The Effect of Lakeshore Coarse Woody Habitat on Predator-Prey Interactions between Benthic Invertebrates and Littoral Fish in Lentic Ecosystems

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Abstract

Coarse woody habitats (CWH) are fallen dead trees and branches that are important for some aquatic species due to their roles as refuge from predators and areas of food availability for some aquatic species. Humans tend to remove CWH for recreational, transportation and other purposes. As CWH is removed from lakes potential refuge for invertebrates is lost. To see if CWH functions as a refuge for invertebrates, pieces of worms (our model for benthic invertebrates) were set with varying number of initial worms placed (1 through 8) to simulate patches of different food abundance in 32 CWH and 32 exposed habitat (EH) sites in Crampton Lake, WI. It was expected that there would be a higher bait percent mortality (i.e. the probability that an individual worm is eaten) in the EH because the CWH provide refuge to benthic invertebrates. Our statistical analyses, however, suggested a higher percent mortality in the CWH ($p=0.0307$). This result can be explained due to the fact that CWH also serve as refuge for small littoral fish that are hiding from predators. This project suggests that CWH is not an adequate refuge for macroinvertebrates but it does serve as a refuge for small littoral fish. For future research it is pertinent to consider predator-prey relationships between small fish like bluegill and large predatory fish like largemouth bass when considering the outcomes of loss of CWH.

Introduction

Littoral zones of lakes (i.e. shallow areas near shore) often have coarse woody habitat (CWH), which provide an important habitat for many fish and invertebrates. CWH in lakes is classified as trees, branches, roots, and wood fragments at least 4 inches in diameter that enter a lake by natural (beaver activity, toppling from ice, wind, or wave scouring) or anthropogenic (logging, intentional habitat improvement, flooding following dam construction) means (Guyette and Cole 1992; Christensen et al. 1996; Engel and Pederson 1998). CWH in the littoral or near-shore zone serves many functions within a lake ecosystem like controlling erosion, supplying carbon to aquatic consumers, and providing substrate for algal growth, which is an important food base for aquatic macroinvertebrates (Engel and Pederson 1998; Sass 2009). CWH in near shore zones of lakes also constitutes a preferred habitat for birds, turtles, fish, and aquatic macroinvertebrates because it provides refuge as well as foraging and spawning habitat (Hanchin et al. 2003; Lawson et al. 2011). CWH in littoral zones is especially important for macroinvertebrates because they have the potential to function as a refuge from predatory fish.

CWH is highly sensitive to human land use as it is often removed on highly developed lakes. Residents and property owners often remove these habitats for aesthetics and recreation and also as a way to ease navigation through the lakes. In Wisconsin, dead tree branches and logs, which are potentially refuge for invertebrates, are highly abundant in lakes with no shoreline development but are often completely absent in lakes with high shoreline development (Everett and Ruiz 1993; Christensen et al. 1996). For example, Jennings et al. (2003) quantified CWH in lakes along a human development gradient (based on counts of residential structures and watershed cover types detected by satellite imagery) and reported a negative relationship between residential lakeshore development and the amount of CWH. Benthic macroinvertebrates are an important food source for many fish. Therefore, development of shorelines and the removal of potential refuge for benthic macroinvertebrates may affect fish production.

For this study we considered the predator-prey interaction of three littoral fish—bluegill sunfish (*Lepomis macrochirus*), largemouth bass (*Micropterus salmoides*) and yellow perch (*Perca flavescens*) — with benthic macroinvertebrates. Bluegill are a popular fish for recreational fisheries and are abundant in most water bodies in Wisconsin, including ponds, lakes, streams, and rivers. In highly developed lakes, bluegill sunfish tend to grow 2.5 times slower than those in undeveloped lakes (Schindler et al. 2000). In northern Wisconsin and upper Michigan lakes, growth rates of largemouth bass and bluegill were highest in lakes with little or no lakeshore residential development where CWH was most abundant (trends for bass were not statistically significant) (Schindler et al. 2000). One hypothesis to explain this is that bluegill and other littoral fish species may overexploit their invertebrate prey base when refuge for invertebrates is absent (i.e. no CWH). CWH may prevent bluegill and other littoral fish from eating all benthic invertebrates, allowing this prey base to persist at higher abundances. With this in mind, an important question is: Does CWH provide refuge for benthic macroinvertebrates?

