# Cumulative Effects of Incremental Shoreline Habitat Modification on Fish Assemblages in North Temperate Lakes

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*Abstract.*—To evaluate effects of habitat modification at different spatial scales, we assessed species richness and tolerance of fish assemblages in littoral zones of 17 Wisconsin lakes with extensive residential and recreational development, and compared fish associations among site-specific and lakewide conditions. Samples consisted of combined DC electrofishing and seining. Stations were randomly selected within strata defined by type of shoreline erosion control structure, including retaining walls, rock riprap, and no structure. Habitat characteristics differed among the site types. Species richness at the site level was greatest in complex habitat (riprap) regardless of fish assemblage structure. However, more effort was required to achieve complete sampling of fish species present in sites without erosion control structures. This result may be related to homogeneity of habitat among sites altered by manmade structures. We used an analysis of covariance (ANCOVA) to compare site level habitat effects with basin scale impacts as indexed by total phosphorus, which is affected by land use in the riparian zone and surrounding watershed. Although species richness is positively correlated with local habitat complexity across the range of lakes sampled, assemblage structure, assessed as proportion of intolerant or tolerant species, shifted in response to cumulative effects. Habitat management programs, such as shore land zoning and permitting, should consider the cumulative effects of small habitat modifications in addition to local effects.

Changing land use patterns and incremental changes to riparian areas and nearshore littoral zone habitat alter north temperate lakes. Anthropogenic activity alters structural elements of aquatic systems, such as composition and density of macrophytes (Bryan and Scarnecchia 1992), quantity and composition of shoreline habitat such as woody debris (Christensen et al. 1996), and size and uniformity of substrate particles (Jennings et al. 1996). Human activity throughout watersheds causes changes to the landscape that affect water quality through runoff of nutrients, sediments, organic material, and contaminants. Although fish–habitat relations have been extensively studied in streams (Gorman and Karr 1978; Schlosser 1982; Angermeier and Karr 1984; Marcus et al. 1990), biological consequences of changes to physical habitat in lakes are poorly understood. Studies directly addressing links between habitat modification and effects on fishes usually have focused on single species of game fish (Hoff 1991) or on predator–prey interactions (Savino and Stein 1982).

Studies of variation in lake community structure, while useful for understanding patterns of distribution (Tonn and Magnuson 1982; Tonn et al. 1983; Benson and Magnuson 1992), have generally not addressed response to anthropogenic habitat change.

Most alterations of littoral zone habitat in central North America are incremental and cumulative, occurring primarily at the spatial scale of individual recreational and residential properties. Broad objectives of maintaining ecosystem function at landscape scales are addressed piecemeal, in part through management tools such as regulatory programs (zoning, permitting programs) or other mechanisms (easements, cooperative agreements) at this highly fragmented, local scale. At odds are concern for ecosystem function and the widespread perception that minor localized modifications are insignificant. The issue of cumulative effects has acknowledged importance in the conservation and management of aquatic systems (Panek 1979; Burns 1991), yet only recently have studies addressed the association between incremental shoreline habitat modification and effects on riparian areas, near-shore habitat, littoral habitat, and aquatic communities (Bryan and Scarnecchia 1992; Beauchamp et al. 1994; Ward et al. 1994; Christensen et al. 1996).

Measuring a biological response to anthropogenic disturbance is conceptually simple, but lakes present challenges stemming from their inherent variability in chemistry and morphometry, unknown lags in response time, confounding effects of fisheries harvest and management, and natural variation in assemblage structure resulting from historical processes (Burr and Page 1986; Underhill 1986). Because of these issues, results of single-lake studies may not be generally applicable, even within a region. In addition, structural habitat alteration and changes to water quality typically occur concomitantly, confounding results of single-lake studies attempting to measure effects of one of these factors. Measuring fish–habitat associations across a broad range of system conditions allows tests of hypotheses concerning site level habitat differences within lakes as well as cumulative effects of development among lakes. These cumulative effects include both alteration of physical habitat in the littoral zone and the increase in nonpoint inputs of nutrients, silt, and contaminants, which can result from numerous activities including roads, buildings, septic systems, agriculture, and vegetation removal.

