Creek and Brown Creek I observed the opposite relationship. According to this data, a greater distance from the nearest lake actually would yield more crayfish or would have a greater chance of having crayfish present. This conclusion does not make sense, unless put into context with the interaction of other variables. I think that substrate and barriers such as culverts may play a role of greater importance than distance. I believe that in a stream with consistently good to average substrate, without culverts or dams, one would observe the true effects of distance upon crayfish dispersal in streams. Unfortunately, the one stream that had this potential was Ontonagon, however, it was much too short in length, since crayfish were distributed evenly throughout its length, independent of distance.

The factors that seem to be more important based on the data, are conductivity and substrate. Conductivity showed a fairly strong positive relationship with the presence of crayfish. Though there are other ions in the water, I was originally using conductivity as a relative measure of calcium in the water. Since crayfish are dependent on calcium for the maintenance of their carapace, it would make sense that a higher concentration of calcium would be more likely to have crayfish present. I did not, however, find a conductivity at which crayfish abundance or presence dropped to zero and in Plum Creek between Kickapoo and Plum Lakes there were crayfish present when conductivity was below 70μS. In the future, it would be interesting to see how much of the variation in conductivity was caused by calcium and how much was from other ions.

Furthermore, it would be interesting to see what the effects of other ions are upon crayfish development and dispersal.

It seems that the most important factor that I studied contributing to crayfish dispersal in streams is substrate and habitat quality, which is an important finding in other studies (Capelli and Magnuson 1983). In the highest quality substrate, I found crayfish in those traps every single time, and this was significantly higher than any of the other substrates. It shows that crayfish are much more likely to be found in a stream when there are large boulders and rocks present. On the other end of the spectrum, substrates that are less hospitable such as silt and muck still may contain crayfish, but are much less likely than if the substrate were cobble or boulders.

I believe then that it is mainly substrate therefore, that can explain the lack of an inverse relationship between distance and crayfish presence. On Tenderfoot Creek, for example, there is a stretch that has a very rocky streambed, providing great habitat for crayfish. This stretch happens to be about 3000m from Tenderfoot Lake. The crayfish then, are using this stretch of habitat as a more permanent dwelling than perhaps the rest of the stream, which may only be used as a corridor for movement between the lake and this stretch of stream. A similar thing may be happening in Brown Creek though on a less drastic scale. Though it does not have the best cobble substrate, Brown Creek does have a stretch of gravel with many fallen trees and logs in the water 1600 to 1800m from the nearest lake, which consistently had crayfish during all three weeks.

The last thing I analyzed was the effect of flow on presence of crayfish, which did not turn out to be significant except in Tenderfoot Creek. There was no difference in the presence of crayfish at sites that had a flow in comparison to those sites that were stagnant without a flow. The vast majority of sites were without flow and this could be due to several reasons, the primary being the lack of a gradient in northern Wisconsin. Also, this summer was very dry and water levels in the streams dropped drastically so that the macrophytes could be slowing any potential movement of water. Finally, all of the creeks had at least one beaver dam on it and in the case of Brown Creek, there were several beaver dams creating pools of water without flow. It could be that flow does have an impact on crayfish presence and distribution perhaps in the more mountainous western United States, however, I did not find this to be the case in this study.

Beaver dams and culverts, which were often dammed at the study site, may have other impacts in addition to affecting flow. They may act as physical barriers to crayfish movement. For example there is a culvert on Brown Creek right before it flows into Palmer Lake and on this stretch of Brown Creek, there were hardly any crayfish found until almost 1000m from Palmer. The crayfish found 1000m from Palmer may in fact have traveled downstream from either Kickapoo or Brown Lake. Perhaps the culvert is acting as a barrier as Puth and Allen (2004) suggest, which crayfish cannot move upstream against. The substrate around this culvert is relatively good in comparison with the rest of the creek and yet there are still no crayfish present. Culverts seem to have an effect on downstream movement as well. On Tenderfoot Creek, 500m from the lake, there is a culvert and crayfish have been found on the upstream side, but not on the downstream side for several hundred meters.

It is interesting that in all the cases except Tenderfoot Creek, the number of crayfish per trap is greater on the creeks than on the actual lakes. These lakes, are not the best suited for crayfish in terms of habitat, yet it would seem that the streams are not any better. The original hope was that I would be able to monitor crayfish movement by marking and recapturing several throughout the summer. This was not possible though since I was only able to recapture a single crayfish. More studies could be done however, with extensive trapping every day that could focus strictly on recapture and movement in an attempt to determine whether streams act strictly as corridors for crayfish movement between two lakes or two other suitable permanent habitats, or whether streams themselves can be permanent habitats. Future studies could also focus on the temporal movement of crayfish, whether it is seasonal or just happens randomly.

In conclusion, this study has shown what factors are important for crayfish to be present in streams. The spread of rusty crayfish through streams then will be facilitated mainly by the type of substrate in the stream available for habitat use and hindered by things like culverts and dams. From our data, if rusty crayfish were to be found in Brown Lake, like in 2003, it seems that they will be able to disperse readily throughout Brown Creek. The other concern, from a management perspective, is the fact that Palmer Lake is open to the public. If rusty crayfish were brought in by anglers, it could easily spread down the Ontonagon into Tenderfoot Lake.

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