Abiotic Factors Affecting the Distribution of Native and Invasive Crayfish in a Northern Wisconsin Lake

BIOS 569: Practicum in Field Biology

Patrick Wood

Advisor: Jody Murray

2005

Abstract

Crayfish of the genus *Orconectes* provide a good model for the mechanisms and dynamics of invasive species. A characterization of the physical factors effecting the distribution of *Orconectes* species may lead to a better understanding of mechanisms and dynamics of invasive crayfish in the Great Lakes region. In order to characterize crayfish populations according to abiotic factors, Tenderfoot Lake was surveyed for crayfish of the species *O. propinquus* and *O. virilis* according to dissolved oxygen and temperature. These physical characteristics were suspected to vary according to substrate and time. *O. propinquus* was expected to be more prevalent in low temperature, high dissolved oxygen conditions, while *O. virilis* was predicted to be more prevalent under high temperature, low dissolved oxygen conditions. Using modified minnow traps, crayfish were captured and physical characteristics measured at trap sites for two, five-night trapping periods. Data were analyzed using ANOVA and t-tests on the program SYSTAT11; significant relationships were drawn between higher temperature and higher *O. propinquus* density. *O. propinquus* density appeared to increase with higher temperatures but dissolved oxygen appeared to have no effect on distribution; *O. virilis* density was not affected by temperature or dissolved oxygen to a statistically significant degree. Biotic factors such as reproductive cycles, interspecific competition for preferred cobble substrate, and predation may have interfered as uncontrolled variables.

Introduction

Invasive crayfish present a serious threat to biodiversity and lake health in the northern lakes region of Wisconsin and Michigan. The invasion of *Orconectes rusticus* in the 1960s has led to unprecedented impacts on benthic communities as a result of macro invertebrates and macrophyte predation and interspecific competition with other crayfish species (Lodge, et al. 1994). An earlier invader, *O. propinquus*, has, in contrast, had a lesser impact and has not been as successful in displacing native *O. virilis* populations (Capelli and Munjal 1982). An understanding of the dynamics and mechanism of *O. propinquus* invasion may be useful as a baseline for comparison with the more virulent invader *O. rusticus*. A thorough understanding of the contrasting mechanisms and dynamics of invasion between the two species might lead to a better understanding of invasive crayfish ecology. Such an understanding is crucial, as invasive crayfish have and continue to impact a variety of commercially and ecologically valuable resources. For example, invertebrates consumed by invasive crayfish are often the preferred food of sportfishes (Blumenshine, et. al. 2000).

Currently, scientists understand that population dynamics are governed by both biotic and abiotic factors (Krebs 1994). In an effort to better understand and control crayfish distribution and invasion, a great deal of literature has been produced describing the biotic factors that govern crayfish populations (Lodge and Hill 1994). Less work, however, has been produced detailing the abiotic factors that effect crayfish. Dissolved oxygen (D.O.) and temperature have been well characterized in laboratory settings. For example, previous lab work by Lippson (1976), as described by Lodge and Hill (1994) has determined that crayfish metabolism is dependent on temperature and dissolved oxygen, but results from experiments under artificial conditions have been poor indicators for crayfish distribution in the field (Lodge and Hill 1994). For example, predicted values for low temperature tolerance have not accurately predicted the northern range of *O. rusticus* (Olsen et al. 1991). Very little work has been performed to determine the effects on different species in the field as temperature and oxygen conditions change. A better characterization of how different crayfish species respond to varying levels of dissolved oxygen and temperature in a natural setting is required. In order to achieve such a characterization, Tenderfoot Lake, a large, oligotrophic lake containing both invasive *O. propinquus* and native *O. virilis* populations, will be surveyed in different organic and inorganic substrate types. These substrates, I hypothesize, will vary in dissolved oxygen concentrations, as demonstrated by Frodge, et al. (1990). From measurements of dissolved oxygen, temperature, and crayfish catch, a characterization of native and invasive crayfish distribution during early- to mid-summer was determined. According to previous experimental results, *O. virilis* may hold an advantage in low dissolved oxygen conditions and higher temperatures, while *O. propinquus* is more tolerant to low temperatures and high dissolved oxygen (Berrill 1978). I predict that, in a natural setting, *O. virilis* will indeed be better adapted to low dissolved oxygen conditions than *O. propinquus*, and will thus be more prevalent in traps as summer progresses and temperatures increase; *O. virilis* will be more prevalent in organic substrates with low dissolved oxygen levels, such as macrophyte or muck substrate. Conversely, *O. propinquus* will be more prevalent in substrates with high dissolved oxygen levels, such as cobble and sand, and will be relatively more prevalent in traps than *O. virilis* in early summer, when temperatures are lower.