In this study, we investigated fish assemblage structure in relation to small-scale shoreline alterations on residential and recreational lakeshore property. Although the individual property might be viewed as the appropriate level of analysis given the regulatory environment of lakeshore development, differences in habitat characteristics among sites might affect sampling efficiency and, therefore, the adequacy of single sites as sample units. Therefore, we investigated the question of appropriate sample effort to evaluate relations between local habitat modification and the fish assemblage. In addition, we used trophic state, which is related to both natural characteristics of the watershed and nonpoint inputs of nutrients, as an index of cumulative impacts at the basin scale. Our overall objective was to evaluate the relation between habitat modification and fish assemblage structure at different scales including habitat types within lakes and among lakes with different levels of cumulative impacts.

## Methods

### Shoreline Habitat Data Set

Physical habitat was quantified in the near-shore littoral zone in 17 Wisconsin lakes (Figure 1; Table 1). Lakes were widely distributed across most of the state with the exception of the southwestern driftless region, which has few lakes. Lake shorelines in all cases had some residential development, although the lakes varied in quantity of shoreline development and patterns of basin land use.

Within lakes, study sites were randomly selected within strata that represented three different treatments defined by commonly occurring shoreline management practices. Shoreline treatments were defined as modified with addition of rock riprap (riprap), modified with construction of retaining walls (wall), or unmodified by addition of a structure (no structure). We used the term "no structure" because sites were selected randomly with respect to other modifications such as paving or vegetation removal in the riparian zone; therefore, these sites were not necessarily natural or unaltered. The 300 study sites contained a minimum of 25 continuous meters of each shoreline type ($N$ = 6 of each type within lakes except in Lake Winneconne, where $N$ = 4 of each); this distance was typical of minimum lot widths on many lakes, and therefore represented the increments at which habitat modification occurred. Habitat differences among shoreline types are described in detail elsewhere (Jennings et al. 1996) and summarized in

FIGURE 1.—Map of Wisconsin indicating locations of study lakes. See Table 1 for morphometry data.

TABLE 1.—Lake morphometric and trophic state index of total phosphorus (TSTP) for the study lakes (NA means not available).

| Lake | Area (ha) | Depth (m) | | TSTP |
|------|-----------|-----------|-----|------|
| | | Maximum | Mean | |
| Big Silver | 139 | 15 | 6 | 50.5 |
| Camp | 186 | 6 | 2 | 44.0 |
| Chetek | 311 | 7 | 4 | 70.6 |
| Clark | 351 | 8 | 2.5 | 34.6 |
| Fox | 1,062 | 6 | 2.5 | 78.5 |
| Kawaguesaga | 271 | 13 | 5 | 47.3 |
| Mead | 129 | 5 | 2 | 78.4 |
| Minocqua | 550 | 18 | 7 | 44.7 |
| Minong Flowage | 651 | 6 | 3 | 57.6 |
| Nagawicka | 371 | 27 | 11 | 44.1 |
| Nebagamon | 369 | 17 | 6 | 44.7 |
| Park | 126 | 8 | 2.5 | 75.8 |
| Ripley | 169 | 13 | 5 | 50.1 |
| Shawano | 2,454 | 12 | 3 | 55.4 |
| Silver | 187 | 13 | NA | 47.3 |
| Wind | 378 | 14 | 3 | 55.1 |
| Winneconne | 1,824 | 3 | NA | 65.6 |

Table 2. Selection of wall and riprap sites was random with respect to construction material or rock type and size; this information is also described by Jennings et al. (1996).

*Water Quality*

We used existing Wisconsin Department of Natural Resources databases to generate a trophic state index, TSTP (trophic state index using total phosphorus; Carlson 1977) for the 17 lakes. This index (Table 1) provides an overall indication of productivity and is based on available summer total phosphorus. We assume that TSTP will generally increase with cumulative sources of watershed modification. The rate of increase will obviously depend on both intensity of land use and natural characteristics of soils and hydrology; however, our purpose is to seek general, robust trends in fish assemblage characteristics across a range of conditions rather than to produce quantitative models of phosphorus loading.

