Habitat complexity and shoaling behavior in *Pimephales promelas*

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Abstract: Hamilton's selfish herd theory dictates that individuals will seek protection from predation by locating to the center of a group in order to hide behind other members. This study focused on applying the selfish herd theory to shoaling behavior between habitats of varying complexity. Fathead minnows were placed either in a simple or complex environment and shoaling behavior was measured in response to the presence or absence of a predator. The results indicated that habitat complexity and predator presence/absence did not have a significant effect on shoaling behavior. While the data were not significant the results did suggest that in complex environments shoaling behavior is independent of predation risk, which indicates individuals are seeking shelter similar to Hamilton's selfish herd theory.

Grouping behavior is often used as a strategy to defend against the risk of predation. In prey species of fish, shoaling behavior occurs in response to a predator with individuals sorting by species and size to become less distinct and thus, less likely to be captured (Krause et al. 2000). Studies have shown that as shoal size increases, the success of a predator decreases (Hager & Helfman 1991). Therefore, it is favorable for fish to shoal in larger groups of like individuals to increase their chance to survive and reproduce. In discussing group behavior, Hamilton (1971) described the concept of the selfish herd where each individual attempts to reduce the risk of being captured by locating to the center of the group. Recent studies have focused on applying the concept of the selfish herd to shoaling behavior between habitats of differing complexity. Orpwood et al. (2008) predicted that by applying Hamilton's selfish herd theory to complex environments, individuals would be prone to seek shelter behind vegetation rather than group with other individuals.

This study focused on determining whether shoaling behavior differed in response to predation between open and complex systems using the fathead minnow (*Pimephales promelas*) and the perch (*Perca flavescens*) as a predator in an artificial environment. Fathead minnows are not strong swimmers and rely on shoaling behavior for defense against a predator (Savino &

Stein 1989). In addition, fatheads exhibit several behaviors when presented with a predator including surface swimming, inspection of predator, and use of vegetation for shelter (Sullivan & Atchison 1978). Sullivan and Atchison (1978) discuss how the fathead minnow's behaviors are for detection of a predator and therefore require social interactions rather than individual choices. However, when vegetation is present fathead minnows have been shown to abandon shoaling behavior and seek shelter individually. Thus, we predicted that in an open environment minnows would move in tighter groups and therefore shoal more frequently than in complex environments.

Materials and Methods:

For this experiment, fathead minnows and a perch were captured from Lake Itasca and placed in 61x31x39 cm tanks filled to 33 cm deep of lake water. Four treatments were imposed testing predator versus no predator in both an open and complex system. To create a complex system, polypropylene rope was cut into 25 cm or 30 cm strands and tied to test tubes filled with sand to mimic wild rice. For each treatment, four minnows were placed in the tank and their behavior was video recorded for five minutes for a total of ten replicates. In the treatments testing predator response, the perch was placed in the same tank as the minnows to elicit the optimum defense response. The videos were then analyzed and the distances between each fish and the total diameter (largest distance) of the shoal were recorded every ten seconds. A two factor ANOVA using the SAS statistical software was than completed to test the significance of the data.

Results:

The results of the experiment indicated that there was no significant effect on the average distance between fish due to habitat complexity ($F_{1,36}$=0.357, P=0.742), predator presence/absence ($F_{1,36}$= 6.753, P=0.157) or the interaction of these two factors ($F_{1,36}$= 5.671, P= 0.194). Further, the results showed no significant effect on the shoal diameter due to habitat complexity ($F_{1,36}$= 1.400, P= 0.713), presence/absence of the predator ($F_{1,36}$= 9.045, P=0.353), or the interaction of these two factors ($F_{1,36}$= 20.308, P=0.167). Figures 1 and 2 show the average distances between fish and total shoal diameter for each of the four treatments, respectively.

Discussion:

This study indicated that habitat complexity and presence of a predator had no significant effect on the shoaling behaviors of fathead minnows. The average distances between fish in complex habitats were similar independent of the presence or absence of the predator. This is congruent to studies done by Savino and Stein (1989) which saw that shoaling behavior was highly reduced at higher plant densities, or a more complex environment. Further, fathead minnows when using vegetation to hide do not move as frequently, even in the presence of a predator (Sullivan and Atchison 1978). Therefore, if sufficient vegetation is provided, shoaling behavior would be consistent independent of predator presence. Orpwood et al. (2008) found that in complex systems shoal size was not affected by predation risk, which is congruent to the findings in this study.

While the mean distances between minnows remained constant in complex systems, there was a difference between means in open systems. The results indicated that in open systems the distances between fish were approximately two times larger in the presence of a predator compared to the no predator treatment. This result contradicts Hamilton's (1971) idea of the selfish herd in that individuals were not seeking to be at a center of a group in order to reduce their risk of predation. Further, Orpwood et al. (2008) found that in the presence of a predator individuals would move less frequently, while shoals would form more often in simpler systems.