Our hypothesis was that CWH does provide refuge to benthic macroinvertebrates; therefore, in highly exposed areas (i.e. less CWH) bluegill and other littoral fish would completely extirpate benthic macroinvertebrates because of the increased successful predation attempts by these fish in these areas. Conversely, some but not all invertebrates in CWH areas would be eaten due to the inability of fish to observe prey items and the refuge provided to macroinvertebrates by CWH.

We further hypothesized that the number of worms eaten would be the same in both habitat types if CWH does not impact predator consumption of benthic invertebrates. If the CWH does impact the predator-prey relationships, we expected that the number of eaten worms would be lower in areas where there is a greater abundance of CWH as there is increased refuge. We also hypothesized that as the worm patch size increased (i.e. greater number of worms set), the mortality percent would decrease because more prey in a patch should reduce the individual probability of an invert being consumed. This work will help determine the function of CWH, which is sensitive to human use, and its ultimate effects on predator-prey interactions

Methods

Study Site

To test our hypotheses, we picked Crampton Lake at University of Notre Dame Environmental Research Center (UNDERC) as an experimental site as it contains both EH and CWH areas. Crampton Lake has an area of 66 acres and a depth of 31 feet and is located in Vilas County Wisconsin, USA. The following fish have been reported in the Crampton Lake: Bluegill, Pumpkinseed, several types of shiners, largemouth bass and smallmouth bass. This lake does not have anthropogenic disturbance in the form of lakeshore development and serves as a reference for the roles of EH and CWH in an undisturbed lake.

Experimental design

Invertebrates were tethered to areas that have CWH and areas that do not (EH) with a fishing line that was attached to a small anchor. We tethered varying numbers of worms (one through eight) at the onset of each trial to simulate varying patch sizes of invertebrates. Each patch size was replicated four times in both habitat types. We placed anchors in 32 EH and 32 CWH sites distributed evenly around the lake making up a total of 64 sample sites (Figure 1). We recorded the number of invertebrates that were eaten in a six hour period. We calculated the probability of an individual invertebrate being eaten in a given habitat as the number of worms eaten divided by the total number set (presented as percent mortality). At each site we also recorded the number of pieces of wood and the number of branch sites on the pieces of wood.

We conducted behavioral observations of fish feeding in CWH versus EH. These were done by tethering invertebrates to anchors not included in our feeding trials, and by snorkeling to observe fish feeding in CWH and EH. We recorded fish species, number of successful predation attempts, and time spent foraging in each habitat type to provide the necessary information to look for differences in behavior between the two habitats. We did not run statistical tests or graphs for these observations because our presence while making them startled the fish and would affect the results.

Statistical Analysis

A t-test was conducted to determine if there were statistically significant differences in the mean number pieces of wood and branch sites between the 32 sites of CWH and the 32 sites of EH. A two-way ANOVA with an interaction between CWH and EH was conducted to determine if percent mortality was affected by the patch size of invertebrates in both habitat types. Finally, a t-test was used to determine if there was an effect of habitat type on benthic invertebrate percent mortality.

Results

There were significantly higher pieces of wood in CWH areas on Crampton Lake ($p<0.001$; Figure 2). There were also significantly more branch sites in CWH areas than EH ($p<0.001$; Figure 2).

The two-way-ANOVA determined there was not a significant relationship ($p>0.05$) between invertebrate patch size and individual invertebrate mortality. Habitat type (CWH and EH) did have a significant impact on the percentage mortality ($p<0.05$; Figure 3). For almost every patch size, the average mortality was higher in CWH with the exception of the first worm set. Lastly, the test indicated there was not a significant interaction between habitat type and the relationship of patch size and percent mortality ($p>0.05$).

Finally, we compared CWH and EH percent mortality using a t-test. The average percent mortality was significantly higher in CWH (p=0.031; Figure 4).

As for the behavioral observations, only largemouth bass were seen in EH while bluegill and yellow perch were seen in the CWH. The largemouth bass observed in the EH only swarmed around in the area where the bait was placed but they never made any attempts to consume it. Largemouth bass also arrived minutes after the bait was placed in the EH. On the other hand, as soon as the bait was placed in the CWH, a school of fish immediately appeared and after sixteen minutes of observations, numerous attempts on the baits were made and a successful attempt was made by a yellow perch.

