A comparison of fish communities between a developed and an undeveloped lake in northern Michigan

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Summer 2008

Abstract

Lakes tend to attract human development, but the effects of human development on lakes and their fish communities have not been well documented. We compared fish communities in two lakes in Northern Michigan under different levels of human lakeshore development: Burt Lake, which has high levels of human development, and Douglas Lake, which is mostly undeveloped. Over the course of two weeks, we sampled fishes at two similar sites in each lake using minnow traps and seines. The sites were chosen to be similar in habitat complexity, vegetation, and substrate. We compared species richness, diversity (using the Shannon diversity index), abundance in terms of catch per unit effort (CPUE), and standard length distribution of yellow perch between paired sites and between the lakes as a whole. Besides differences in human shoreline development, we looked at differences in nutrients and habitat complexity between sites, to see if these affected fish community as well. We hypothesized that fish community would differ between the lakes. We found that diversity was significantly higher in Burt Lake compared to Douglas, although there was no difference between lakes in terms of richness and abundance. There were other differences in terms of water chemistry, length of game species yellow perch (longer in Douglas Lake) and in terms of which species were found in which sites. We concluded that while human development might indirectly affect fish communities through changing nutrient levels and habitats, fish communities are perhaps more directly affected by factors such as habitat complexity.

Introduction

Large freshwater lakes have historically played important roles in society, providing recreational, aesthetic, and economic resources, and attracting human settlement along their shores (Beeton 2002). Because they attract human populations so strongly, an understanding of the effect of human development on the lakes' natural systems becomes very important. Aquatic ecosystems, however, are often ignored in the spectrum of human development effects. Streams, at least, have received some recent study in terms of development effects; the effects of human activity on lakes, especially their biotic components, have received little scientific attention (Jennings et. al. 1999).

Some of the many uses of freshwater lakes are derived from their fish communities. Fishes are integral parts of lacustrine food webs, and their activity can impact terrestrial trophic levels as well. As such, they are often indicators of environmental health of lakes. More importantly to humans personally, they provide food, jobs, and recreational opportunities for many.

The amount of human development physically present on a lakeshore impacts the lake and its fish communities (Brazner 1997, Scheuerell and Schindler 2004, Bryan and Scarnecchia 1992, Jennings et. al. 1999, Stedman and Hammer 2006). Scheuerell and Schindler (2004) suggest that older models looking at fish distribution, which assume that fishes are not affected by humans, are probably false, and that the effect of human development on fishes simply has not been studied enough.

Human development changes lake habitats by removing woody debris and vegetation. (Changes can also occur via changes in benthic substrate, another side effect of development [Scheuerell and Schindler 2004].)Vegetation is necessary for fish feeding, refuge, and spawning habitat (Bryan and Scarnecchia 1992). Bryan and Scarnecchia (1992) found that a lack of vegetation along developed sections of the shoreline of an Iowan lake resulted in a decrease in that area of fish abundance. These effects were most notable in the littoral zones of lakes, where vegetation is normally most common. Bryan and Scarnecchia (1992) concluded that human development led to decreases in species richness and abundance of fishes, and predicted that the short-term effect of human development is a decrease in especially vegetation-dependent fishes, with long-term effects being complete changes in fish community richness and composition.

Human development can also cause changes in lacustrine nutrient cycles, particularly nitrogen and phosphorus levels (which are often limiting factors for plant and fish growth) via runoff of lawn fertilizers and other outdoor-use products or dumping of waste (Stedman and Hammer 2006, Scheuerell and Schindler 2004). Development affects input in another way as well: nutrient input is increased, but terrestrial input of leaf litter and woody debris is decreased. Scheuerell and Schindler (2004) found that terrestrial input to lakes is very important to fishes (adding useful nutrients and complexity to habitats), and that the quality and amount of this input can be severely impacted by lakeshore development.

Fish community is further affected by the presence of swimmers, boaters, and anglers, which often come with human development, and which are perceived as predation threats. The spatial distribution of fishes is especially affected by the presence of these types of human activity, and mating and feeding activity can be hindered. (Scheuerell and Schindler 2004).

The relationship between human development and fish communities is not simple. Fishes tend to need complex habitats. Human development usually results in simpler habitats, which decreases fish abundance and richness. However, if development increases complexity, as in the case of added rip-rap or docks to shorelines, it could have the opposite effect on the communities (Jennings et. al. 1999).

