INTERACTIONS BETWEEN EXOTIC AND NATIVE CRAYFISH: FORAGING EFFECTS ON NATIVE BIVALVES

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Abstract. The rusty crayfish, *Orconectes rusticus*, displaces native crayfish and reshapes communities of macroinvertebrates in ecosystems where it has been introduced. I investigated aggressive interactions and competition for shelter between *O. rusticus* and a native crayfish species, *O. limosus*, under laboratory conditions. *O. rusticus* dominated *O. limosus* in aggression trials but dominance did not affect which crayfish obtained shelter. Feeding trials revealed that both species of crayfish consumed freshwater mussels (Unionidea) and fingernail clams (Sphaeriidae), preferring prey of smaller sizes. These findings suggest that previous and future introductions of *O. rusticus* into the Hudson River Valley may affect native crayfish and bivalves. Further study should use larger samples to focus on the potential effects of this exotic species on native communities.

INTRODUCTION

The introduction of an exotic species to an area may have a large effect on the ecosystem. According to the "tens rule," one in ten imported organisms will appear in the wild and then one out of ten of those will become established as an exotic population (Williamson and Fitter 1996). In the fresh waters of the Hudson River Basin alone over 113 exotic species of vertebrates, large invertebrates, and vascular plants have been found as established populations (Mills et al. 1996). The rate of species invasions and introductions has increased dramatically due to human activities (Hill and Lodge 1994, Ruesink et al. 1995). One species introduced into the Hudson River and other areas of the United States is the rusty crayfish *Orconectes rusticus*.

O. rusticus is native to Midwestern North America, from southern Ontario and Michigan to Kentucky and Tennessee (Jezerinac et al. 1995). This species has been introduced into other parts of the Midwest and New England (Jezerinac et al. 1995, Mills et al. 1997). Because of its ability to thrive in disturbed freshwater habitats, introduced *O. rusticus* populations have been successful in many areas (Hobbs et al. 1989). Its use as fishing bait is thought to account for many of its introductions (Hobbs et al. 1989, Taylor and Redmer 1996).

O. rusticus has had large effects on benthic communities by displacing native crayfish and reducing macrophyte populations (Lodge et al.1994, Charlebois and Lamberti 1996). In Wisconsin lakes and streams *O. rusticus* is displacing its native congeners, *O. virilis* and *O. propinquus* (Capelli and Munjal 1982, Lodge et al. 1986). In laboratory experiments *O. rusticus* has been found to be more aggressive than these two species (Capelli and Munjal 1982). This, along with its ability to grow more quickly than other species (Hill et al. 1993), its ability to live in high densities (up to $21/m^2$), (Jezerinac et al. 1995) and its ability to interfere reproductively with its congeners (Lodge et al. 2000) may contribute to *O. rusticus'* success. These advantages may help *O. rusticus* succeed in competitive interactions, reproduce, and avoid size-selective fish predation (Hill et al. 1993). The introduction of *O. rusticus* not only has direct effects on other crayfish species but also indirect effects on the habitats that they invade. *O. rusticus* has decreased densities of macrophytes and macroinvertebrates (Lodge et al. 1994, Stelzer and Lamberti 1999) and increased primary productivity of periphyton (Charlebois and Lamberti 1996).

O. limosus is native to the Hudson River Valley and its range stretches from Maine to Virginia (Aiken 1965, Smith 1981, Jerzerinac et al. 1995). *O. limosus* is threatened in West Virginia due to the presence of *O. virilis*, which has the ability to displace the native *O. limosus* (Jezerinac et al 1995). The introduction of *O. rusticus* in the Hudson River Valley could possibly have the same negative effect on this species.