Materials and Methods

Following a characterization of Tenderfoot Lake according to substrate type, twelve locations of varying substrate were selected at which minnow traps were set during the week of May 29 2005. Four traps, each baited with approximately 80g beef liver and modified according to the methods described by Lodge, et. al. (1986), were set in the littoral zone 1-2 meters deep in cobble, sand, and muck substrates. At these locations, crayfish were trapped and counted nightly for five days. Dissolved oxygen and temperature for each catch site were measured at the benthos using an YSI meter. Numbers of *O. propinquus* and *O. virilis* males and females were counted from each catch. This procedure was repeated two weeks later during the week of July 20 in order to determine trends in crayfish distribution as the lake warms and stratifies. In order to perform statistical tests, total catches were converted to average catches per day per substrate type. From these compiled data, ANOVA tests with Bonferroni ad-hoc analysis were performed using SYSTAT 11 in order to compare temperatures and dissolved oxygen levels between substrate types. Similarly, ANOVA with Bonferroni ad-hoc analysis was utilized to compare crayfish catch in three substrates. Unpaired t-tests were utilized to compare numbers of each species caught from session 1 and 2, determine temperature and D.O. changes between trapping sessions, and compare sex ratios. Figures for ANOVA and t-test results were made using Microsoft Excel.

Results

Physical characteristics varied significantly according to time of year and substrate. For example, a significant change in temperature occurred for all substrate types between early- and mid-summer trapping sessions ($p< 0.001$, Fig. 1). Dissolved oxygen also varied significantly according to substrate type. D.O. was significantly higher in cobble and sand substrates compared to muck ($p=0.003$, Fig. 2). In addition, a significant change in D.O. occurred overall between the two trapping sessions ($p<0.001$, Fig. 3).

Crayfish catch for *O. propinquus* and *O. virilis* fluctuated according to substrate to varying degrees of significance. In terms of average catch per trap in each substrate, a significant difference was found between *O. propinquus* catch in cobble versus sand or muck substrates ($p<0.001$, Fig. 4). In contrast, differences in *O. virilis* distribution were less significant. While more *O. virilis* were caught in sand and muck than in cobble, these differences were not statistically significant (ANOVA; $p=0.380$, $df=2$, F-ratio=1.002).

Catch varied by trapping session, as well. A marginally significant increase in average catch for *O. propinquus* occurred between early and midsummer (p=0.068, Fig. 5). No significant corresponding increase occurred for *O. virilis*. In addition, unexpected trends in sex ratio were present. Sixty-five males were captured, while twenty-one females were caught. In terms of average catch, a significant difference occurred between male and female catch (p<.0.001, Fig. 6). Finally, an unexpected, significant increase in average female catch occurred between early and mid-summer (p<0.001, Fig. 7). In fact, only one *O. virilis* female was captured during the first trapping session; no *O. propinquus* females were caught until the second trapping session.

Discussion

A pair of physical characteristics acted as independent variables in this survey. First, dissolved oxygen acted as a variable across substrate types in order to confirm the hypothesis by Berrill (1978) that crayfish densities may be affected by dissolved oxygen. *O. propinquus* was more prevalent in cobble, a substrate in which dissolved oxygen levels are high. This result supports the results of laboratory experiments by Berrill, indicating *O. propinquus* may be better adapted to high dissolved oxygen conditions because the species is native to river habitats. While these findings initially appear to support Berrill's findings, *O. propinquus* was also more prevalent later in summer, when dissolved oxygen levels were lower. Additionally, *O. propinquus* were not more prevalent in sand substrate, which, like cobble, was significantly higher in D.O. than muck. As a result, we must conclude D.O. was not a determining factor for *O. propinquus* distribution. Furthermore, no statistically significant changes in *O. virilis* distribution occurred, indicating that D.O. was not governing distribution for this species.