Our study examines the effects of human development on fish communities by comparing a relatively undeveloped lake and a highly developed lake, in northern lower Michigan. Burt Lake (Cheboygan County) is large, 17,000 acres, and the shoreline is almost completely developed, both privately and commercially. There are sections of state forest and state park on the lake, but these are still heavily used by campers, boaters, and swimmers (Hanchin et. al., 2005). There are approximately 24.7 residences per kilometer of shoreline (Vande Kopple – personal communication). Douglas Lake (Cheboygan and Emmett Counties) is smaller (3,395 acres), slightly north of Burt, and is largely undeveloped, with only approximately 13.7 residences per kilometer of shoreline, most of this highly concentrated at one end of the lake (Vande Kopple – personal communication).

Most of the lakeshore is owned by the University of Michigan Biological Station (UMBS) and contains no development. Fishing pressure is lighter than at Burt and access to the lake is limited (Cwalinski, T.A., 2004).

Both lakes are similar in terms other than development; they are within 2.2 km of each other, were both glacially formed, have similar maximum depths, and their lakeshores have much of the same vegetation and habitat. Douglas Lake is part of Burt Lake's watershed and both are part of the Cheboygan River watershed. The major difference, then, besides size, is the amount of human development. We were interested in how this factor influenced nearshore fish communities in the lakes. Our hypothesis is that fish diversity, richness, and abundance differ between Burt and Douglas lakes as a result of differences in human development.

Methods and Materials

We chose two sites in each lake (Burt and Douglas), in an attempt to compare similar habitats. In each lake we had one sandy and marly open-water site dominated by bulrush (*Schoenoplectus spp.*), and one sandy and rocky site dominated by fallen woody debris and overhanging trees. Our sites in Burt Lake were the State Campground in Maple Bay off Maple Bay Rd. (BL1, the marly site) and Kings Point Boat Launch off Ellinger Road further south (BL2, the woody debris site.) (Fig. 1) Our sites in Douglas Lake included a site just north of Hook Point in North Fishtail Bay (DL1, the marly site) and Grapevine Point, at the tip of South Fishtail Bay (DL2, the woody debris site.) (Fig. 1) All sampling was done between July 21st and July 29th, 2008.

Habitat Evaluation

To ensure that the habitats we were comparing were in fact similar, we used quadrat evaluation to compare vegetation and substrate among sites. We deployed three one meter^2 quadrats in each site and quantified the substrate and any vegetation within. We used a modifed Index of Habitat Complexity (IHC) (Hook et. al., 2001) to calculate the complexity of habitat at each site using percent coverage values and number of growth forms of vegetation. Using our own slightly modified version of the equation already modified by Hook et. al. (2001), the area of benthic substrate covered by submergent macrophytes and the area of surface water covered by emergent macrophytes is evaluated on a "scale from 0 to 3 where; 0=open water; 1= >0%-33% coverage; 2= 34%-67% coverage; 3=68%-100% coverage." These numbers were used to calculate the IHC with the equation:

$$IHC = \frac{\left(\frac{A_{sub}}{3} \times \frac{F_{sub}}{2}\right) + \left(\frac{A_{emg}}{3} \times \frac{F_{emg}}{2}\right)}{2}$$

where A_{sub} is the area of substrate covered by submergent plants (by ordinal ranking as assigned previously), F_{sub} is the number of submergent growth forms (0-2) detected (rosette and/or flexus), A_{emg} is the area of open water covered by emergent plants (by ordinal ranking as assigned previously), and F_{emg} is the number of emergent and/or floating growth forms (0-2) detected. We define rosette species as those not possessing a vertical stem system (e.g. *Chara spp.*), while flexus species are those possessing a vertical stem system (e.g. *Schoenoplectus spp.*). Varying from the equation used by Hook et. al. (2001), we included woody debris and leaf litter as "submergent vegetation," counting it as a rosette form, as it has no vertical system. At BL2 and DL2, woody debris was prevalent and equally served the purpose of making the habitat more complex; thus we felt it deserved inclusion in the index.

Substrate size was evaluated according to a modified Wentworth Classification Scheme (Wentworth, C.K., 1922). We looked at what types and sizes of substrate material were present at each site.

Water Chemistry

We took water samples in acid-washed plastic Nalgene bottles twice at each site (the second samples a few days after the first) in undisturbed water just under the surface, and returned the samples to the UMBS chemistry lab for analysis. We measured total nitrogen, nitrate, ammonia, total phosphorus and phosphate. At the same sites we took a second water sample in non-acid-washed plastic Nalgene bottles. These samples were analyzed for levels of dissolved organic carbon and chloride.