Many species of unionid mussels and fingernail clams are also native to the Hudson River Valley. Unionid mussels have been hit hard by both introductions of other species and other human activity (Bogan 1993). For example, introductions of the zebra mussel, *Dreissena polymorpha*, are reducing native unionid populations in the Hudson River Valley and many other areas of the United States (Bogan 1993, Williams et al. 1993, Mills et al. 1997, Strayer 1999). Unionids' greatest shell growth often occurs in the first four years of life (Thorp and Covich 1991). The quicker the mussel grows, the sooner it can escape threats such as predation and crushing. Thus unionids have a high adult survivorship and long lifespan but low juvenile survivorship. Fingernail clams on the other hand have a short lifespan. The species *Sphaerium striatinum* has an average lifespan of approximately one year and adults grow to be only slightly larger than 10mm in length (Hornbach and Wissing 1982). Compared to other freshwater bivalves they have a low rate of reproduction. *S. striatinum* were found to only have an annual selection rate of 10.49:1 while unionids have been found to > 500,000:1 (Hornbach and Wissing 1982).

Crayfish eat zebra mussels (Piesik 1974, Martin and Corkum 1994, Perry et al. 1997, Stewart et al. 1998) but no one has studied the consumption of unionid mussels and fingernail clams by crayfish. Both *O. rusticus* and *O. limosus* consume zebra mussels in both lab and field trials (Piesik 1974, Perry et al. 1997). *O. rusticus* was able to eat mussels 17 mm and smaller (Perry et al. 1997) and *O. limosus* was able to eat mussels smaller then 12 mm (Piesik 1974). This certainly suggests that crayfish would also have the ability to eat small unionid mussels. Therefore changes in the crayfish populations due to the introduction of *O. rusticus* may not only affect other crayfish species but also native bivalve populations.

It is important to understand the interactions between *O. rusticus* and *O. limosus* to predict the fate of the native species, *O. limosus*, due to this recent introduction of the rusty crayfish into the Hudson River Valley. The displacement of the native crayfish could affect not only these crayfish populations but also the benthic communities in which they live. If both or either crayfish species consumes these native bivalves, the introduction of the rusty crayfish into the Hudson River Valley could reshape both native crayfish and bivalve populations. The purpose of this study was to look at what effect the introduced species, *O. rusticus*, has on native crayfish species and what effects both the introduced and native crayfish species have on native bivalves.

MATERIALS AND METHODS

Subjects: Specimens were collected in the months of July and August 2000. *O. rusticus* was collected from the Webatuck Creek, Dutchess County, New York. *O. limosus* was collected from the East Branch of the Wappinger Creek in Dutchess County, New York, and the Neversink River in Orange County. Crayfish were collected by seining and snorkeling. Upon collection the crayfish were sexed and their carapace length (from the anterior tip of the rostrum to the posterior edge of the carapace) was measured. Animals were housed in 37.85-liter aquariums, with clay pots for shelter, and fed tuna, fish food, and potatoes until used for experiments. Mussels, *Elliptio complanata*, were collected from the Neversink River. Fingernail clams, *Sphaerium striatinum*, were collected from the Neversink River and the Wappinger Creek. Mussels and fingernail clams were housed in separate 37.85-liter aquariums.

Experiment 1: Aggression Trials

The purpose of this experiment was to determine which species was aggressively dominant over the other in physical contests. Trials took place in early August. Three different types of trials were used to determine the effect of size and species on dominance: 1) *O. rusticus* was larger in carapace length than *O. limosus* by 4-7 mm, 2) *O. limosus* was larger in carapace length than *O. rusticus* by 4-7 mm, and 3) *O. rusticus* and *O. limosus* were equal in carapace length, within 1 mm of each other. Five replicates for each of these three types of trials were performed using one crayfish of each species. Trials took place in a 37.85-liter aquarium in which the corners were rounded using clear flexible plastic to ensure that crayfish could not be backed into corners. Four types of aggressive encounters were recorded, Avoidance, Threat, Strike, and Fight, following the definitions of Vorburger and Ribi (1999). Trials took place for one hour or until at least five aggressive encounters were observed. Crayfish were not used for more than one trial.

