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[Management Brief]

Relationships Between Shoreline Development and Nest Site Selection by Black Crappie and Largemouth Bass

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Abstract.—To evaluate potential effects of lakeshore development on nest site selection, we compared locations of black crappie *Pomoxis nigromaculatus* and largemouth bass *Micropterus salmoides* nests in three Minnesota lakes with available habitat in the littoral and riparian zones and the presence or absence of developed shoreline. We used binomial logistic regression to determine how the frequency of nest sites varied among lakes and with the presence or absence of five habitat variables. Black crappies in all three lakes were more likely to nest adjacent to undeveloped shoreline. Black crappies were also more likely to nest in stands of emergent vegetation, particularly hardstem bulrush *Scirpus acutus*. Largemouth bass were more likely to nest near undeveloped shoreline but were less dependent on hardstem bulrush. Shoreline development has the potential to alter nest site selection by largemouth bass and, particularly, by black crappies.

North American lakeshores have been highly developed and altered by human activity. Alterations to shoreline areas have recently increased in Minnesota (Kelly and Stinchfield 1998). Coinciding with the rapid increase in development has been a change in the types of alterations to shorelines. Small, often seasonal cabins are being replaced with larger, permanent homes. These properties commonly have large, highly managed yards and beach areas.

The ultimate consequence of shoreline development is a decline in diversity of riparian and littoral habitat. Christensen et al. (1996) found that the amount of coarse woody debris along developed shorelines in Wisconsin and Michigan was substantially less than along undeveloped shorelines. Dramatic declines in native vegetation, particularly of riparian brush and emergent aquatic vegetation, have also been linked to housing development on northern Wisconsin lakeshores (Meyer et al. 1997). In a subset of Minnesota lakes, Radomski and Goeman (2001) found that emergent and floating-leaved vegetation in littoral areas adjacent to developed shorelines was less abundant than along undeveloped shorelines. They reported a 66% reduction in vegetative cover when development was present. Other human-induced changes in aquatic ecosystems include declines in the composition and density of macrophytes (Bryan and Scarnecchia 1992) and declines in the size and uniformity of substrates (Jennings et al. 1996).

Freshwater fish depend on littoral zone habitat for at least a portion of their life history. Black crappies *Pomoxis nigromaculatus* and largemouth bass *Micropterus salmoides* use littoral habitat to construct nests for spawning. Black crappies use areas of firm substrate usually associated with some type of macrophyte (Becker 1983; Pope and Willis 1997). Largemouth bass, while more cosmopolitan in their nest site selection, also have specific habitat needs. Shallow, protected sites in bays, among emergent vegetation or rocks, logs, and stumps are preferred largemouth bass spawning habitat (Miller and Kramer 1971; Annett et al. 1996). Any changes or alterations to those habitats could affect spawning success and recruitment.

Loss and degradation of habitat from development has raised concerns about how fish populations may be affected by increases in development. The objectives of this study were (1) to quantify the probability of nesting by largemouth bass and black crappies relative to five types of habitat, (2) to quantify the probability of nesting by largemouth bass and black crappies relative to the presence or absence of developed shoreline, and (3) to evaluate the effect of lakeshore development on depth of nesting by largemouth bass and black crappies.

Methods

Study sites.—Bergen, Crooked, and Cowdry lakes, all located in west-central Minnesota, were included in this study. All three lakes had self-sustaining populations of black crappie and largemouth bass. The lakes range in size from 62 to 96 surface ha (Table 1). Summer Secchi disk readings of each of the lakes

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approach or exceed 2 m (Minnesota Department of Natural Resources, unpublished). The fish communities of all three lakes consisted mainly of bluegill *Lepomis macrochirus*, largemouth bass, black crappie, northern pike *Esox lucius*, and yellow perch *Perca flavescens*. Lakeshore development ranged from 23% to 75% developed shoreline on the three lakes (Table 1).

Nest searches and habitat assessment.—Researchers located black crappie and largemouth bass nests during the spawning season in 2000 by navigating the entire circumference of each lake by boat. Nest searches were conducted in early morning to avoid wind and other water surface disturbances. Because water clarity in each of the three lakes was very good, locating nests of both species was possible in water depths exceeding 3 m. The location of each nest was entered into a GPS unit to eliminate duplicate nests from the data set. Nest searches continued each day until either the entire shoreline was circumnavigated or weather conditions (i.e., wind) made observations difficult. Searches continued until no spawning fish were found. Spawning activity for each species was synchronous and lasted approximately 3 weeks, from mid-May through early June, in all three lakes. The entire shoreline of each lake was surveyed a minimum of five times.