While D.O. appeared to have no effect on crayfish distribution, temperature appeared to have a more substantial effect on *O. propinquus* distribution. A corresponding increase in *O. propinquus* catch indicates higher temperature may be a factor in predicting the distribution of the species. In contrast, *O. virilis* appeared to be less affected by the change in temperature. No significant difference was found between *O. virilis* catch over the two trapping sessions. Berrill (1978) has suggested that *O. propinquus* is more tolerant of low temperatures than *O. virilis*; results of this experiment suggest instead that early summer distribution of *O. propinquus* may be limited by low temperature tolerance compared to *O. virilis*. While results of this experiment may appear to contradict findings for temperature tolerance of *O. propinquus* in laboratory settings, a few key experimental limitations must be taken into account before any strong conclusions can be made.

Catch numbers used for statistical analysis may not be indicative of actual crayfish activity and distribution for Tenderfoot Lake. Most telling is the heavy trap bias towards males encountered in this experiment. Of crayfish captured in this experiment, an overwhelming majority were male. Studies by Dorn, et al. (2005) have suggested the use of minnow traps for crayfish surveys may lead to a sex bias towards males. Indeed, such a sex bias is quite evident in this experiment. Furthermore, the timing of the experiment may have skewed the data used for analysis. Specifically, the first trap session appears to have coincided with the egg-carrying portion of the reproductive cycle described by Capelli and Magnuson (1974). During this period, females carry large egg masses on their abdomens and are far less active than usual. As a result, female catch during the first week of trapping was disproportionately low. In addition, non-scientific, casual surveys of the lake by skin divers during the first trapping session yielded a number of females that were, in fact, carrying eggs. As a result, the changes in female crayfish activity may be a result of changes in reproductive status in addition to physical environmental characteristics such as temperature or dissolved oxygen.

Other biotic factors may have compromised the results of this experiment. As described by Lodge and Hill (1994), competition for substrate type itself appears to be a factor in crayfish distribution independent of temperature and dissolved oxygen. Cobble substrate may act as a refuge for crayfish, providing protection from predation. According to Lodge and Hill, interspecific competition for preferred cobble refuges may be a determining factor for crayfish species distribution. Because D.O. levels were identical for cobble and sand substrates, but *O. propinquus* densities were significantly higher in cobble, we may conclude *O. propinquus* densities are governed in this case by substrate type itself and not dissolved oxygen levels. These results confirm those of Capelli and Magnuson (1983), as described by Lodge and

Hill (1994), who suggested cobble substrate as a governing factor for crayfish distribution. The results of this study are similar to those of Garvey, et al (2003), who determined cobble substrate as a governing factor for the distribution of another invasive *Orconectes* species, *O. rusticus*.

Additionally, the timing of the sample sessions may have coincided with the molting seasons for one or both species. As described by Capelli and Magnuson (1974), summarized in Lodge and Hill, crayfish of the genus *Orconectes*, like most crustaceans, undergo periodic molting. During this period, individuals may be inactive in an attempt to avoid predation and cannibalism (Dionne 1985, summarized by Lodge and Hill). During the first trapping session, a number of *O. propinquus* were captured that possessed exoskeletons which were soft and discolored; as a result, we must conclude that at the time of the first trapping session, at least some *O. propinquus* were still molting. As a result, significant increases in *O. propinquus* may be partially a result of the coinciding of the first trapping session with molting season. While water temperature and dissolved oxygen levels may indirectly govern molting season, the direct correlation between *O. propinquus* catch and temperature is questionable, at best.

Finally, the limitations in size and scope of this survey must be addressed. Sample size was, to say the least, inadequate. While conducting the study, a concurrent crayfish experiment by Emmanuel Zervoudakis yielded catches indicating densities five to six times greater than the numbers encountered in this experiment.

Clearly, the sample used in this survey may not be representative of crayfish in Tenderfoot Lake as a whole. While sample size was limited to 12 sites totaling 120 trappings because of time and cost constraints, a better characterization of the lake using more traps and other resources might get a more accurate representation of crayfish distribution in Tenderfoot Lake. In addition, the use of a single lake as a survey subject severely limits the bounds of any experimental conclusions. In order to expand on these results, I suggest a much larger scale survey of Tenderfoot Lake, involving perhaps as many as 40 trap sites totaling 400 trappings, as well as other crayfish-inhabited lakes in the UNDERC region for substrate type, temperature, dissolved oxygen, and crayfish populations.