Experiment 2: Shelter Trials

Shelter trials were performed to see if dominance affected whether a subordinate crayfish could be excluded from obtaining shelter. Dominance was determined from the results of the aggression trials. Immediately after the aggression trials, a small clay pot was placed in the middle of the aquarium along the back wall. Approximately 20-24 hours later, the species of crayfish found within the clay pot was recorded and then recorded every hour for the next nine hours (Vorburger and Ribi 1999).

Experiment 3A and 3B: Feeding trials

The purpose of this experiment was to determine whether *O.limosus* and O. *rusticus* would eat unionid mussels and fingernail clams. Feeding trials took place throughout July. Crayfish used for the feeding experiment were not used in the aggression and shelter experiments. Crayfish were deprived of food for at least 24 hours before the trials began.

Experiment 3A: Mussels

Juvenile mussels were divided into three size ranges according to shell length: small (3-8.5 mm), medium (13.5-22.0 mm), and large (18.5-30.0 mm). The size ranges for the mussels were determined by the availability of juvenile mussels that could be found. Finding juvenile mussels was difficult so this limited the ranges that could be used.

Trials took place in 37.85-liter aquaria that were divided in half by a piece of clear plexiglass secured in place with aquarium sealant. Also a piece of black plastic was clipped into place on the plexiglass divider so that the crayfish were unaware of the presence of another crayfish on the other side. One mussel of each size range was placed in one side of the aquarium with a crayfish. Five trials were run with *O. rusticus* and four with *O. limosus*. Mussels and crayfish were randomly assigned to tanks. Mussels were allowed to float down from the middle of the tank so that they were haphazardly spaced. They were placed in the tank approximately one hour before the crayfish were added. Crayfish were added from the center of the tank and were allowed to float down in the same manner. Tanks were inspected many times a day to determine if mussels were eaten and in what order they were eaten. The trials ended when crayfish had not eaten for 48 hours (Perry et al. 1997).

Experiment 3B: Fingernail clams

Fingernail clams were separated into four size groups of 3.0-3.9 mm, 5.0-5.9 mm, 7.0-7.9 mm, and 9.0-9.9 mm. These size ranges were used so that the differences between the ranges could be easily determined visually.

One fingernail clam of each size range was placed in the tanks with one crayfish. The same setup for the tanks was used as for the mussels. Six trials with *O. rusticus* and six trials with *O. limosus* were performed. Tanks were examined many times a day to determine if fingernail clams were eaten and in what order they were eaten. The trials ended when crayfish had not eaten for 48 hours.

RESULTS

Experiment 1: Aggression Trials

O. rusticus was dominant in 12 out of the 15 trials (Fig. 1). *O. rusticus* dominated in all five aggression trials when it had a larger carapace length than *O. limosus*. *O. rusticus* also won all five trials when *O. rusticus* and *O. limosus* had equal carapace lengths. Finally, *O. rusticus* won two out of the five trials when *O. limosus* had a larger carapace; therefore, the only three trials that *O. limosus* won were all trials when *O. limosus* had a larger carapace length than *O. rusticus*. Chi-square analysis revealed a significant correlation between species and dominance ($\chi^2 = 5.4$, p =0.02). Also upon looking at the relationship between size and dominance, thus excluding the five trials were crayfish were equal in size, the larger crayfish won eight out of the ten trials ($\chi^2 = 3.6$, p = 0.06).

Experiment 2: Shelter trials

In 10 out of the 15 trials the dominant crayfish was inside the shelter for a majority of each trial. At no time were both of the crayfish found inside the claypot.
Dominance did not correlate with which crayfish was found inside the shelter (exact binomial probability =0.15).

Experiment 3: Feeding trials
3A: Mussels

Both species of crayfish ate only the smallest mussels (Fig. 2). Of the four *O. limosus* used, two of them did not eat at all. The two mussels that were not eaten by *O. limosus* were both at the higher end of the small size range (8.2 mm and 8.3 mm). After the conclusion of the experiment, the crayfish remained housed with the mussels until they were returned to their collection site. Later observations showed that one of the crayfish ate the small mussel four days later. During those four days the crayfish were fed flake food. Therefore even though the mussel was at the higher range of the small mussels the crayfish still was able to eat it.