Habitat and shoreline alterations were measured at nest sites and at randomly selected sites on each lake. Depth (m) was measured at each nest site, and the presence or absence of emergent and submerged vegetation was noted for a 10 × 10-m area surrounding each nest. The presence or absence of canopy and understory layers for an area 10 × 10 m on the shoreline adjacent to each nest was also noted (Baker et al. 1997). Canopy cover included trees taller than 5 m, while understory included shrubs and bushes 3 m tall or less. Additionally, the shoreline adjacent to each nest was classified as either developed (i.e., the shoreline had been impacted by human activity) or undeveloped (i.e., shoreline had little or no human impact). Habitat variables were also measured at random sites around each lake. Starting from the center of each lake, random compass headings were used to locate sites on shore until a minimum of 5% of the shoreline of each lake was sampled (Baker et al. 1997); this protocol ensured that all available habitat types would probably be included in surveys. Random sites included a 10 × 10-m area on the shoreline and a 10 × 10-m area that extended into the lake. Random sites were also classified as either developed or undeveloped and were checked for the presence of nests. No largemouth bass nests were found within the random sites. Abandoned black crappie nests were located in several of the random sites, but because they had been abandoned, most likely due to a cessation of spawning activity, they were included in analyses as random sites.

TABLE 1.—Physical characteristics of Bergen, Cowdry, and Crooked lakes, Minnesota, in 1999.

Lake	Area (ha)	Shoreline length (km)	Percent developed shoreline
Bergen	74	4.2	66
Cowdry	96	4.8	75
Crooked	62	4.5	23

Statistical analysis.—Our design was a case control study, and the primary objective of the analysis was to determine how frequency of nest sites varied across three lakes and the five different binomial (i.e., presence or absence) habitat variables (canopy, development, emergent vegetation, submergent vegetation, and understory) (Keating and Cherry 2004). We analyzed each habitat variable in a separate analysis. The analysis was a standard logistic model with a binomial response variable expressed as the fraction of particular habitat types with a nest present. Thus, in the logit form the model is logit (probability nest present) = b0 + b1 × "habitat" + b2 × "lake," where "habitat" is presence or absence of one of the five habitat types that we examined and the "lake" effect considers differences in nesting frequency across the three study lakes. The model above is simplified because the lake effect was actually a factor with two levels. We used the Arc software package for this analysis (Cook and Weisberg 1999); the software and accompanying tutorial are available online (www.stat.umn.edu/arc/software.html).

Our primary interest was to determine if the test for habitat was significant. If this test was significant, then the logit (log odds ratio for a nest being present versus not present) is significantly different than zero. A positive logit (or log odds ratio) indicates a preference for a particular habitat type, while a negative value indicates avoidance. The test for lake indicates if nesting frequency differed among lakes. However, our primary motive for including multiple lakes was to determine if preference or avoidance for specific habitats varied among lakes. This would therefore constitute a test for the habitat×lake interaction in the model statement above, which is not possible because such a test would constitute a saturated model (i.e., no degrees of freedom). We therefore proceeded as follows to confront the issue of a lake effect. First, we used likelihood ratio tests (LRT) for the habitat effect first, followed by the lake effect. A nonsignificant LRT for the lake effect indicates no differences in nesting frequency among lakes, and thus the habitat×lake interaction is statistically meaningless. In