Acknowledgements

I would like to thank Emmanuel Zervoudakis for countless hours of help in trapping and surveying. Without him, I would still be stuck on the lake paddling a canoe in circles. Thanks to Jody Murray for help with editing, statistics, and general advising. Dr. Gary Belovsky, and Dr. James English were invaluable resources for statistics. Brett Peters provided additional assistance on trapping techniques and, with Jody, did a skin dive to confirm crayfish reproductive and molting status. Thanks to Dr. Karen Francl for help with editing and purchasing beef liver for bait. Finally, I would like to thank the Hank family and everyone who has made my UNDERC research experience possible.

References Cited

Berrill, M. 1978. Distribution and ecology of crayfish in the Kawartha Lakes region of southern Ontario. Can. J. Zool. 56: 166-177.

Blumenshine, S.C., D.M. Lodge, and J.R. Hodgeson. 2000. Gradient of fish predation alters body size distributions of lake benthos. Ecology. 81(2): 374-386.

Capelli, G.M., and B.L. Munjal. 1982. Aggressive interactions and resource competition in relation to species displacement among crayfish of the genus *Orconectes*. Journal of Crustacean Biology 2: 486-492.

Capelli, G.M., and J.J. Magnuson. 1974. Reproduction, molting, and distribution *Orconectes propinquus* in relation to temperature in a northern mesotrophic lake. Freshwater Crayfish 2: 415-427.

Capelli, G.M., and J.J. Magnuson. 1983. Morphoedaphic and biogeographic analysis of crayfish distribution in Wisconsin. J. Crust. Biol. 4: 252-260.

Dionne, M. 1985. Cannabalism, food availability, and reproduction in the mosquito fish (*Gambusia affinis*): a laboratory experiment. Am. Nat. 126:16-23.

Dorn, N.J., Urgelles, R., Trexler, J.C. 2005. Evaluating active and passive sampling methods to quantify crayfish density in a freshwater wetland. Journal of the North American Benthological Society. 24 (2): 346-356

Frodge, J.D., G.L Thamas, and G.B. Pauley. 1990. Effects of canopy formation by floating and submergent aquatic macrophytes on the water quality of two shallow Pacific Northwest lakes. Aquatic Botany 38: 231-248.

Garvey, J.E., J.E. Rettig, R.A. Stein, D.M. Lodge, and S.P. Klosiewski. 2003. Scale-dependent associations among fish predation, littoral habitat, and distributions of crayfish species. Ecology: 84: 3339-3348

Krebs, C.J. 1994. Ecology: The experimental analysis of distribution and abundance. 4th edition. Harper Collins College Publishers, New York. pp. 322-335.

Lodge, D.M., and Hill, A.M. 1994. Factors governing species composition, population size, and productivity of cool-water crayfishes. Nordic J. Freshw. Res. 69: 111- 136.

Lodge, D.M., M.W. Kershner, J.E. Aloi, and A.P. Covich. 1994. Effects of an omnivorous crayfish (*Orconectes rusticus*) on a freshwater littoral food web. Ecology. 75(5): 1265-1281.

Lodge, D.M., T.K. Kratz and G.M. Capelli. 1986. Long-term dynamics of 3 crayfish species in Trout Lake, Wisconsin. Canadian Journal of Fisheries and Aquatic Sciences. 43 (5): 993-998.

Olsen, T.M., D.M. Lodge, G.M. Capelli and R.J. Houlihan. 1991. Mechanisms of impact of an introduced crayfish (*Orconectes rusticus*) on littoral congeners, snails and macrophytes. Can. J. Fish. Aquat. Sci. 48: 1853-1861.