3B: Fingernail clams

All six of the *O. rusticus* used in the experiment ate the fingernail clams in the 3.0-3.9 mm size range within the first 24 hours of the trials (Fig. 3). One of the crayfish also ate a clam in the 5.0-5.9 mm size range. None of the other clams were eaten. For *O. limosus*, all six tested ate the 3.0-3.9 mm clams, five out of six of them within the first 24 hours. Also, five out of the six *O. limosus* ate the clams in the 5.0-5.9 mm size range, three of them within the first 24 hours. Finally one of the *O. limosus* that ate both the 3.0-3.9 mm clam and 5.0-5.9 mm clam also ate the 9.0-9.9 mm clam.

DISCUSSION

O. rusticus won 12 out of 15 trials, all 5 when *O. rusticus* was larger and all 5 when *O. rusticus* was equal in length to *O. limosus*. *O. rusticus* also won two trials in which it actually was smaller in size than *O. limosus.* In contrast *O. limosus* never dominated *O. rusticus* in any of the trials in which *O. limosus* was smaller than *O. rusticus*. These results show a possible harmful trend for the native *O. limosus* because one of the characteristics' that is believed to have contributed to much of *O. rusticus'* success is that it is often larger in size then many of its congeners (Garvey and Stein 1993). Surveys of the average carapace length of *O. rusticus* and *O. limosus* would need to be done in the rivers within the Hudson River Valley but if this is the case between the two species then O. *rusticus* poses a definite risk to *O.limosus.*

Results of the shelter trials showed no significant correlation between dominance and a crayfish's success with obtaining shelter inside the clay pot. However, the size of the study may have had an effect on these results. In 67% of the trials the dominant crayfish was found inside the clay pot more often than the subordinate crayfish. Nevertheless, because of the small number of trials (15), this trend was not statistically significant. Other factors may have also had an effect on these results. For instance, the clay pot offered multiple sites for the crayfish to find shelter. Besides just being inside the shelter, crayfish were often found beside or behind the shelter. This allowed both crayfish to be sheltered by the pot at the same time. Also, at many times throughout the study neither crayfish was seeking shelter or even near the shelter. This could possibly be due to the fact that the tanks in which the crayfish were held were fairly undisturbed. There was no threat posed by a predator, the most common reason why a crayfish may seek shelter. In Vorburger and Ribi's (1999) aggression and shelter study of *Austropotamobius torrentium* and *Pacifastacus leniusculus*, after which the aggression trials and shelter trials of my study was modeled, they hypothesized that species preference for different types of shelter may affect which crayfish obtains shelter. Therefore, preference difference and dominance should both be taken into consideration when looking at the interactions for shelter between *O. rusticus* and *O. limosus*.

The feeding experiments showed that both species of crayfish ate both fingernail clams and mussels. The crayfish tended to prefer smaller bivalves. Since very few trials were done, these data were not statistically analyzed. Crayfish have been effective in greatly reducing the numbers of zebra mussels (Martin and Corkum 1994, Perry et al. 1997, Stewart et al. 1998) and have the potential to do the same to native bivalves. Not only does the introduction of *O. rusticus* into the Hudson River Valley have the potential to harm native crayfish species but also to the native bivalve populations. Since *O. rusticus* can live in high densities (Hobbs et al. 1989) the threat of more predators can affect the already threatened unionid populations. Personal observations at the collecting sites were that *O. rusticus* was much easier to collect because they were practically everywhere. *O. limosus* on the other hand took days to collect the number of individuals used and were much scarcer at the sites in which they were collected.

Further studies need to look into feeding preference of these two crayfish species with more then one prey choice. Also, since no substrate was at the bottom of the aquarium for these juvenile mussels and fingernail clams to burrow into, studies should look at whether crayfish are able to find and prey on these bivalves when in a more natural type of habitat. These further studies could determine more closely the actual risk these mussels and fingernail clams face.