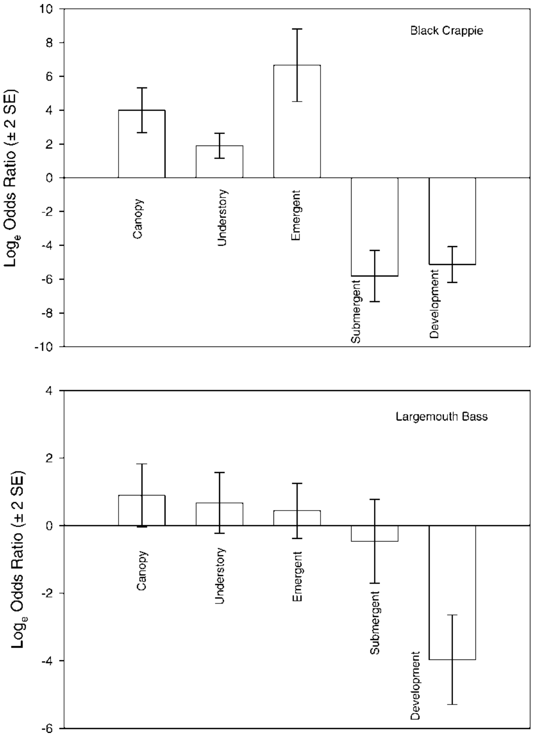

FIGURE 1.—Log odds ratios for black crappie and largemouth bass for five habitat measurements from Bergen, Cowdry and Crooked lakes, Minnesota. A positive ratio indicates preference for a particular habitat, and a negative ratio indicates avoidance. For black crappie, all ratios were highly significant ($P < 0.00005$). For largemouth bass the log odds ratio was only significant for developed shorelines ($P < 0.00005$).

cases where the LRT test for lake was significant ($P < 0.05$), we then examined the observed proportions of nests in the presence and absence of a habitat type among lakes to see these proportions relative to a specific habitat metric were consistent across lakes. For example, if one lake had a higher proportion of sites along undeveloped shoreline than developed shoreline while the other lakes had the opposite associations between the proportions of sites relative to developed and undeveloped shoreline, this would indicate a strong interaction effect, indicating a habitat type was preferred in some lakes and avoided in others.

To determine the effect of development (developed or undeveloped) and lake on the mean depth of nests constructed by both species, we used a two-way analysis of variance (ANOVA). The interaction between two main effects was included in the model, and a Tukey's honestly significant difference (HSD; alpha = 0.05) was then used to test for differences in mean depths between lakes.

TABLE 2.—Statistics from binomial logistic regression analysis of black crappie ($n = 478$) and largemouth bass ($n = 119$) nest site data. Estimated log odds ratio (SE, P-value) for each habitat type in the binomial regression model that included both habitat and lake effects, and the likelihood ratio test statistic (P-value) for adding a lake effect to the model that already includes the habitat effect, and thus testing if the logs odds ratio is different across lakes.

Habitat Type	Habitat effect	Lake effect
Black Crappie		
Canopy	3.992 (0.665, 0.000)	3.108 (0.211)
Emergent vegetation	6.651 (1.076, 0.000)	4.315 (0.116)
Submergent vegetation	−5.816 (0.757, 0.000)	8.071 (0.018)
Development	−5.132 (0.525, 0.000)	1.474 (0.479)
Understory	1.896 (0.368, 0.000)	0.857 (0.652)
Largemouth bass		
Canopy	0.893 (0.467, 0.056)	0.598 (0.742)
Emergent vegetation	0.438 (0.407, 0.281)	0.088 (0.957)
Submergent vegetation	−0.467 (0.620, 0.451)	0.007 (0.932)
Development	−3.966 (0.663, 0.000)	7.610 (0.022)
Understory	0.671 (0.449, 0.135)	0.016 (0.992)

Results

We examined the habitat associated with 478 black crappie nests and 119 largemouth bass nests. Nest depths ranged from 0.32 to 3 m for largemouth bass and from 0.25 to 1.5 m for black crappies. Black crappie nest site selection indicated a high degree of habitat specificity. Estimates of log odds ratios for black crappies were highly significant ($P < 0.00005$) for all five habitat measurements (Figure 1; Table 2). These results indicated that black crappies showed a preference to nest near shorelines with canopy, emergent vegetation, and understory, while avoiding submergent vegetation and developed shorelines. The LRT for the lake effect was significant only for the submergent vegetation factor (Table 2). However, examination of proportions of nests in each lake associated with this habitat factor indicated that avoidance of submerged vegetation was consistent across lakes (Figure 2, top). This further suggests that if the habitat×lake effect was significant (i.e., the log odds ratio varied among lakes) it was not of biological significance because it did not appear that the sign of the ratio changed. A change in the sign of the ratio would indicate that black crappies might prefer this habitat type in some lakes and avoid it in others.

In contrast to black crappies, largemouth bass showed fewer nest habitat preferences, though the sign (positive or negative) of all five logits was the same. Developed shoreline was the only attribute that had a strongly significant effect, with largemouth bass avoiding developed shorelines for nesting (Figure 1).