*Fish Collections*

Fish samples were taken with a combination of electrofishing and seining. Both gears were em-

TABLE 2.—Summary of habitat differences between shoreline types. All habitat variables differ among site types (Kruskal–Wallis; 2 df; $P < 0.0001$). Table is modified from Jennings et al. (1996).

| Variable[a] | No structure | Riprap | Wall |
|---|---|---|---|
| Mean depth (cm) | 25.08 ± 0.82 | 33.34 ± 1.1 | 37.54 ± 1.5 |
| Mean minimum depth (cm) | 4.28 ± 0.52 | 7.51 ± 0.57 | 20.77 ± 1.6 |
| CV of minimum depth | 58.44 ± 6.2 | 65.3 ± 5.0 | 26.58 ± 3.6 |
| CV of the mean depth | 58.18 ± 1.3 | 52.65 ± 1.2 | 39.34 ± 1.8 |
| Mean dominant substrate size category | 3.56 ± 0.06 | 3.84 ± 0.06 | 3.65 ± 0.08 |
| Mean embeddedness category | 4.11 ± 0.10 | 3.83 ± 0.09 | 4.19 ± 0.08 |
| CV of embeddedness | 22.23 ± 2.3 | 36.98 ± 2.2 | 20.59 ± 1.9 |
| Floating macrophytes (%) | 10.77 ± 2.2 | 7.44 ± 1.9 | 4.38 ± 1.3 |
| Small woody debris (%) | 4.32 ± 0.87 | 0.66 ± 0.12 | 1.07 ± 0.80 |
| Medium woody debris (pieces/site) | 0.627 ± 0.13 | 0.068 ± 0.03 | 0.01 ± 0.008 |
| Large woody debris (pieces/site) | 0.737 ± 0.12 | 0.051 ± 0.02 | 0.042 ± 0.02 |

[a] CV = coefficient of variation.

ployed along a 15-m length of shoreline. The sample area extended 5 m out from shore or to the 1-m depth contour (minimum of 4 m from shore), and was enclosed by a 5.6-mm-mesh block seine. Fish abundances in sites 4–4.9 m wide were standardized to a 5 × 15-m area; this involved only 15 of the 300 sites. Three-person crews used a towed DC generator and two electrodes to make two electrofishing passes through the site. This gear was effective in drawing small fishes from complex shoreline habitat, and was effective in sites where a seine could not be effectively maneuvered through or around woody structure or coarse substrates. After electrofishing, sites were also sampled with a 5.6-mm-mesh bag seine, which effectively sampled fishes throughout the water column. The combination of gears was selected based on evaluations of boomshocking, fyke nets, wading electrofishing, and seining (wading electrofishing and seining evaluated with and without block nets), which were conducted in the habitats of interest (Jennings et al. 1996).

*Statistical Analyses*

*Fish relations to habitat.*—Differences in habitat characteristics among sites might affect sampling efficiency, and therefore, the adequacy of single sites as sample units. To address this issue, we evaluated the relation between habitat type and sample effort required to approach an asymptotic estimate of species richness. This was accomplished through the use of segmented asymptotic regression (Snedecor and Cochran 1980). In this analysis, species additions were regressed against a number of sampling sites for each habitat type resulting in three distinct asymptotic regression equations. Each equation was composed of a quadratic or inflected segment and a linear or flat segment resulting in an asymptotic model (SAS Institute 1990). In the quadratic segment of the asymptotic models, parameter estimates were compared between habitats for homogeneity of slopes to determine if differences existed between habitat types with regards to rate of species accumulation. This was accomplished by linearizing the quadratic segment of the model and comparing species accumulation between habitats by general linear models procedures (Neter et al. 1985).

*Local habitat versus basin scale impacts.*—We evaluated differences in species richness, abundance of intolerant fish, and abundance of tolerant fish among habitat types and along a gradient of lake productivity. The concept of tolerance has proven to be useful in assessing anthropogenic impacts in a wide range of aquatic environments and is widely used in biological monitoring applications (Fausch et al. 1984; Karr et al. 1986; Lyons 1992). The use of tolerance designations focuses on the part of the assemblage most likely to respond to anthropogenic change, allowing an ecologically relevant analysis of a data set including lakes from a fairly wide geographic range and, therefore, slightly different species pools. Tolerance designations (Appendix 1) are based on Lyons (1992) except for largemouth bass *Micropterus salmoides* and minnows *Pimephales* spp., which are based on findings of Whittier and Hughes (1998) in lakes of the northeastern USA.