The two species of crayfish used in this study were collected from separate sites in which they did not coexist. Hazlett et al. (1992) found that if *O. virilis* and *O. propinquus* were collected from sites in which they coexisted with *O. rusticus*, they tended to lose aggressive encounters with *O. rusticus*. On the other hand, *O. virilis* and *O. propinquus* collected from sites at which *O. rusticus* was not present were not dominated by *O. rusticus*. *O. rusticus* and *O. limosus* were collected from separate sites for this study and *O. rusticus* was still dominant over *O. limosus*. Further studies might look at the difference between interactions of *O. rusticus* with *O. limosus* and other native coexisting species, as well as those that do not.

Another factor that was not controlled for in this study was that chela size could have had a large effect on the winner of the aggressive encounters. Even though a crayfish may have been larger in carapace length, its chelae sometimes may have been smaller. A crayfish can regenerate its chelae; therefore, if it has recently lost them, its chelae may be smaller then a crayfish of similar body size and carapace length that has not lost its chelae. Rutherford (1995) found that body size (thus, carapace length) had no significance in aggression encounters between *O. rusticus* individuals, while those that had larger chelae won significantly more encounters then those with smaller chelae. Garvey and Stein (1993) found that *O. rusticus* in Wisconsin lakes had larger chelae than the native *O. virilis* and believe this contributed to *O. rusticus*' success in displacing the native species. Chelae of the *O. rusticus* used in this study were on the whole larger then those of *O. limosus*. Further study could not only survey the body and chelae size of both *O. rusticus* and *O. limosus* in the Hudson River Valley but also examine the effect of carapace length and chelae size on dominance in aggression trials.

This study was performed under laboratory conditions and therefore cannot account for all of the variables that these organisms encounter in their natural environments. It does provide evidence of the possible risks that native species are facing from the introduction of the rusty crayfish into the Hudson River Valley. Further studies should look at the effects *O. rusticus* has on these species in a more natural setting. Studies should also begin to look at how to solve the problems created by this recent introduction and prevent it from further occurring in other areas.

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APPENDIX

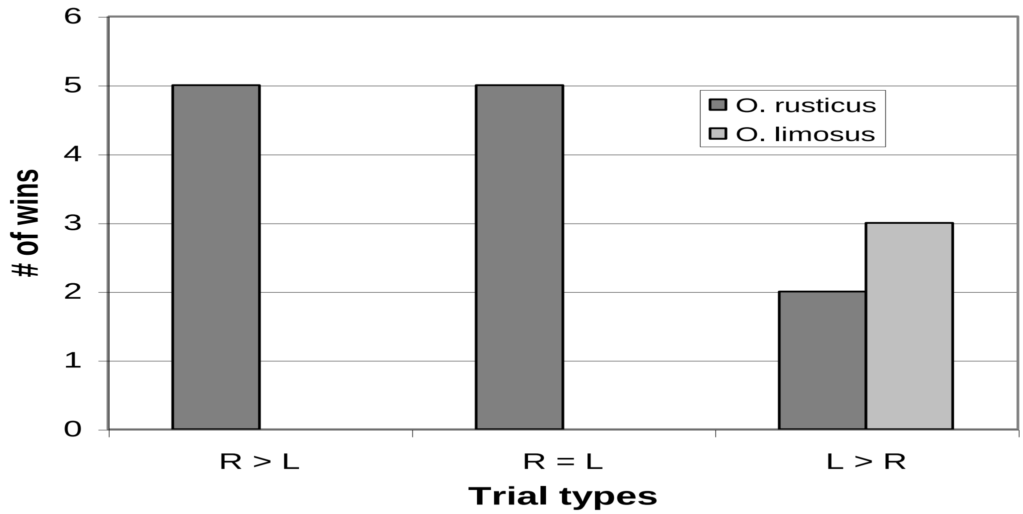

FIGURE 1. The number of wins by each crayfish species in aggression trials. The winner of each aggression trial was considered the dominant crayfish of the two. Trial type R>L (where R represents *O. rusticus* and L represents *O. limosus*) were trials in which *O. rusticus* was larger in carapace length by 4-7 mm, R=L were trials where the two species had a carapace length within 1 mm of being equal to each other, and L>R were trials in which *O. limosus* had a larger carapace length by 4-7 mm than *O. rusticus*. Chi-square analysis showed a positive correlation between species and dominance ($\chi^2 = 5.4$, p =0.02).