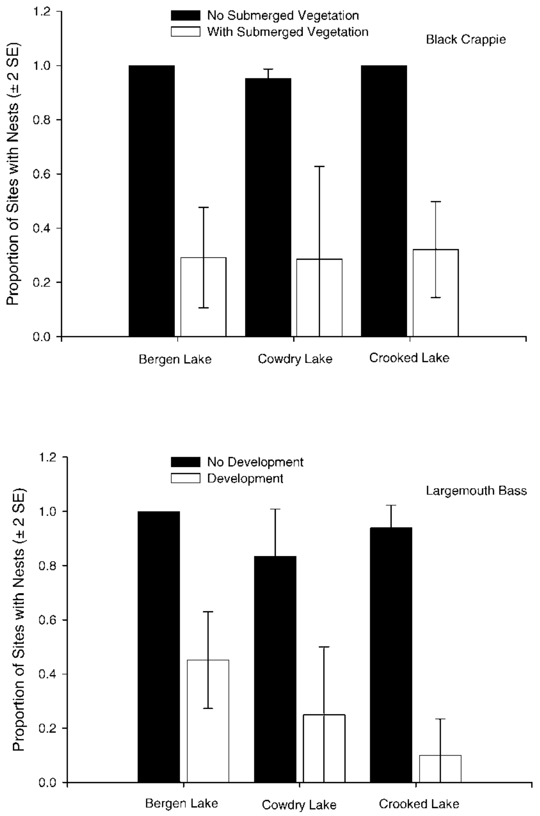

FIGURE 2.—Proportion of nests relative to presence or absence of a particular habitat type in Bergen, Cowdry, and Crooked lakes, Minnesota, for cases where the likelihood ratio test (LRT) for the lake × nest effect was significant. Top: Black crappie for submerged vegetation (LRT $P = 0.018$). Bottom: Largemouth bass and developed shorelines (LRT $P = 0.022$).

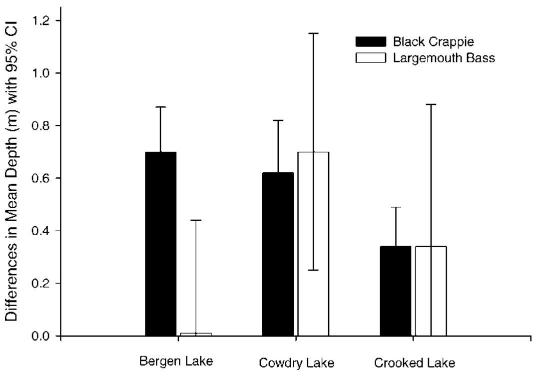

FIGURE 3.—Mean depth (m) of nests along developed shorelines minus mean depth along undeveloped shorelines for black crappie and largemouth bass in Bergen, Cowdry and Crooked lakes, Minnesota (with 95% confidence intervals). Differences for largemouth bass in Bergen and Crooked Lakes were not significantly different than zero, and thus the lower limit of the confidence interval is less than zero and not shown on the figure.

Although the test for canopy was not significant ($P = 0.056$), this attained significance level suggested some preference for nesting along shorelines with canopy. The LRT for the lake effect with the development habitat factor was significant ($P = 0.022$). However, examination of proportions of nests in each lake in the presence and absence of developed shorelines indicated that avoidance of developed shorelines was consistent across lakes (Figure 2, bottom).

Black crappie nests located adjacent to developed shoreline were significantly deeper than those found near undeveloped shoreline in all three lakes (Figure 3). Largemouth bass nests in Crooked and Cowdry lakes that were adjacent to developed shoreline were deeper than those adjacent to undeveloped shoreline; however, only those in Cowdry Lake were significantly deeper (Figure 3).

