PREDATION BEHAVIORS OF INVASIVE AND NATIVE CRAYFISH ON JUVENILE AMERICAN EELS IN THE HUDSON RIVER BASIN

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Abstract. The rusty crayfish, *Orconectes rusticus*, is an invasive species that has had negative impacts on native flora and fauna in the Hudson River basin. Its influence on the American eel (*Anguilla rostrata*) population native to the Hudson was the focus of this study. I examined the predatory relationships of the rusty crayfish and a native crayfish, *Orconectes limosus*, with juvenile American eels. In laboratory experiments, both crayfish species consumed glass eels (young juveniles) at the same rate, and neither crayfish species ever attacked elvers (older juveniles) The results suggest that the rusty crayfish is no more predacious than the native crayfish species, but that crayfish may influence American eel population decline in the Hudson River basin.

INTRODUCTION

American eel populations have been declining over much of their North American range in recent decades, and the Hudson River basin is no exception (Haro et al, 2000). Possible causes include fishing, mortality at turbines for power generating facilities, and barriers for migration (Macgregor et al, 2008). In the Hudson River basin an obvious cause is the dams that have been built in the creeks and streams, as they prevent eels from swimming upstream as they have done in the past (Machut et al, 2007). A system of eel ladders has been built as a proposed means for the eels to swim upstream in dammed areas, which may help offset the decline in eel numbers in the tributaries that has been recorded since the early 1980's (Haro et al, 2000, Nedeau, 2007). However, additional information is needed on other factors that may be contributing to eel decline in the Hudson River basin.

American eels are spawned in the Sargasso Sea and drift into the Hudson River as leptocephalae and glass eels on ocean currents. Eels in Hudson River tributaries range in length from approximately 45 to 100 mm when they are juveniles to over 1.2 m as adults (Etnier and Starnes, 1993). Juveniles include transparent glass eels (45 to 70mm) and the older, nontransparent elvers (65 to over 100mm) (Nedeau, 2007). Adult eels prey upon various crayfish species as well as other crustaceans, small fish, and insects (Wenner and Musick, 1975); however, large crayfish are unlikely prey for juvenile American eels, as the crayfish are considerably larger than glass eels and comparable in size to elvers. However, additional information is needed on other factors that may be contributing to eel decline in the Hudson River basin.

I hypothesized hypothesized that the rusty crayfish (*Orconectes rusticus*) may contribute to the decline in the American eel (*Anguilla rostrata*) population because of the destructive effects of this invasive species in the Hudson River basin. *O. rusticus* is native to the Midwest but has been introduced to much of the Northeast through bait bucket releases since the 1960's or possibly earlier (Kuhlmann and Hazelton, 2007; Kuhlmann et al, 2008). This species is larger and more aggressive than crayfish native to the area, including the spinycheek crayfish (*Orconectes limosus*). In fact, rusty crayfish often attack and displace other less aggressive crayfish species when competing for food or refuge (Klocker and Strayer, 2004). The rusty crayfish is also omnivorous and decreases abundances of invertebrates such as snails, macrophytes, and periphyton (Lodge et al, 1994). The destruction of aquatic vegetation and overall decrease in plant biomass caused by the rusty crayfish also indirectly affects species native to the ecosystem (Flinders and Magoulick, 2007). This may have an impact on American eel populations in streams where *O. rusticus* has invaded because eels are benthic and often hide in the aquatic vegetation at the bottom of a stream. Destruction of these plants could expose eels to attack by predatory fish and birds.

This study focused specifically on predator-prey relationships between juvenile American eels and adults of the two crayfish species. I compared the predatory relationships of juvenile eels and the nonnative rusty crayfish to those of juvenile eels and the native spinycheek crayfish. Interactions of each crayfish species with glass eels and with elvers were studied independently to determine if predation rates on the eels differed by eel size among juveniles.

MATERIALS AND METHODS

All crayfish and elvers were collected from June to July 2009. Glass eels were collected from April to May of 2009 through the New York State Department of Environmental Conservation's Eel Study Program. Rusty crayfish were collected from Webatuck Creek, spinycheek crayfish were collected from the East Branch of Wappinger Creek, and American eels were collected from the Fall Kill and Sawkill using electroshocking, hand netting, and fyke netting. Spinycheek crayfish ranged in length from 54-65 mm measured from the tip of the rostrum to the end of the tail, rusty crayfish ranged from 51-66 mm, glass eels ranged in length from 51-69 mm, and elvers ranged from 108-139 mm. Only crayfish with both chelae intact were used in experimental trials. The animals were kept in half-filled 38-L aquaria. An airstone was used to oxygenate the water, and 50% of the water in each tank was changed every day to maintain low ammonia levels. The crayfish were fed sinking shrimp pellets daily, the glass eels were fed bloodworms every other day, and the elvers were fed mosquito larvae every other day. Similar to the artificial burrows used in studies by Nakata and Goshima (2003), half sections of PVC pipe were used as artificial shelter. Three different diameters (2.54 cm, 3.81 cm, and 5.08 cm) of PVC (polyvinyl chloride) pipe were cut into 15.24-cm segments and split lengthwise to provide three shelter options in each tank. The lights were put on a 12-hour timer so the room was lit from 7:30am to 7:30pm every day.