We used TSTP values as the covariate in analyses of covariance performed with each of the fish
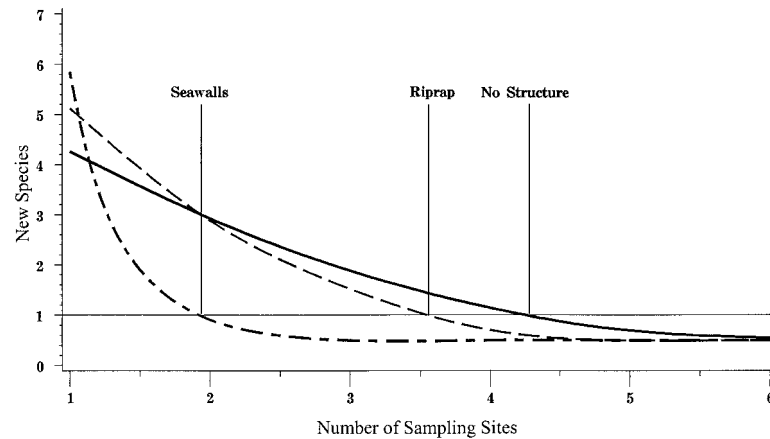
FIGURE 2.—Species accumulation curves for sampling effort at each of three shoreline habitat types. More effort was required to estimate species richness at sites without structures.

assemblage metrics (species richness, proportion of intolerant fish, and proportion of tolerant fish). Proportions of fish as tolerant or intolerant species used tolerance designations in Appendix 1 and included only fish age 1+ or older, whereas calculations of species richness included age-0 fish. To perform each analysis of covariance (ANCOVA), we used general linear models (SAS Institute 1990), in which the dependent variable was modeled as a function of site type, TSTP, and their interaction. The interaction term tests for homogeneity of slopes. If this term is not significant, the model is then run without the interaction. This analysis provided a way to evaluate the relative importance of watershed level impacts (TSTP) and localized differences in structural habitat in the littoral zone. Based on results of the asymptotic regression (see Results) species richness was also calculated by combining the replicates of each habitat type within lakes into a single cumulative estimate of species richness. Where the site type term was significant, differences among the three site types were evaluated by individual *t*-test of the least-square means within the GLM analysis.

The TSTP values were compared between lakes in northern and southern Wisconsin with analysis of variance (ANOVA). This analysis addressed the question of whether regional differences in TSTP could be confounded with zoogeography (Burr and Page 1986; Underhill 1986), affecting interpretation of assemblage tolerance as a response to basin scale impacts.

## Results

### Fish Relations to Habitat

Testing for the homogeneity of slopes revealed that the number of samples required to reach an asymptote of species richness was different among the three shoreline types ($F = 6.06$; df $= 2, 294$; $P < 0.001$; Figure 2). The asymptote was reached in fewest samples in the wall sites, which tended to be the least variable in habitat characteristics. The asymptote was reached in the greatest number of samples in the sites without structures, which tended to be the most variable. This result indicated that analyses of species richness should use pooled replicates of site types within lakes as the appropriate sample unit.

### Local Habitat versus Lake Productivity

The ANCOVA results demonstrated that relative abundance of intolerant and tolerant species varied significantly as a function of TSTP (Table 3; Figure 3). Intolerant species, primarily darters *Etheostoma* spp., mottled sculpin *Cottus bairdi,* smallmouth bass *M. dolomieu*, and rock bass *Ambloplites rupestris*, were rare or absent from most samples in highly productive (i.e., disturbed) systems, whereas they were frequently encountered in less productive systems, or systems with less disturbance in the watershed. Many of these species are also habitat specialists, mostly requiring benthic habitats with larger bottom substrate particle size. The TSTP effects in the models were stronger than the site type effects, suggesting that system-wide impacts were more important than localized habitat differences in determining relative abundance of fishes that are either intolerant or tolerant species. The TSTP did not differ between lakes in northern and southern Wisconsin ($N = 8$ north; $N = 9$ south; $F = 0.15$, df $= 1$, $P = 0.70$); therefore, values of tolerance metrics are not confounded with zoogeography.

TABLE 3.—Result summaries of ANCOVA for assemblage metrics as a function of habitat type (shoreline structure) and trophic state total phosphorus (TSTP). Upper section contains results for the interaction term, testing homogeneity of slopes; lower section contains results from the second step of the ANCOVA, in which the models are run without the interaction term. Two analyses are presented for species richness. The first treats each site as the sample unit, the second uses the cumulative samples of a site type within a lake.