Figures

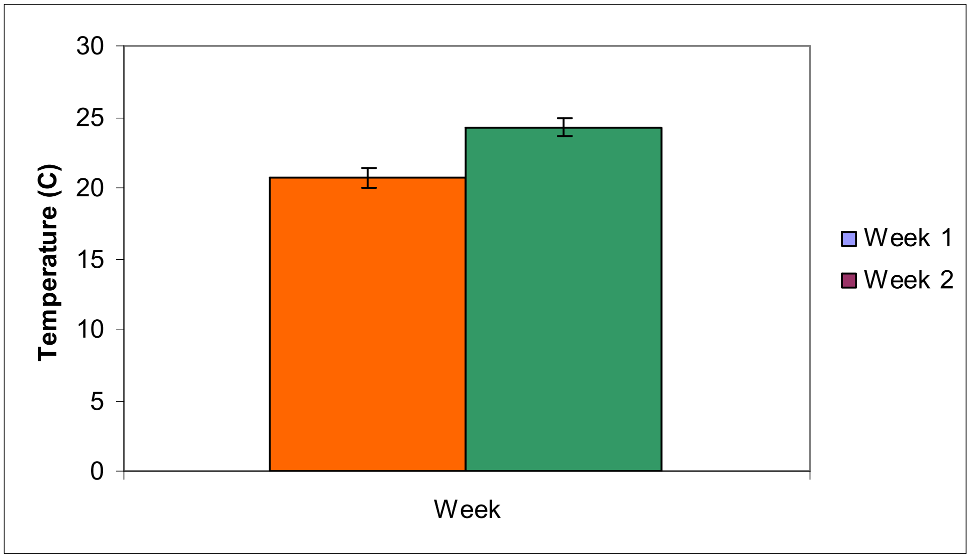

Figure 1: Temperature for Two Trapping Sessions. Temperature was significantly higher for the second trapping session than the first (T-test; p<0.001, t=-24.100, df=116).

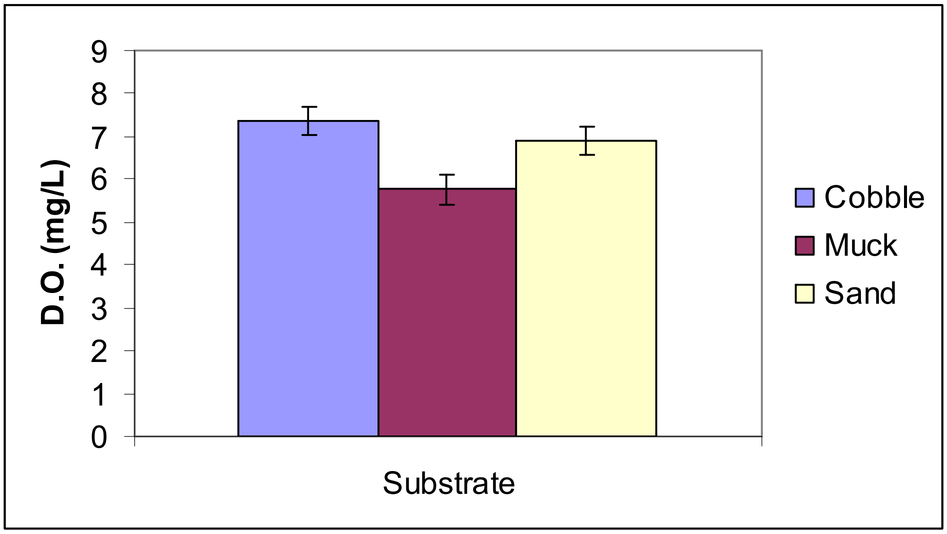

Figure 2: Dissolved Oxygen for Three Substrates. Dissolved oxygen varied significantly by substrate type (ANOVA; p=0.003, df=2, F-ratio=6.077, MSE=4.285). Dissolved oxygen was significantly higher in cobble and sand than in muck (Bonferroni probabilities: Muck-Sand: p=0.048, Muck-Cobble: p=0.003).