During each predation trial, one eel and one crayfish were kept together in a tank. The aquaria were observed daily to check for interactions between the two species, and the number of days the eels survived was recorded. The trials were run for 7 days, although in the glass eel trials, none of the eels survived the fully allotted time. Fourteen replicates were run using glass eels, seven with spinycheek crayfish and seven with rusty crayfish. Ten replicates were run using elvers, five with each species of crayfish.
Student's t-tests were used to determine if a significant difference in predation rate exists for native and invasive crayfish on juvenile eels. A Student t-test was also used to compare glass eel and elver survival rates to determine if crayfish predation differs for the two juvenile stages.

RESULTS

All of the predation trials run with glass eels and the two crayfish species resulted in death of the glass eels and, in 12 of 14 trials, consumption of the eel (Figure 1).

There was no significant difference in the number of days survived by the glass eels under predation from the rusty and spinycheek crayfish ($t = 1.022$, $P = 0.327$).

The predation experiments run with elvers and each crayfish species did not result in any eel deaths over the 7-day trial (Figure 2).

There was no significant difference in the number of days survived by the elvers under predation from the rusty and spinycheek crayfish ($t = 0$, $P = 1.0$). In comparing the data for glass eels versus elvers, a significant difference in crayfish predation exists for the two juvenile stages ($t = 32.08$, $P < 0.0005$).

DISCUSSION

When the glass eels were introduced into the tanks with the rusty crayfish, 71% were killed and eaten within 24 hours, and all were dead within 96 hours of introduction. The average time survived by the eels under predation from the rusty crayfish was 38 hours. In three of the tanks, the remains of the eels' spinal column were found, providing evidence that the crayfish were preying upon the eels. Because of a limited availability of glass eels, the predation trials with glass eels were stopped after fourteen trials, as it was evident that the rusty and spinycheek crayfish readily preyed upon the juveniles in the glass eel stage.

In the spinycheek crayfish trials, 86% of the glass eels were killed within 24 hours, and the average survival time was 27 hours. Although the eels in all of the spinycheek trials died, not all of the eels were eaten by the native crayfish. In one tank, the tail half of the eel was found intact. In another tank, the entire eel remains were found intact with no signs of damage to the body to indicate that the crayfish had attacked it.

Glass eels may better avoid predation by the crayfish in the natural environment than in the laboratory because rocks on the streambed offer hiding areas. A stream bottom could not be mimicked in the tanks because it would be too difficult to locate the eels to assess signs of damage, but this change to a more complicated habitat may increase glass eel survival in the laboratory. Another important consideration is the possibility that eel behavior changes in the aquarium setting from the way they act in the natural environment. The glass eels, for example, seemed more inquisitive than the elvers; they swam near the crayfish and spent more time in the water column, while the elvers tended to avoid confronting the crayfish and generally remained in the PVC shelters.

Eels did not appear to eat as frequently in the presence of crayfish as they did in the holding tank that had no crayfish. Although the eels were fed the same food with the same frequency in the different tanks, many of the glass eels did not eat the bloodworms when in the experimental tanks. A possible reason for this could be that the crayfish outcompete the eels for the food or because the eels are hiding to avoid consumption by the crayfish. This could explain the cause of death of the undamaged glass eel in the spinycheek trial, and contribute to glass eel vulnerability in all predation trials.

The elvers seemed to prefer the smallest (1-inch diameter) PVC shelters, while the crayfish seemed to prefer the 1.5-inch diameter PVC shelters. This would indicate that when several shelter options are available, the elvers and the crayfish will not compete for shelter. This conclusion is supported by the results, as none of the elvers were killed by crayfish during the experimental trials. These results suggest that population restoration efforts in the Hudson River basin might focus on restoring older juveniles to the tributaries, as American eels were susceptible to predation by crayfish in the glass eel stage, but not as elvers.

Although the results indicate that there is no significant difference in the predation rates of rusty and spinycheek crayfish on juvenile American eels, the frequency with which the two species interact with eels may be different. The rusty crayfish can reach high population densities (Lodge and Lorman, 1987, Lorman 1980), which would make predatory interactions with eels more frequent. If rusty crayfish populations in the Hudson River tributaries reach these high densities, they may exacerbate American eel population decline.