Discussion

Our results from the two-way-ANOVA suggested there was not a significant relationship between invertebrate patch size and invertebrate percent mortality. These results are contrary to what we expected, which was a decrease in percent mortality with the increase in patch size. This result suggests that it does not matter whether an individual invertebrate or a group of invertebrates occurred in each habitat type,, the percent mortality was essentially the same in all patch sizes. CWH did have a higher average mortality in almost all of the sets (Figure 3). This can also be seen from the results shown in Figure 4 (p=0.0307, df=1, F=4.89. These results also contradicted the proposed hypothesis. We expected that there would be a lower number of worms eaten in areas where there is a greater CWH because the invertebrates use this habitat as a refuge from fish. Instead, we found that the number of worms eaten was higher in CWH.

Our results may have occurred because prey fish were using CWH as a refuge and, therefore, fed more heavily in these areas. CWH may provide refuge for prey fishes because physical structure decreases the foraging success of their predators (Savino and Stein 1982). The interstitial spaces created by the CWH provide refuge for small littoral fish. This decreases the foraging success of larger predatory fish by lowering the encounter rate between predator and prey. Both yellow perch and bluegill were found in CWH but largemouth bass were only found in EH. Perch frequently use CWH as spawning substrate, foraging site, and as a refuge from predators (Sass et al. 2006). Similarly, bluegills forage and take refuge from bigger predatory fish in CWH as well. Thus, the abundance of small littoral fish is expected to be higher in these habitats in comparison to EH. This could explain why the percent invertebrate mortality was higher in CWH and is supported by the results obtained from a similar research project in Crampton Lake, where the majority of prey fish caught were in CWH. Because there is more abundance of fish in these woody habitats and since the bait cannot escape predation, the percent mortality in these habitats was higher.

The presence of largemouth bass has been shown to alter the types of woody structure preferred by bluegill, which will select smaller spaces within the structure in the presence of this predation threat (Johnson et al. 1988). There were several largemouth bass observed in EH that were close to woody areas, while numerous bluegill and yellow perch were observed in the actual woody habitats. Small fish like bluegill and yellow perch were probably using the CWH as refuge from those largemouth bass and forced to hide in tight spaces where they found invertebrates.

It is imperative to conserve CWH because it has several important roles that include adding a significant amount of organic matter to the soil, providing a primary source of energy for food webs and offering a habitat for not only aquatic species but also other organisms like bacteria, among other important roles (Stevens 1997).

The results of this study suggest that there was no relationship between the patch size and percent mortality, however, it suggests there was a significant relationship in the mortality percent between the CWH and the EH. We found a considerably higher mortality percent in CWH which suggests that these habitats function as a refuge for small littoral fish. This indicates that the sampled CWH sites in Crampton Lake are not adequate shelters for macroinvertebrates; however, evidence does suggest that CWH are refuge for small littoral fish. Whether these habitats are an actual refuge for macroinvertebrates from predatory fish should be further studied. Although Crampton Lake is an undeveloped lake, many lakes all over the world are experiencing anthropogenic disturbance that affect entire food webs. The loss of CWH has been associated with the reduction of forage fish species and the decline of predator growth rates (Gaeta et al. 2014). Thus, the loss of CWH in lake ecosystems may result in changes in predator-prey relationships that could alter whole-lake ecosystems.