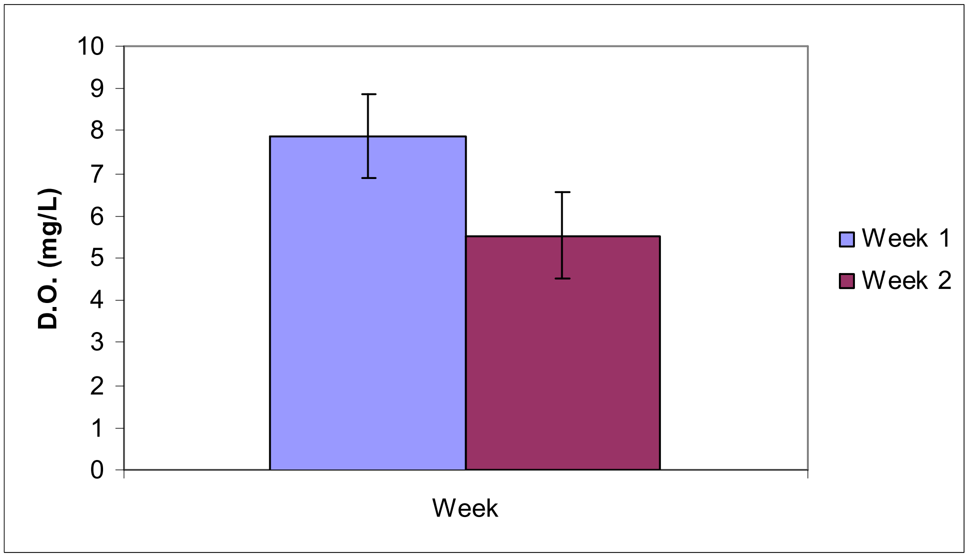

Figure 3: Dissolved Oxygen for Two Trapping Weeks. Dissolved Oxygen varied significantly between the first and second trapping sessions (T-test; p<0.001, df=116, t=6.990)

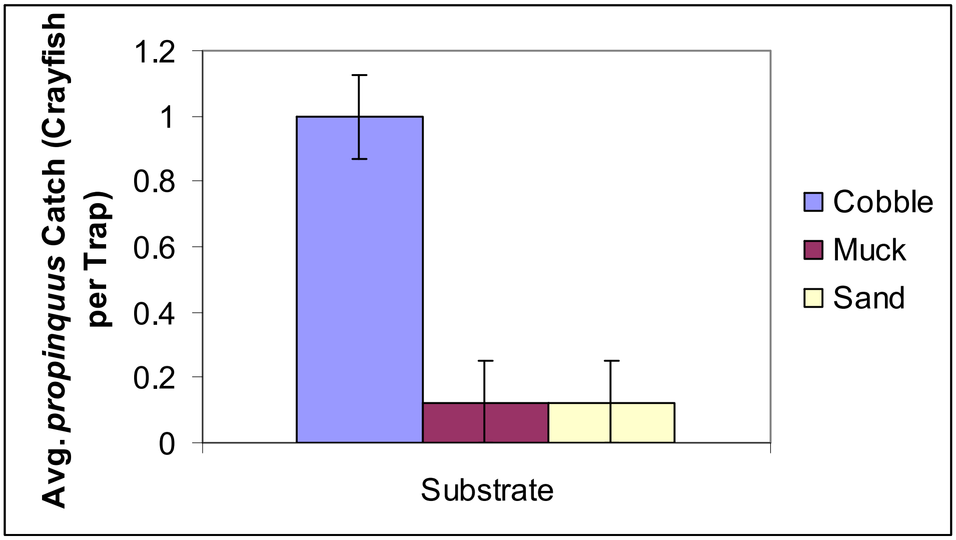

Figure 4: Average Catch for *O. propinquus* in Three Substrates. Average catch for *O. propinquus* was significantly higher in cobble than muck or sand (ANOVA; p<.001, df=2, F-ratio=15.528, MSE=0.164; Bonferroni probablilities: Cobble-Muck: p<0.001, Cobble-Sand: p<0.001).

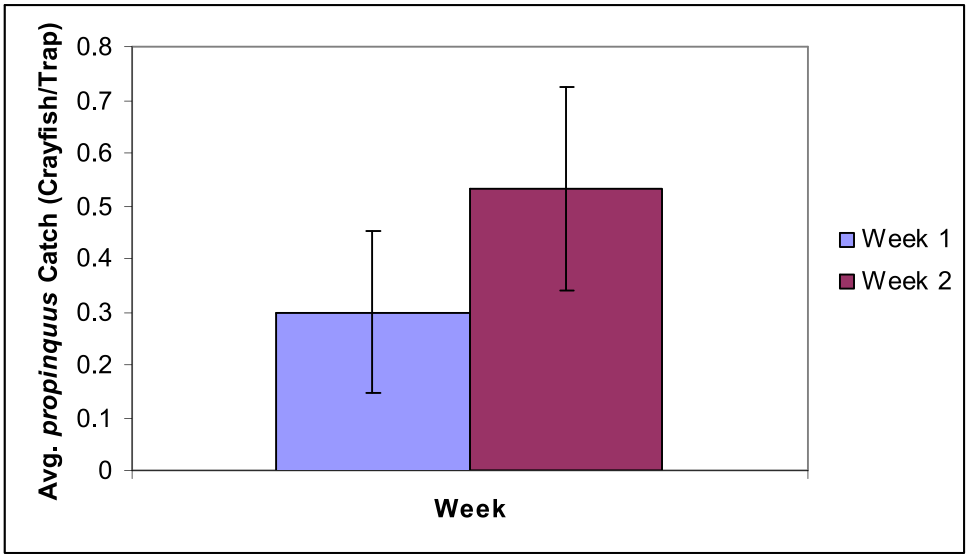

Figure 5: Average *O. propinquus* Catch for Two Trapping Sessions. *O. propinquus* catch increased to a marginally significant degree (T-test; p=0.068, t=-2.107, df=8) between trap sessions 1 and 2.