Discussion

We identified a significant relationship between human activity along the shores of three lakes included in this study and nest site selection of black crappies. Analyses showed the strong preference for nesting adjacent to shorelines with emergent vegetation, understory, and canopy cover. This is likely due to the fact that undeveloped shorelines are more likely to have stands of hardstem bulrush and other emergent vegetation, a phenomenon that is common to small centrarchid lakes in Minnesota (Radomski and Goeman 2001). It was very evident that black crappies had a strong affinity for nesting in and around stands of hardstem bulrush in all three lakes; overall, more than 90% of the black crappie nests that we located were within stands of hardstem bulrush. Radomski and Goeman (2001) found emergent and floating-leaved species more vulnerable and sensitive to human activities, and estimated the loss of emergent and floating-leaved vegetation might reach 45% by 2010. Thus, as current development trends continue, the strong preference for nesting in hardstem bulrush could become a liability for black crappies. Loss of emergent vegetation may potentially create a situation where black crappies are continually crowded into the remaining stands of emergent vegetation. Black crappies not only nest in emergent vegetation, they also tend to seek nest sites that offer the greatest protection from wind and waves (Pope and Willis 1997). Concentrating spawning fish into small, fragmented habitats that are not protected from wind and waves could make them more susceptible to weather-induced recruitment failures. For example, Cowdry Lake has two small stands of hardstem bulrush where most of the black crappie spawning activity occurred during this study. Both of these locations are located in areas that make them especially vulnerable to north and south winds. Conversely, Crooked Lake is largely ringed with hardstem bulrush, so even if a portion of the lake was affected by high winds, other areas would remain unaffected.

Black crappies also selected nest sites adjacent to shoreline with understory. The presence of understory actually determining a nest site is doubtful; however, the selection for areas with understory reinforces their preference for undeveloped shoreline. Meyer et al. (1997) showed that shrubs and other understory plants were substantially reduced on developed shoreline. Although a direct relationship between understory presence and nest selection is lacking, we cannot rule out physical or chemical changes that may occur in the nearshore littoral area when understory vegetation is removed. Research examining the effects of understory vegetation removal on the nearshore littoral area is therefore warranted. Furthermore, the presence of black crappie nests in substantially deeper water near developed shoreline suggests that they prefer to nest in areas that are less disturbed by human activity. Deeper nests could partially isolate them from human water activity such as boating and other visual disturbances. Therefore, we suggest that black crappies may be using greater water depths and distances from shore as surrogates for hardstem bulrush, understory, or other cover.

We found largemouth bass to be less affected by development than black crappie. Although largemouth bass were affected to a lesser degree in their selection of nest sites, they were nonetheless influenced by human activity and development. They did avoid developed shoreline when constructing nests, but did not show a preference for either type of aquatic vegetation or canopy cover; this indicates that they will tolerate some degree of development. Only largemouth bass in Cowdry Lake nested in deeper water when adjacent to developed shoreline. This further illustrates the cosmopolitan nature of largemouth bass; overall, they were much less influenced by human activity than were black crappies.

Because they are not colonial nest builders, largemouth bass are less susceptible to weather-induced recruitment failures (e.g., wind and wave action). Largemouth bass were not as dependent on hardstem bulrush when selecting nest sites and are, therefore, likely to be less affected by the anthropogenic loss of emergent vegetation. Furthermore, if largemouth bass are similar to smallmouth bass *Micropterus dolomieu* in their reproductive strategy, only a few successful nests are required to produce a viable year-class (Raffetto et al. 1990; Gross et al. 1994).

Various researchers have found that both black crappie and largemouth bass appear to be somewhat tolerant of some forms of degraded conditions (Jennings et al. 1999; Whittier 1999; Drake and Pereira 2002). This is contrary to our results, particularly for those pertaining to black crappie. However, unlike broad-scale studies of biotic integrity, we examined only the reproductive needs for each species. Therefore, we believe our results are due to local habitat alterations rather than large-scale stressors. The differences between our results and those examining biointegrity at a much larger scale demonstrate the importance of examining the effects of human alterations to aquatic life at multiple scales.

The compatibility between lakeshore development and centrarchid nest site selection is apparently low. In all three study lakes, hardstem bulrush was found growing in areas with hard sand bottoms, areas that are sought out by prospective developers and homeowners because they provide the best recreational potential. However, these are the same areas that spawning centrarchids, particularly black crappie, seek for nest construction. Removal of emergent vegetation usually accompanies shoreline development (Radomski and Goeman 2001). The removal of emergent vegetation in Minnesota lakes is regulated by the Department of Natural Resources. Permits are issued that allow the removal of emergent plants to provide a channel to open water that is no more than 4.6 m wide. Permits are currently issued regardless of the amount of emergent vegetation that exists on the lake. Furthermore, losses of vegetation from boat activity have been documented in other systems (Kahl 1993; Ostendorp et al. 1995), and the permitting process does not take these losses into account. Further research on cumulative loss of aquatic vegetation, particularly emergent vegetation, would support further refinement of regulatory policy.

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