We measured chlorophyll-a twice at each lake. To measure planktonic chlorophyll-a, we used a syringe to press lake water through and Millipore filter papers. The filter paper was then analyzed to determine the amount of chlorophyll-a (mg/L.) Benthic chlorophyll-a measurements were taken from 2-4 rocks collected from each lake, in total mg chlorophyll-a per unit area of rock.

PH was measured twice at each lake with a Fisher Scientific Accumet portable laboratory APGI pH meter. Conductivity was also measured twice at each lake with a YSI-30 conductivity meter. Dissolved oxygen levels were measured once at each lake with the Hach HQ30d DO meter. We also measured air and water temperature each time we visited a site with a standard alcohol thermometer.

Fish Sampling

We deployed a line of five minnow traps at each site (traps were four meters apart), with an anchor, float, and flag at both ends of each line. The lines started just offshore and ran out into the water, perpendicular to shore, so that a slightly different depth and local habitat were present at each trap. We baited each trap with 5-7 pieces of dog food each time we set them.

At each site, we emptied all of the traps three times, taking care to record exactly how long it had been since they were last emptied and set. Minnow traps in Burt Lake were emptied more frequently than those in Douglas Lake because of the high crayfish population; crayfish in the traps ate the trapped fish if left for too long. We also measured depth at each minnow trap.

We also seined a total of nine times at each site on two different days (six times one day and three times another day.) We used a 4.57 m (15 foot) seine, with two people on each end and one to two people scaring fish into the net. We seined in different locations each time, within 1.5 m of shore.

All collected fish, from seines and minnow traps, were identified to species and a haphazard sub-sample of the total was measured (standard length). Fish that could not be identified in the field were killed and preserved in formalin and taken back to the lab to identify; all other fish were identified in the field and released.

Statistical Analysis

We combined seining and minnow trap data from all sampling days at each site for a total of five replicates at each site (two seine samples and three minnow trap samples.) The unit of effort for seining was calculated as one haul and for minnow trapping as one trap set out for one day. We calculated species diversity of fishes for each site using the Shannon Diversity Index (Shannon 1948). We compared average diversity and average total abundance values with two sample t-tests (assuming unequal variances) between paired sites BL1 and DL1, BL2 and DL2, and between Burt and Douglas lakes as a whole, using an α value of 0.05.

We visually compared length frequency histograms of yellow perch (*Perca flavescens).* Yellow perch were common in each lake and are a popular local species of game fish. We also had a sufficient sample size of *P. flavescens* to examine length in each lake.

Finally, we compared water chemistry data on DOC, Cl-, NO3, NH4, PO4, Total N, and Total P with two sample t-tests (assuming unequal variances) between Burt and Douglas lakes as a whole, also using an α value of 0.05.

All graphing and statistical analyses were completed using Excel.

Results

Habitat Evaluation

None of the sites we studied had abundant vegetation, and thus all had relatively low IHC values. The IHC at BL1 was 0.139, 0.056 at DL1, 0.167 at BL2, and 0.278 at DL2. (Fig. 2) The substrate at each ranged from medium sand to pebble, according to the Wentworth scale.

Our data illustrate that paired BL1 and DL1 sites and BL2 and DL2 sites were relatively similar, as we intended. The habitat at BL1 was slightly more complex than at BL2 and traps were laid in a wider range of depths, but substrate and types of vegetation were very similar between sites. Each site also had a sandy beach dominated by bulrush, with deciduous trees beginning at least a meter away from shore. (Fig. 3)

Woody debris and fallen trees were common in both BL2 and DL2. Depth profiles and vegetation present were slightly different, but onshore vegetation was similar at each, with deciduous and coniferous trees growing up to the shoreline and overhanging the water. The substrate at each included pebbles mixed with a finer-grained sand. (Fig. 3)

Water Chemistry

Levels of chloride were significantly higher in Burt than in Douglas lake (t= 14.69524, df=3, p=0.000684). Dissolved organic carbon levels were significantly higher in Douglas Lake (t=-20.883, df=5, $p=4.66*10^{-6}$). In terms of nitrate, ammonium, phosphate, and total nitrogen and phosphate, we found no significant differences between Burt and Douglas lakes, although there tended to be higher levels of nitrate and ammonium in Burt Lake. Total phosphorus was slightly higher in Douglas Lake. (Fig. 4)

Both lakes were basic and similar in pH, with Burt Lake being very slightly more acidic. Burt Lake had a much higher conductivity and alkalinity than Douglas Lake. Douglas Lake, on the other hand, had higher levels of dissolved oxygen, at 9.77 compared to Burt Lake's 8.84. (Fig. 4)