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Figures

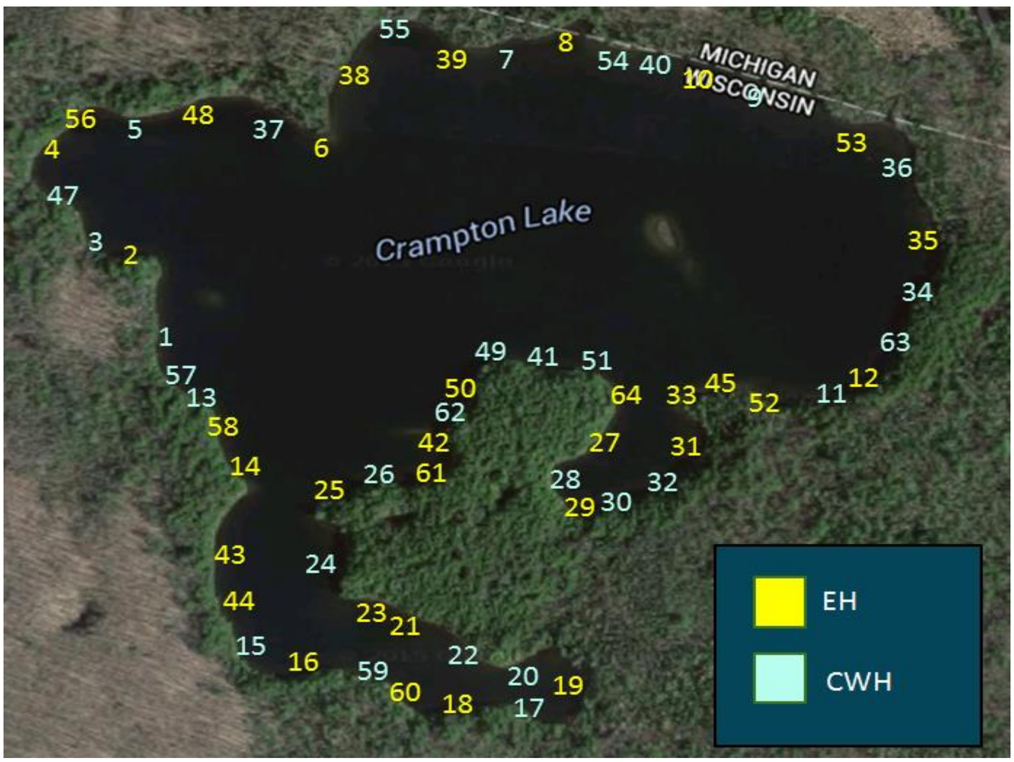

Figure 1. Crampton map. Map of Crampton Lake with the 32 CWH sites and the 32 EH sites that were sampled. The CWH are identified by the red numbers while the EH are identified by the yellow numbers.

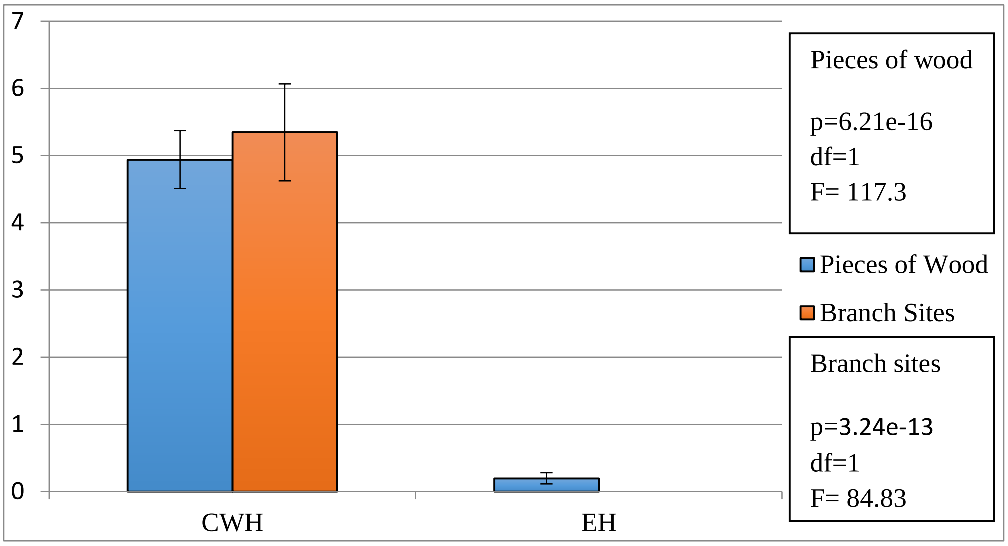

Figure 2. Pieces of wood and number of branches in CWH and EH. The number of pieces of wood in the CWH sites sampled were significantly higher than the EH sites. The number of branch sites in the CWH sites sampled were significantly higher than the EH sites.