Thus, in simple systems minnows would shoal together and stay in tighter conformations to reduce their predation risk. Our results indicated that the open with predator treatment had the largest mean distance between individuals which contradicts our initial hypothesis. However, some of the other anti-predator behaviors of fathead minnows which include surface swimming to avoid predators, and inspection behavior, may account for these differences. Sullivan and Savino (1978) recorded that fathead minnows would often swim over the predator as an avoidance mechanism if the predator was not actively pursuing the minnows. These behaviors could have caused more separation between individuals after the initial introduction of the predator, causing the open with predator treatment to have a higher mean distance.

The analysis of shoal diameter in each treatment also indicated that the open with predator treatment had the least amount of shoaling formation while open no predator had the most. These results again contradict Hamilton's selfish herd theory but the anti-predator behaviors of fathead minnows may again account for these unexpected results. Although the data for open systems contradicted previous research, the results from the complex systems showed that with vegetation shoaling behavior is independent of predation risk, as seen in the Orpwood et al. (2008) study. Future paths of research may incorporate the use of a model as a predator to maintain constant predatory behaviors to limit inconsistencies between trials. Other modifications may include using a larger system with varying degrees of complexity, and the inclusion of more minnows to obtain more detailed observations of shoaling behavior and the effect of habitat complexity.

References:

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Appendix

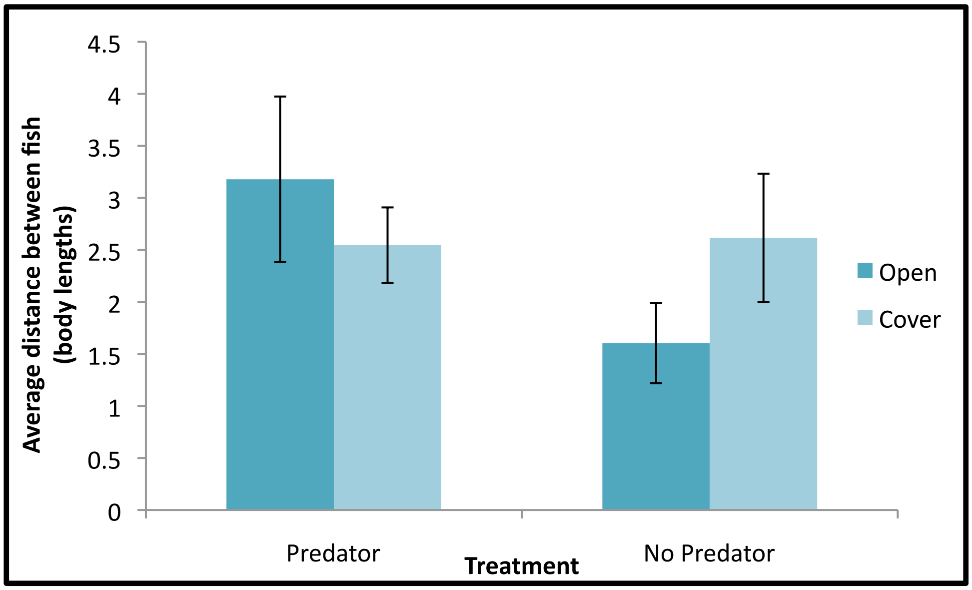

Figure 1: Mean (±) distance between minnows (in body lengths) for each of the four treatments.

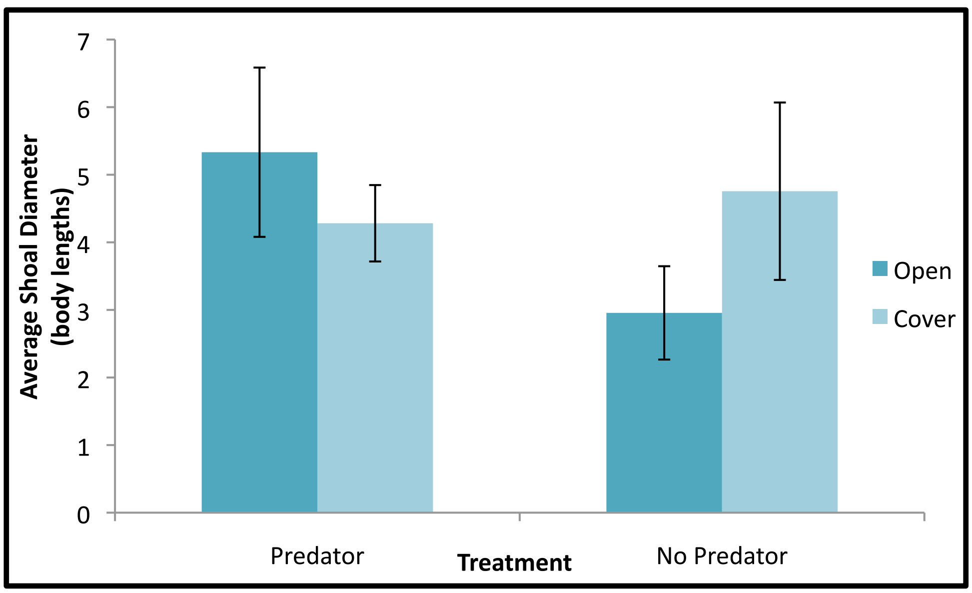

Figure 2: Mean (±) shoal diameter (in body lengths) for each of the four treatments.