Levels of chlorophyll-a did not appear to differ largely between the two lakes. The difference was greater in terms of planktonic rather than benthic chlorophyll-a, with Burt Lake showing slightly higher levels. (Fig. 4)

Fish Sampling

We collected 556 fishes in a total of 13 different species between all four sites over the course of our study.

a) Diversity of Fishes

Overall, average diversity index values were significantly higher for Burt Lake (0.753) than for Douglas Lake (0.245) (t=3.98, df=17, p=0.000976). (Fig. 5) They were also significantly higher at BL1 (0.658) than at DL1 (0.054) (t=5.026, df=6, p=.00238). However, there was no statistically significant difference between diversity at BL2 and DL2, although diversity index values were slightly higher at BL2 (0.848 as opposed to 0.436). (Fig. 6)

b) Species Richness of Fishes

Species richness was higher at BL1 (8) than at DL1 (3). It was also higher at BL2 (10) than at DL2 (5.) (Fig. 7) Overall, Burt Lake had a species richness of 11 as opposed to only 6 in Douglas Lake. (Fig. 8) The BL2 and DL2 sites, while they have lower diversity levels, had higher species richness compared to the other sites in the same lake.

There are however no statistical differences in species richness between sites and between lakes. There was no statistical difference in richness between BL1 and DL1 (t=1.319, df=4, p=0.257), between BL2 and DL2 (t=0.242, df=5, p=0.818), or between Burt Lake as a whole and Douglas Lake as a whole (t=0.787, df=12, p=0.447.)

c) *Abundance of Fishes*

Total catch per unit effort (CPUE) was higher on average in Douglas Lake, although these data were heavily influenced by one seine catch of over 300 fish, which was rather an anomaly. This catch was at DL2, which led to an average total CPUE for that site of 12.83 fish per seining/trapping effort. The average total CPUE for DL1 was much lower (0.61 fish per seining/trapping effort). Average total CPUEs in Burt Lake were slightly higher than this, at 2.08 fish per seining/trapping effort at BL1 and 3.53 fish per seining/trapping effort at BL2. (Fig. 9) The average total CPUE for Douglas Lake was thus higher than that for Burt Lake: 6.72 fish compared to 2.81. (Fig. 10)

Once again, however, there are no statistical differences in abundance between the sites and lakes. There was no statistical difference in abundance between BL1 and DL1 (t=0.912, df=5, p=0.403), between BL2 and DL2 (t=-0.971, df=4, p=0.386), or between Burt Lake as a whole and Douglas Lake as a whole (t=-0.779, df=10, p=0.453.)

d) *Size of Fishes*

The yellow perch we caught in Douglas Lake tended to be longer than those we caught in Burt Lake. The most populated size group in Douglas Lake was 8-10 cm, and the fish ranged from 4 to 11 cm. In Burt Lake the most populated size group was 4-6 cm, and the fish ranged from 2 to 8 cm. We also caught more yellow perch in Douglas Lake. (Fig. 11)

e) *Fish Community by Species*

There were several fish species found in Burt Lake and not in Douglas, with only smallmouth bass and bluegill being unique to Douglas Lake. Rock bass and a few minnows were found in both lakes. (Fig. 12)

f) *Diversity, Richness, and Abundance in Relation to IHC*

We graphed average diversity index values, richness, and average abundances for each site in correspondence with their calculated IHC values to see if there appeared to be any relationship. All three showed positive relationships: when habitat complexity, so did diversity, richness, and abundance. The trend was particularly obvious in the case of abundance, which had a positive slope of 56.68. (Fig. 13)

Discussion

Overall, Burt Lake has higher diversity than Douglas Lake. This pattern was also reflected in the comparison of paired sites BL1 and DL1, with BL1 having a higher diversity. (There was no statistically significant difference between BL2 and DL2.) Richness and abundance, however, were not statistically different between sites, although abundance tended to be greater in Douglas Lake, with richness being higher in Burt Lake.

Fish diversity could be higher in Burt Lake for a variety of reasons. Its size alone could result in a wider variety of habitats, leading to a greater diversity of fishes. The very fact that it is heavily used by humans could also lead to higher diversity: many fish are stocked there as game fish or food for the game fish, and small fish used as bait are frequently lost to roam free in the lake (Hanchin, P.A. et. al., 2005). Almost all of the species which were unique to Burt Lake are common bait species in the United States (Scott and Crossman 1973). It’s possible that these species exist in Burt Lake only because they have been used as bait and were thus released into the lake. Fish communities in both Burt and Douglas Lake both have histories of fish stocking, but today Burt Lake is more of an important lake for game fishing and has been stocked with game fish, particularly walleye, since 1925 (Hanchin, P.A. et. al., 2005). Douglas Lake was stocked beginning in the 1920s, but stocking essentially stopped after the ‘70s. Removals of white suckers and bowfin were also done in the ‘50s and ‘70s (Cwalinski, T.A., 2004.) These management efforts likely changed abundance and diversity values for both lakes; in Burt Lake, diversity is increased by stocking, but in Douglas Lake these effects have been halted, and in fact, species that now still exist in Burt Lake (i.e. the white sucker) were removed from Douglas.