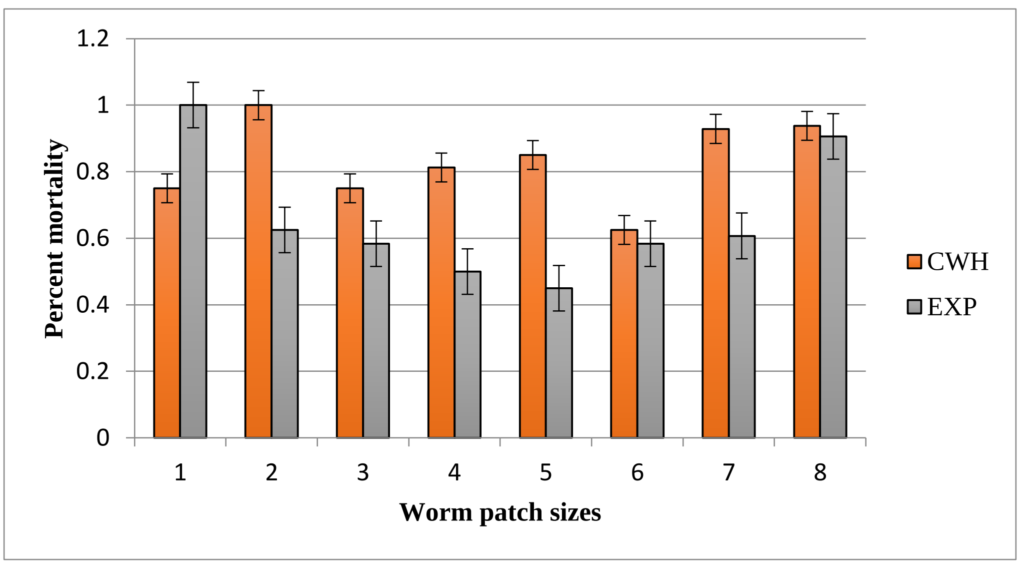

Figure 3. Percent mortality of worms observed in each of the worm patch sizes. The number of eaten worms (percent mortality) in CWH is significantly higher than the number of eaten worms in the EH. The patch size, however, showed no significant relationship with the percent mortality in neither habitat type.

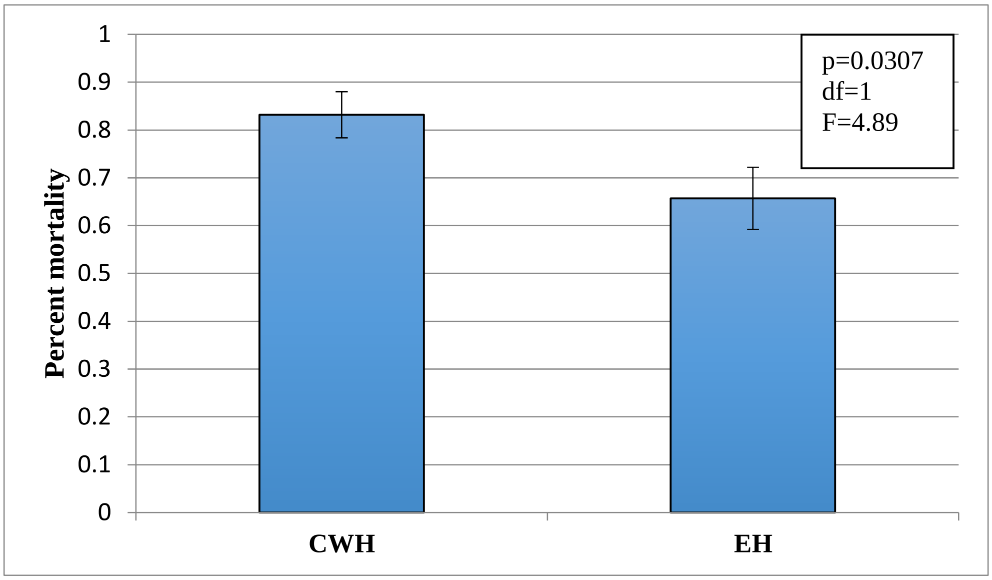

Figure 4. Percent mortality in CWH and EH. The percent mortality of CWH is significantly higher than in EH.