| Dependent variable and source | df | Mean square | $F$ | $P$ |
|---|---|---|---|---|
| **With interaction term** | | | | |
| Species richness × TSTP | 2 | 0.80 | 0.09 | 0.92 |
| Species richness × TSTP | 2 | 1.43 | 0.10 | 0.90 |
| Proportion intolerant × TSTP | 2 | 0.00 | 0.06 | 0.94 |
| Proportion tolerant × TSTP | 2 | 0.01 | 0.11 | 0.89 |
| **Without interaction term** | | | | |
| Species richness | | | | |
| Habitat type | 2 | 45.86 | 5.08 | 0.007 |
| TSTP | 1 | 4.93 | 0.55 | 0.46 |
| Error | 296 | 9.02 | | |
| Species richness | | | | |
| Habitat type | 2 | 26.02 | 1.93 | 0.16 |
| TSTP | 1 | 3.81 | 0.28 | 0.60 |
| Error | 47 | 13.45 | | |
| Proportion intolerant | | | | |
| Habitat type | 2 | 0.039 | 0.45 | 0.64 |
| TSTP | 1 | 10.57 | 122.05 | 0.0001 |
| Error | 296 | 0.087 | | |
| Proportion tolerant | | | | |
| Habitat type | 2 | 0.047 | 0.85 | 0.43 |
| TSTP | 1 | 1.28 | 23.04 | 0.0001 |
| Error | 296 | 0.056 | | |

Species richness differed among site types in the analysis conducted at the site level (Table 3; Figure 4), with multiple comparison tests indicating that riprap sites had greater species richness than no structure sites ($P = 0.002$). Species richness did not differ between wall sites and no structure sites ($P = 0.17$), although the comparison between riprap and wall sites approached statistical significance ($P = 0.07$). These results suggest that
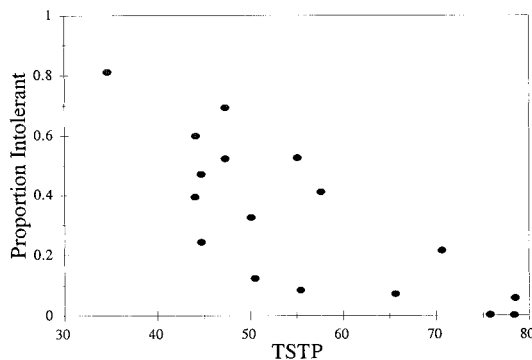


FIGURE 3.—Relation between a measure of assemblage tolerance (proportion of individuals that are intolerant species) and trophic state total phosphorus (TSTP), which provides an index related to basin-wide nutrient inputs.

although fish assemblage structure shifts in response to system-wide impacts, complex habitat (riprap tends to have high site level complexity) contains more fish species than simple habitat across the range of assemblage types sampled. The analysis using cumulative estimates of species richness from pooled replicates of site types within lakes (Figure 4) suggested a different, although nonsignificant, trend in the relation between no structure sites and wall sites. The trend for greater species richness in no structure sites compared with wall sites suggests that perceptions of appropriate scale of analysis may introduce sampling artifacts that affect interpretation of data.

## Discussion

### Fish Abundance and Shoreline Habitat Structure

This study used widespread and abundant shoreline modifications as a simple model of incremental habitat change in littoral zones of lakes. We observed a trend for sites with riprap shorelines to contain greater species richness than other sites; this result was independent of assemblage structure in the lake. This result is not surprising because riprap provides complex habitat with interstitial spaces for cover and food production. This result is consistent with analogous studies on
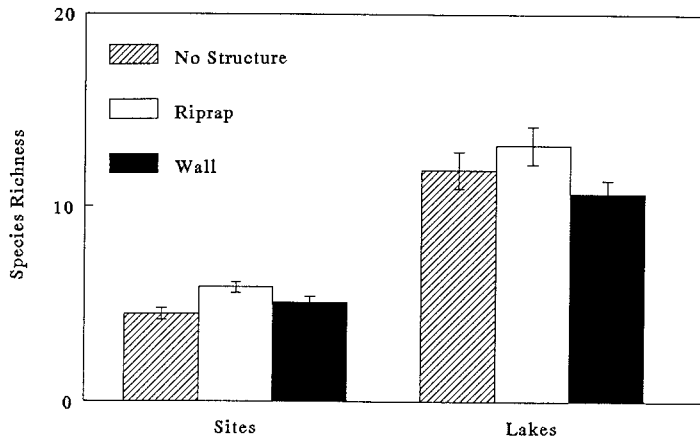
FIGURE 4.—Species richness (±SE) at sites defined by presence or type of shoreline structure. The first set of bars represents species richness at the level of sites ($N = 100$ for each site type), the increment at which habitat modification occurs. The second set of bars represents a cumulative estimate of species richness based on six replicate sites (four in Winneconne) within a lake ($N = 17$ for each site type).

streams where positive correlations between biota and habitat complexity are well established (Gorman and Karr 1978; Schlosser 1982; Hawkins et al. 1983; Angermeier and Karr 1984; Minshall 1984; Marcus et al. 1990).