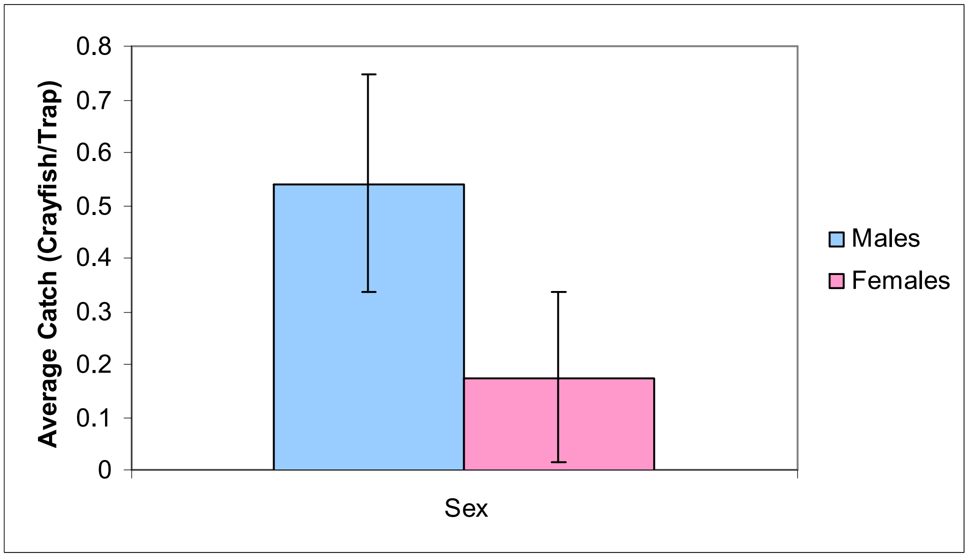

Figure 6: Average Catch for Males and Females. Average catch for males was significantly higher overall than that for females (T-test; p<0.001, t=4.2719, df=19).

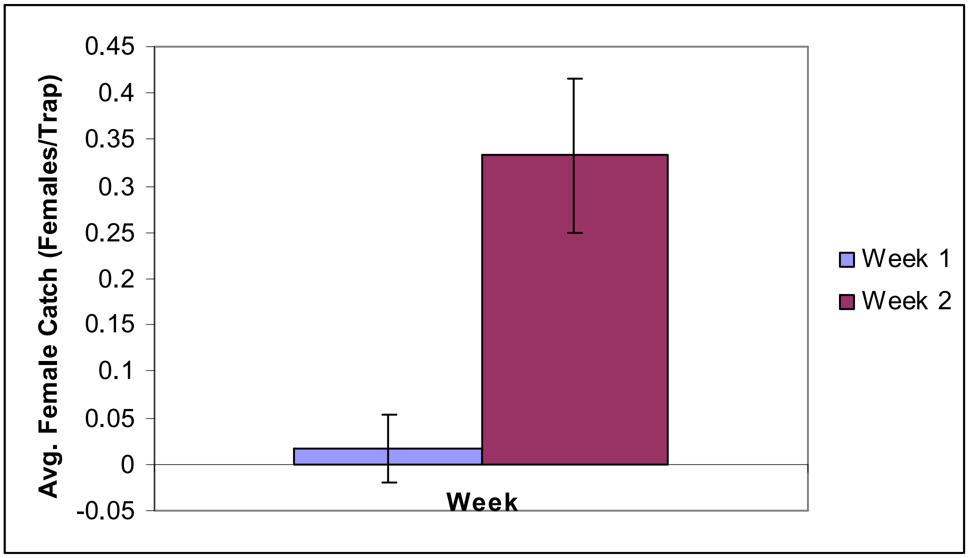

Figure 7: Average Female Catch for Two Trapping Sessions. Average number of females caught per trap increased significantly between sessions 1 and 2 (T-test; $p<0.001$, $t=-7.757$, $df=8$).