Ecological Impact of Introduced Crayfish on Benthic Fish in Strawberry Creek

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Abstract The introduction of the non-native crayfish *Pacifastacus leniusculus* in Strawberry Creek may be expected to have negative impacts on the stream ecosystem. Recent studies have shown that the declining fish population in Strawberry Creek may be due to the presence and establishment of a large crayfish population. The purpose of this experiment is to investigate the interactions between the crayfish and the prickly sculpin (*Cottus asper*), a native benthic fish in Strawberry Creek. The hypothesis that crayfish prey on benthic fish was tested using eight isolation cages placed within the creek: four served as controls and four were experimental. A separate laboratory experiment was also conducted to facilitate direct observations of the interactions using a twelve-gallon aquarium separated by a wire mesh screen. One side served as the control, and the other side was the experimental. Two fish were placed in every cage and the experimental cages each harbored two crayfish in addition to the sculpins. After ten days the remaining fish and crayfish were counted. All of the fish within the control cages survived while only two survivors were found in the experimental cages. Two of the experimental cages only had one survivor each, while the rest of the experimental cages resulted in zero fish. The results of the experiment showed that fish mortalities were significantly higher when crayfish were present. The loss of fish could be partly due to predation, which was directly observed in the laboratory observation tank. The crayfish aggressively attacked the fish, yet did not actively pursue them. The results of this experiment may show the potential for crayfish to reduce fish abundance if not local extinctions in Strawberry Creek.

Introduction

The introduction of non-native species to an area can result in a wide range of ecological changes (Schoener 1993), the most dramatic of which is the replacement of native species by invaders. In addition, introduced species can cause habitat shifts after competitive interactions and can affect the trophic structure of their communities (Schoener 1993). In streams, species interactions such as predation, herbivory, and interference competition are direct interactions that influence the community ecosystem (Allan 1995). The structure of these communities are directly affected by shifting species abundance and species composition. Direct effects of one species on another in ecological communities may determine the number and kinds of species that can successfully coexist (Schoener 1993). These chains of direct interactions in food webs can lead to important consequences for stream communities (Power 1992).

The crayfish offers an example of an important component of the interactions between trophic levels in aquatic ecosystems. Crayfish are abundant omnivores in many aquatic habitats and may be expected to have important direct effects on benthic communities (Momot 1984). Studies examining natural crayfish populations have indicated that crayfish are abundant consumers in many ecosystems and consume invertebrates, filamentous green algae, and detritus (Creed 1994). It is also documented that crayfish can be expected to prey significantly on the eggs of fish, reduce macroinvertebrate abundance, eliminate native crayfish and often exert a considerable influence on their surrounding habitats (Holdich 1988). Researchers believe that crayfish act as a keystone predator and interact at all levels in the trophic structure and are high enough in it to influence the nature and extent of interactions among a whole network of species (Momot 1978). Because of their ability to modify aquatic macrophyte and macroinvertebrate communities, the introduction of crayfish could have a major effect on the structure and composition of the littoral zone, which in turn, could possibly affect the fish community (Chambers 1990). Hobs *et al.* (1989) concluded that "once an exotic crayfish is introduced into a lake or stream, it may impose considerable environmental stress on the system, and in all too many instances, irreparable shifts in species diversity occur."

Given the important role of crayfish in aquatic ecosystems, it is not surprising that this large bodied species has had a number of effects on local systems. Because of these effects, the introduction of the non-native crayfish *Pacifastacus leniusculus*, might be expected to have negative impacts in stream ecosystems such as Strawberry Creek. Although the origins of crayfish establishment in this body of water is unknown, their presence may have affected the creek ecosystem. According to a recent study, the declining fish population in Strawberry Creek can possibly be attributed to the presence and establishment of a large crayfish population (Gold 1998). The purpose of this experiment is to further investigate the aspects of the competing behavior of crayfish and their ecological interactions, especially the impact of the introduced species on the native fish community in Strawberry Creek.

One study, based on one population in the River Great Ouse, England, determined that crayfish may affect the abundance of benthic or bottom feeding fish through predation (Guan *et al*. 1997). Because there have been no prior studies concerning crayfish ecology in Strawberry Creek, this experiment will be a preliminary study to investigate predation by the introduced crayfish on the native, benthic fish, prickly sculpin (*Cottus asper*).