Fish do not respond to shoreline structures; rather, they respond to a suite of habitat characteristics that are the result of the structure, changes to the riparian zone associated with its placement (vegetation and woody structure removal), and often, intensive riparian zone management that occurs on developed properties. The primary differences among the three shoreline types were depth, substrate particle size, and variability in habitat attributes such as depth and substrate embeddedness and amount of woody structure and floating macrophytes. Seasonally variable habitat attributes, such as emergent and submergent macrophytes, did not differ among the three site types (Jennings et al. 1996). Riprap sites have larger mean particle size, providing one type of habitat complexity. Wall sites tend to be deeper, primarily because the structures are placed below the ordinary high-water mark and then backfilled, in effect pushing the shoreline out from its original location to deeper water. Retaining wall sites were least variable in several habitat characteristics including depth and substrate embeddedness, had less woody debris, and as a group were most homogeneous. Sites without manmade structures had more woody structure, overhanging cover, and floating macrophytes (Table 2), all of which provide habitat complexity.

The greater heterogeneity (variability and presence of woody structure) among sites without manmade structures most likely contributes to the greater effort required to estimate species richness within sites of this category. Viewing the sites without structures at the lake scale (cumulative estimates of species richness rather than site scale estimates) leads to a different perception of species richness in comparison with other habitat types. The lake scale analysis is more appropriate although it has less power to detect differences and, therefore, a higher probability of type II error. This issue is important because a common perception of the public is that impacts of habitat alteration should be evaluated on a site by site basis, whereas biological attributes may be more appropriately measured at larger spatial scales. Although riprap may increase structural complexity at the scale of the individual site, when viewed at the scale of the whole lake, conversion of the entire shoreline to this one habitat type does not increase overall habitat diversity; rather, it causes a reduction. Because of this reduction of habitat diversity, conversion of unaltered shoreline to riprap should not be viewed as enhancement. However, when erosion control is a necessity, riprap appears to provide beneficial fish habitat compared with retaining walls.

## Basin-Scale Effects

Broad shifts in fish assemblage tolerance were observed across a gradient of water quality from systems with low TSTP values to systems with high TSTP values. The TSTP provides an index that is associated with nonpoint loadings, contrib-

uting to increased sedimentation (replacing coarse substrates with fines), increased nutrient inputs (changing turbidity and seasonal $O_2$ availability), and increased contaminant loadings—all of which affect fish habitat in a broad sense. With increased TSTP the intolerant portion of the assemblage diminished in abundance while tolerant species became more abundant. We interpret those shifts to suggest that as aquatic systems showed cumulative effects, tolerant generalist species replaced intolerant specialist species. Several of the intolerant species prefer coarse rocky substrates and would be expected to show positive association with good water quality and complex habitat (Becker 1983).

The shoreline structures evaluated herein provide a convenient way to assess fish response to shoreline habitat management but remain only one part of the issue of how lakeshores are developed. On most developed sites, multiple modifications to the riparian zone occur concomitantly, and separating their effects is impractical. In addition, detection of individual effects is complicated by lags between habitat modification and the realization of biological consequences. Many heavily impacted lakes in central North America did not undergo single large, drastic alterations but were subject to very small modifications to structural components of habitat and gradual shifts in land use. Justification of habitat protection should not depend solely on detection of site-specific changes in fish composition in response to incremental impacts, because such an approach is neither practical nor biologically meaningful. Defining the appropriate temporal and spatial scales to measure effects of habitat modification is important for supporting rule development for habitat protection programs and for education of the regulated community.

Management tools such as zoning or permitting programs are designed to prevent drastic alterations to natural systems, thereby conserving habitat heterogeneity, ecosystem function, and biological diversity. Biologically, the objective is to maintain ecosystem function at the landscape scale, but the regulatory tools apply to small shoreline fragments that are widely perceived to be ecologically insignificant. This study demonstrated that local habitat modifications lead to small changes in local species richness, but more importantly, assemblage structure responds at larger spatial scales, when many diverse incremental changes have accumulated within a basin over time. These results suggest that regulatory programs designed to protect ecosystem function by conserving small habitat fragments have merit, even if local responses to single perturbations are not immediately measurable. A useful next approach would be to explore cumulative habitat change within objectively defined limnological lake types and attempt to model responses of indicator species. Predictive, quantitative models might play a useful role in maintaining healthy lakeshore habitat by educating landowners and participants in the rule-making process about consequences of incremental habitat modification. Future work should concentrate on intolerant, habitat specialist species and should be designed with an awareness of appropriate scale.