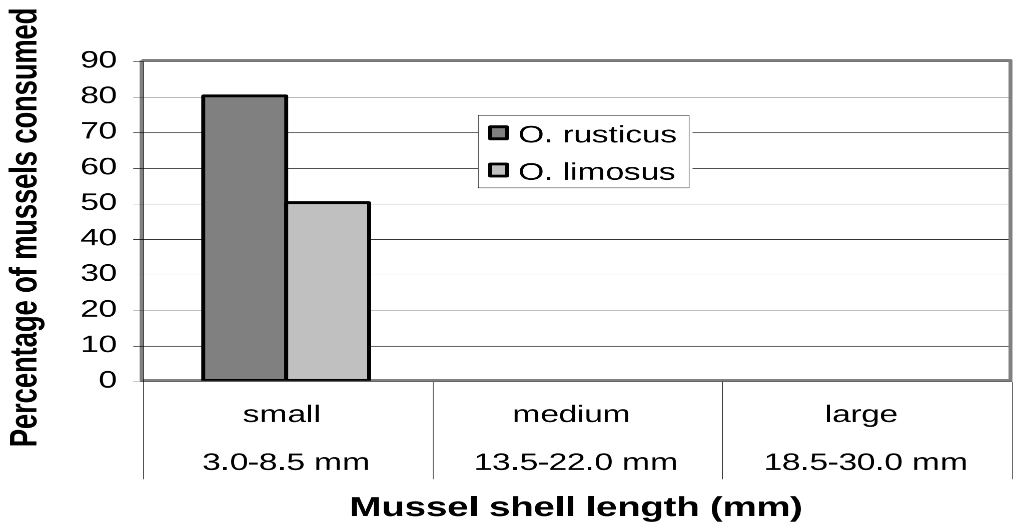

FIGURE 2. Percentage of mussels (*Elliptio complanata*) of different sizes consumed by two species of crayfish in laboratory trials. Medium and large ranges overlap due to low mussel availability.

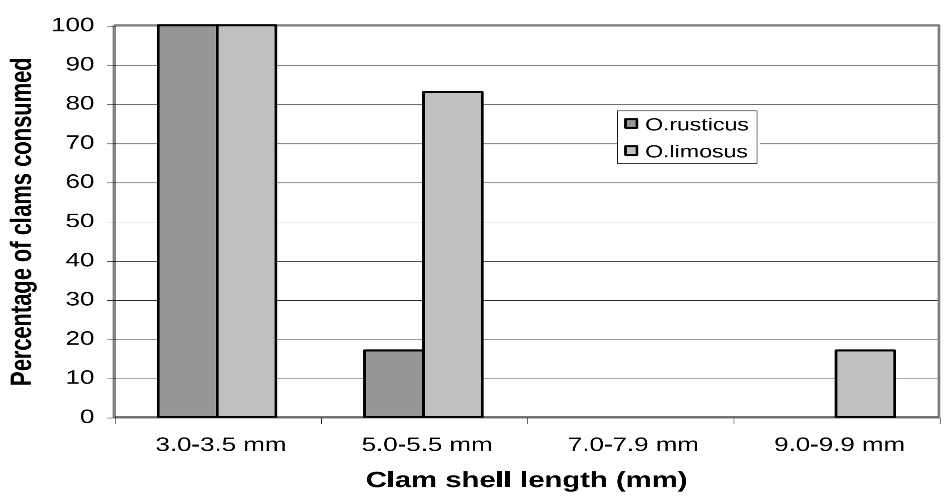

FIGURE 3. Percentage of fingernail clams (*Sphaerium striatinum*) of different sizes consumed by two crayfish species.