There are several possible reasons for the lack of statistical differences in terms of richness and abundance. While we expected human development to noticeably affect the fish communities, other factors could be confounding the impact of the development. Burt Lake is so large that it might not be affected very much overall by its lakeshore development. A study from 1973 predicted that Burt Lake had a low sensitivity to development and would not be greatly affected by it in the future, mostly because of its large size (Taylor 1973).

Site selection also affected the data we recorded. The sites in Burt Lake were in the most undeveloped parts of the shoreline (chosen so that our minnow traps would not be disturbed by the public or residents on the lake.) Out of every site on the lake, Maple Bay and Kings Point (BL1 and BL2) were probably two of the least likely to be affected by human and boat traffic. These partially vegetated, secluded areas might have been used as refuges or spawning sites by all fishes in the lake, resulting in higher levels of fishes in these places. (This also could have contributed to the higher diversities there.) The sites in Douglas Lake, however, were in places affected strongly by currents and waves (Gannon, J.E. and E.J. Fee, 1970; Moffett, J.W., 1943). Both sites were also being used concurrently for other studies by University of Michigan students and were visited frequently by scientists on foot and in motor and pontoon boats.

Our graphs comparing habitat complexity with diversity, richness, and abundance of fish suggest that habitat complexity might have an even greater effect on these factors than human development. While we had low sample numbers for these comparisons, large trends were still apparent: diversity, richness, and abundance of fishes all appear to be positively affected by more complex habitats. These changes could be an indirect effect from human development, if habitats are simplified by development. Hook et. al. (2001) came to similar conclusions during their study in the upper Peninsula of Michigan, looking for differences in fish community in different wetland habitats. They found that the IHC value at each sampling site had a greater effect than the level of human development at that site, but also theorized that habitat complexity could be a result of human development effects. Further research on this relationship is suggested.

The differences in length in yellow perch possibly show a difference in trophic level structure between lakes. Yellow perch were larger and more frequent in Douglas Lake. This could be because they are caught by fishermen more often in Burt Lake than in Douglas Lake (Cwalinski 2004), so in Douglas Lake they have more time to grow and reach greater sizes and numbers.

Our water chemistry data, to some extent, does show that human development (or lack thereof) is having some effect on these lakes. Chloride was significantly higher in Burt Lake. Chloride is found in many products used by humans, such as road salt and bleaches. Rising chloride levels can also be a result of run-off of automotive fluids or sewage, and are almost always a sign of rising human development (Tip of the Mitt Watershed Council 2005). It follows that chloride would be higher in Burt Lake, and if it increases a great deal more, it could lead to detrimental effects on the fish communities (Tip of the Mitt Watershed Council 2005).

Although not statistically significant, there was a trend towards higher nitrate levels in Burt Lake. High levels of nitrate in lakes is also often a result of human activity, primarily run-off of lawn fertilizers or from faulty septic tanks (Tip of the Mitt Watershed Council, 2004). With less nutrient-enriching human activity around Douglas Lake, it follows that the waters there would have lower nitrate levels.

Conversely, dissolved organic carbon (DOC) levels were higher in Douglas Lake. The primary source of dissolved organic carbon is terrestrial input of leaf litter and woody debris. As Scheuerell and Schindler (2004) found, terrestrial inputs are limited by human lakeshore development, which is likely what caused the lower levels of DOC in Burt Lake.

Differences in alkalinity and conductivity, on the other hand, are probably best explained not by human development differences, but rather by underlying geology. Another study found that as water flows from Douglas to Burt Lake, it passes through limestone, which changes its pH and adds ions to the water (Schultz 1985).

In conclusion, development is having some effect on these two lakes, particularly in the area of water chemistry. However, there are clearly other factors at work influencing fish communities, possibly including habitat complexity, management practices by humans, or other physical factors, such as size of the lake. Our results on fish diversity (which is higher in Burt Lake), richness, and abundance make this clear. Further research is suggested on the effect of habitat complexity on fish communities, as well as on what other factors could be playing a role.

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