## Acknowledgments

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## Appendix: Sampled Species

TABLE A1.—Fish species sampled in 17 Wisconsin study lakes. Calculations of species richness used all fish sampled. Assessments of assemblage tolerance used only fish age 1+ or older. Tolerance designations, where indicated, are based on Lyons (1992) and Whittier and Hughes (1998).

| Scientific name | Common name | Tolerance group |
| --- | --- | --- |
| *Lepisosteus osseus* | Longnose gar | |
| *Dorosoma cepedianum* | Gizzard shad | |
| *Umbra limi* | Central mudminnow | Tolerant |
| *Esox americanus* | Grass pickerel | |
| *E. lucius* | Northern pike | |
| *E. masquinongy* | Muskellunge | Intolerant |
| *Cyprinella spiloptera* | Spotfin shiner | |
| *Cyprinus carpio* | Common carp | Tolerant |
| *Luxilus cornutus* | Common shiner | |
| *Nocomis biguttatus* | Hornyhead chub | |
| *Notemigonus crysoleucas* | Golden shiner | Tolerant |
| *Notropis anogenus* | Pugnose shiner | Intolerant |
| *N. atherinoides* | Emerald shiner | |
| *N. heterodon* | Blackchin shiner | Intolerant |
| *N. heterolepis* | Blacknose shiner | Intolerant |
| *N. hudsonus* | Spottail shiner | Intolerant |
| *N. stramineus* | Sand shiner | |
| *N. volucellus* | Mimic shiner | |
| *Opsopoeodus emiliae* | Pugnose minnow | |
| *Pimephales notatus* | Bluntnose minnow | Intolerant |
| *P. promelas* | Fathead minnow | Intolerant |
| *Rhinichthys atratulus* | Blacknose dace | Tolerant |
| *R. catarctae* | Longnose dace | |
| *Semotilus atromaculatus* | Creek chub | Tolerant |
| *Carpiodes cyprinus* | Quillback | |
| *Catostomus commersoni* | White sucker | Tolerant |
| *Erimyzon sucetta* | Lake chubsucker | |
| *Moxostoma macrolepidotum* | Shorthead redhorse | |
| *Ameirus melas* | Black bullhead | |
| *A. natalis* | Yellow bullhead | Tolerant |
| *Noturus gyrinus* | Tadpole madtom | |
| *Percopsis omiscomaycus* | Trout-perch | |
| *Lota lota* | Burbot | |
| *Fundulus diaphanus* | Banded killifish | |
| *F. dispar* | Starhead topminnow | |
| *Labidesthes sicculus* | Brook silverside | |
| *Pungitius pungitius* | Ninespine stickleback | |
| *Morone chrysops* | White bass | |
| *M. mississippiensis* | Yellow bass | |
| *Lepomis cyanellus* | Green sunfish | Tolerant |
| *L. gibbosus* | Pumpkinseed | |
| *L. gulosus* | Warmouth | |
| *L. macrochirus* | Bluegill | |
| *Ambloplites rupestris* | Rock bass | Intolerant |
| *Micropterus dolomieu* | Smallmouth bass | Intolerant |
| *M. salmoides* | Largemouth bass | Tolerant |
| *Pomoxis annularis* | White crappie | |
| *P. nigromaculatus* | Black crappie | |
| *Etheostoma caeruleum* | Rainbow darter | Intolerant |
| *E. exile* | Iowa darter | Intolerant |
| *E. flabellare* | Fantail darter | |
| *E. microperca* | Least darter | Intolerant |
| *E. nigrum* | Johnny darter | |
| *E. zonale* | Banded darter | Intolerant |
| *Percina caprodes* | Logperch | |
| *P. shumardi* | River darter | |
| *Perca flavescens* | Yellow perch | |
| *Stizostedion vitreum* | Walleye | |
| *Aplodinotus grunniens* | Freshwater drum | |
| *Cottus bairdi* | Mottled sculpin | Intolerant |