Study Organisms *Pacifastacus leniusculus* is distributed throughout regions of the western United States. It is native to Washington, Oregon, and Idaho and was introduced to parts of Colorado, Nevada, and California (Fuerst 1978).

The distribution of prickly sculpin (*Cottus asper*) lies on the western coast of the United States extending from the Pacific slope drainages in Washington down to Ventura River in California (Page 1991). These benthic fish thrive in a variety of habitats ranging from freshwater, brackish, and marine environments. They feed primarily on aquatic insect larvae and bottom invertebrates and share similar habitat requirements as the crayfish (Page 1991).

Study Area The upper Strawberry Creek watershed located east of Oxford Street in Berkeley, CA is composed of two major branches: the North and South Forks. According to the Strawberry Creek Management Plan, the total watershed area is 1.82 mi^2. Storm water routing as well as stream culverting and channel confinement have significantly altered the natural drainage courses of both forks. The South Fork is a fourth order stream, whereas the North Fork is a third order tributary. The North Fork sub-watershed comprises 0.6 mi^2. It is bounded by Little Grizzly Peak on the east, Rose Street on the north, and the South Fork sub-watershed to the south. The South Fork sub-watershed comprises 1.2 mi^2. It is bounded by the Panoramic Sugar Loaf Ridge on the south, Frowning Ridge on the east, and the North Fork sub-watershed to the north. The confluence of the two forks is located in the Eucalyptus Grove at the western edge of the central University of California at Berkeley campus. On the central campus alone, there is approximately 6,270 linear feat of stream course.

Methods

Sampling Crayfish sampling is best done in the warmer months of spring and summer when crayfish activity is highest (Holdich 1988). Sampling techniques for crayfish included the use of dip nets in shallow, still waters along with the use of a ¼ inch mesh seine in areas with faster current. Most of the sampling occurred during the night in the month of March. A total of twenty crayfish were captured and grouped according to size (Table 1).

The sampling of the prickly sculpin was done using low-voltage electroshockers and a ¼ inch mesh seine in San Pablo Creek which lies east of the Berkeley Hills. The fish sampling did not take place within Strawberry Creek due to the low abundance of fish and the restrictions on the use of electroshockers. A total of nineteen fish of similar size were captured.

Predation The predation of the prickly sculpin by the introduced crayfishes was studied using eight isolation cages constructed from ½ cm mesh steel screen. The cages, with approximate dimensions of 40cm x 40cm x 12cm, each contained two randomly selected benthic fish. Four of the cages served as controls containing only fish while each of the four remaining experimental cages contained two randomly selected crayfish in addition to the two sculpin. Two locations were chosen in Strawberry Creek, one in the North Fork near the University House, and the other in the South Fork of Strawberry Creek near Wheeler Hall. Two randomly chosen experimental and control cages were placed in the North Fork location and the remaining control and treatment cages were placed in the South Fork. The experiment lasted for ten days after which the number of remaining fish were counted.

The interactions between the crayfish and the benthic fish was also observed in a separate observational tank equipped with a recirculating, filtered water system. This observation tank was divided in half by a sheet of ½ cm steel mesh screen. One side served as the control, with only fish, and the other side was the experimental containing two sculpin and two crayfish. This supplemental laboratory experiment provided the opportunity for direct observations of the interactions between the crayfish and the prickly sculpin. Finally, the remaining crayfish not used in the experiment was observed in a separate tank for further observations of crayfish behavior.

Results

The crayfish used in this experiment were caught adjacent to the Valley Life Sciences building and averaged seven centimeters in body length. The benthic fish were all of similar size between three to four centimeters in length.

Table 1. Captured Crayfish Grouped By Sex and Size.

Size Intervals	Number of Crayfish	Sex
0-5 cm	2	All Male
5-8 cm	12	4 Female and 8 Male
8-10 cm	6	All Male

Size Intervals and Sex of Crayfish Caught Adjacent to the Valley Life Sciences Building.

The results from the predation study, (Table 2) analyzed using a t-test (JMPIN© Statistical Software), show that the survival rates of the prickly sculpin were significantly lower ($p < 0.05$) when crayfish were present. In each of the control cages containing only sculpin, no fish mortalities occurred during the experimental period of ten days. In the experimental treatments where crayfish were added to the cages, only two fish survived. In each of the experimental cages located in the South Fork, only one prickly sculpin remained.