The inhibitory effect of invasive species on native flora and fauna is not a phenomenon limited to this case of the rusty crayfish and the American eel. Invasive species have such widespread effects in the ecosystems in which they are introduced because they commonly have high reproductive rates, lack natural predators, may be destructive to native habitat, and are often more aggressive than native species. These factors, combined with the native species' lack of natural defense or immunity to invasive predators, allow the invasive species to outcompete preexisting species in the ecosystem (Lockwood et al, 2007). The result is that biodiversity is threatened and there is a potential loss of native species.

Alien species are commonly introduced in large rivers like the Hudson because of the high levels of input from various aquatic ecosystems (Strayer et al, 2005). Many restoration efforts in large rivers are designed to eradicate these alien species, but such plans are often expensive and can have negative consequences on other facets of the ecosystem (Davis, 2009). In programs that do not directly aim to control alien populations, these species may still have an impact on restoration. The negative effects of invasive species often include competition, predation, and physical impacts, all of which have effects on the entire ecosystem (Lockwood et al, 2007). This makes it difficult to design a restoration plan because the effect the plan may have on this altered ecosystem is unpredictable. Alien species may also limit the restoration options that are available because some plans may make conditions more favorable for alien species or may even introduce new alien species (Strayer et al, 2005). In the case of the American eel, more effective restoration efforts may be designed after considering and accepting the continued impact of crayfish predation on glass eels. Rather than restoring glass eels upstream of the dams, it may be more constructive to focus restoration efforts on elvers, as eels in this stage may have a better chance at survival.

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APPENDIX

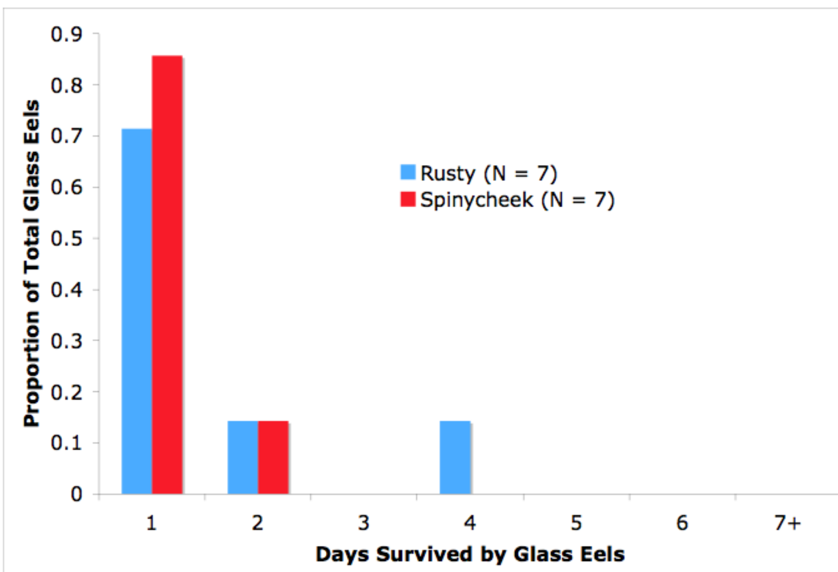

FIGURE 1. Number of days survived by glass eels under predation by rusty and spinycheek crayfish.

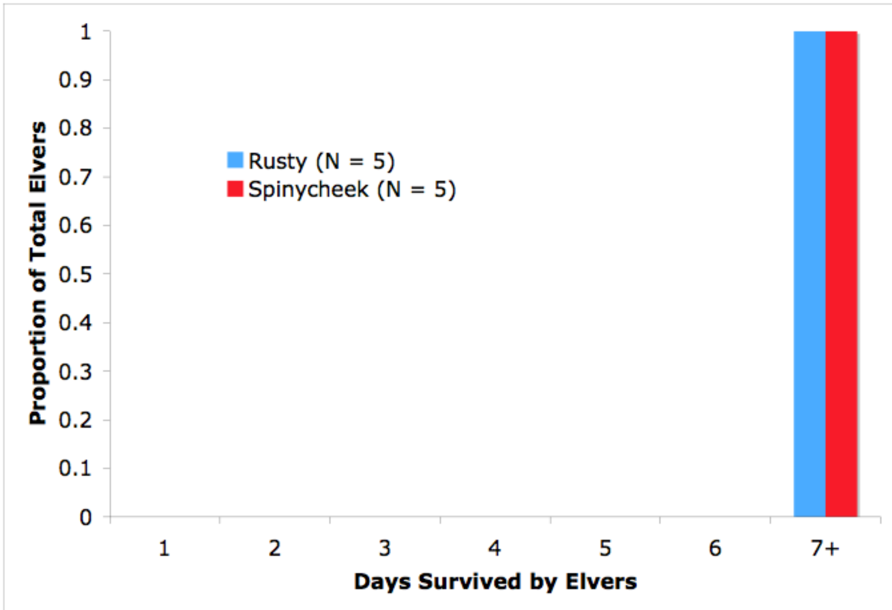

FIGURE 2. Number of days survived by elvers sharing aquaria with either spinycheek or rusty crayfish.