Table 2. Remaining Fish Between Control and Experimental Cages

Cage Location	Control Cages	Experimental Cages
North Fork	2 Fish	0 Fish
North Fork	2 Fish	0 Fish
South Fork	2 Fish	1 Fish
South Fork	2 Fish	1 Fish

Fish Survivals According to Location After 10 Days

The results from the laboratory experiment using the holding-tank separated in half by wire mesh showed similar results. On the experimental side, where the crayfish were kept in the observational tank with the fish, both sculpin were attacked and eaten. The fish were frequently observed to swim actively along the corners of the tank, occasionally wandering elsewhere. Within an hour, one of the fish was captured and eaten. The second fish was eaten after numerous attempts within six hours. The predatory behavior of the crayfish followed a similar pattern. The crayfish did not actively chase the fish. Instead, when the fish swam within striking distance, the crayfish used its chelae or its large pincers, to grab and hold on to the fish while caging it between its other appendages. As soon as the fish was taken hold of, the second crayfish began to actively fight with the other crayfish for possession of the sculpin. This feeding frenzy was also observed in a separate tank containing ten crayfish which were fed with fish food, pelleted cat-food, and aquatic worms. As soon as the food was placed in the tank, the crayfish immediately began to fight with one another in an aggressive fashion. This separate group of crayfish were later fed two minnows collected in Strawberry Creek and subsequently consumed them.

Discussion

The structure of any biological community is affected by various factors and processes such as competition for food or space, predation, and physical disturbances (Allen 1995). The interactions between these factors have great implications for the structures of community ecosystems. Our study focused on the effects of an introduced crayfish species on benthic fish, and consequently the surrounding ecological community.

The results from the predation study revealed that the survival rates of prickly sculpin were significantly lower in the presence of crayfish. The laboratory experiments provided direct observations of the predatory behavior of the crayfish on the benthic fish, and suggest that the loss of fish in the experimental cages was due at least in part to predation. Other factors such as stress caused by direct exposure to crayfish or transplantation to isolation cages may explain their mortalities. A study replicating the natural conditions as closely as possible would better explain the interactions between crayfish and fish in natural systems. Furthermore, interactions between species may be influenced by the densities of predators and prey. Our experiment was limited to the number of benthic fish captured in San Leandro Creek. Predator-prey interactions are influenced by both functional and numerical responses which describes the feeding behavior of individual predators in response to changes in prey and predator densities (Stein 1977, Brower *et al*. 1997). These factors can all affect the predatory behavior of crayfish on benthic fish and may have affected our results. Therefore, a study which provides accurate predator-prey densities, shelter and alternative food sources would be more definitive by closely mimicking natural conditions.

It is not certain whether the crayfish in the experimental cages were actively killing the fish or if they were only scavenging on dead fish. Nevertheless, the observation of crayfish attacking and eating fish in the observation tank strongly suggests that fish mortality in the experimental cages was mainly due to predation. Furthermore, the separate holding tank containing the ten, unused crayfish fed on two minnows despite supplemental feeding with cat food pellets, fish food, and aquatic worms. Therefore, crayfish may be affecting the abundance of benthic fish through predator-prey interactions in natural systems, although other factors may be involved. In particular, competition for shelter may be important because both the crayfish and benthic fish live in riffles and take shelter in crevices between stones (Flint 1975). In addition, the crayfish may be interfering with fish breeding by consuming fish eggs or altering the habitat through their burrowing behavior (Holdich 1988).

P. leniusculus is one of the most aggressive and opportunistic of the crayfishes (Lorman 1978). Studies have shown that their introduction has affected ecological communities by replacing native crayfish and by altering species diversity, thereby creating considerable environmental stress on the system (Fuerst,1978, Hobs *et al.* 1989). This study and others indicate that introduced crayfish can have detrimental affects on benthic fish populations and on the surrounding habitats. As crayfish populations increase, dramatic reductions in fish populations, changes in the physical environment, and other potentially irreversible ecological shifts can occur.

Acknowledgments

I would like to thank Steve Maranzana for steering me towards this project. Many thanks to Tom Dudley and Jose Setka from EBMUD for their help with the fish sampling, supervision of this experiment, and for access to San Leandro Creek. Matt Orr provided helpful criticism and great advice. Thank you to Arnab Mukherjea and Rachita Sethi for helping me with the crayfish collections.

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