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Different Approaches to Habitat Surveys Can Impact Fisheries Management and Conservation Decisions

Potential Impacts of Docks on Littoral Habitats in Minnesota Lakes

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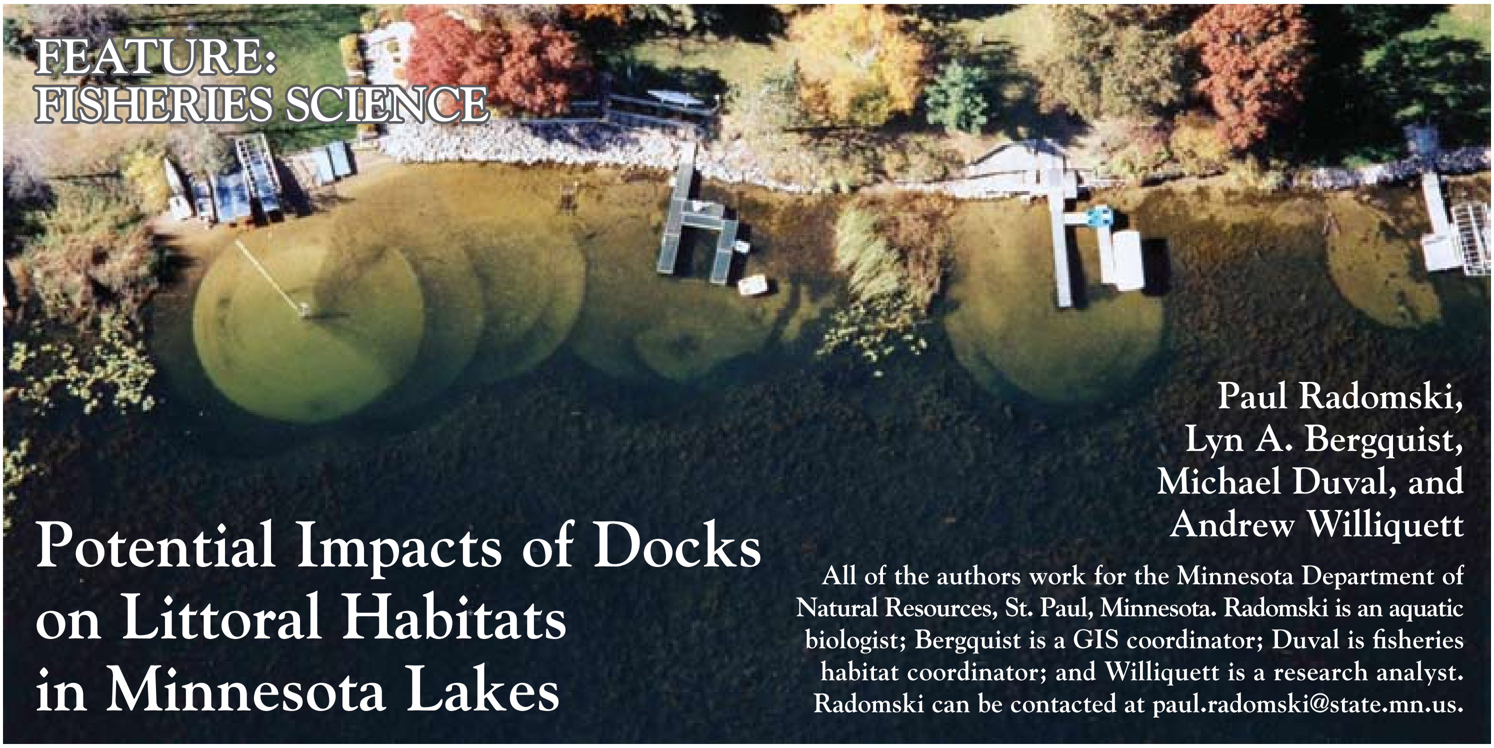

FEATURE: FISHERIES SCIENCE

Potential Impacts of Docks on Littoral Habitats in Minnesota Lakes

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ABSTRACT: To understand the potential impacts of docks on lake shoreline habitat, an inventory of docks across north-central Minnesota was undertaken and full build-out projections were simulated. Lakes were selected randomly from three lake development classifications (lake class), which define statewide minimum development standards for Minnesota. The three lake classes, in order of increasing restrictions for development, are general development, recreational development, and natural environment. Docks were pervasive along shores for many lakes. Over 14% of the shoreline and 3% of the littoral zone were estimated to be impacted by docks. Build-out scenarios estimated that up to half of the shoreline and 14% of the littoral zone could be impacted with future development. Shoreline development policies may need to be revised to address impacts to fish habitat and recreational surface water use.

Potenciales impactos de los muelles sobre los hábitats litorales en lagos de Minessota

RESUMEN: Con el propósito de comprender los impactos potenciales que tienen los muelles sobre los hábitats que se encuentran en las orillas de los lagos, se realizó un inventario de los muelles existentes a lo largo de la parte norte-central de Minnesota y se simularon proyecciones completas de construcción. Los lagos se eligieron al azar a partir de tres clasificaciones de desarrollo de lagos (tipo de lago) en las que se definen estándares estatales mínimos de desarrollo para Minnesota. Los tres tipos de lago, en orden ascendente según las restricciones de desarrollo, son: general, recreativo y de ambiente natural. Se observaron persistentemente muelles a lo largo de la orilla de varios lagos. Se estimó que más del 14% de la orilla y 3% de la zona litoral se encuentra impactada por los muelles. De acuerdo a las simulaciones se estimó que más de la mitad de las orillas y el 14% de la zona litoral puede verse impactada por desarrollos en el futuro. Es posible que las políticas de desarrollo costero deban revisarse detenidamente con el propósito de atender el impacto sobre el hábitat de los peces y el uso del agua con fines recreativos.

Introduction

Shoreline development alters littoral habitats of lake ecosystems. The near-shore of a lake often contains most of the vegetation and is generally the spawning area for fish. Since docks and other man-made structures are placed in these shallow areas, they can have a cumulative impact on aquatic habitat (Jennings et al. 1999). For instance, many dock owners clear out vegetation around their structures, while boating and swimming activity further cuts or uproots plants and suspends sediments. Payton and Fulton (2004) noted that Minnesota lakehome owners often kept an area devoid of aquatic plants on a year-to-year basis to provide swimming areas and boating access. Recreational activity and surface water use in the shallow near-shore can also alter or reduce fish habitat. Sediments can be re-suspended and aquatic plants can be destroyed (Beachler and Hill 2002; Asplund 2000).

Few studies have investigated lake habitat or fish use specifically associated with docks. Garrison et al. (2005) evaluated the effects of dock shading on fish and macrophytes in two Wisconsin lakes. They found significant shading under docks that reduced aquatic plant abundance and altered the aquatic plant community to favor shade-tolerant species.

Plant biomass under docks was significantly reduced compared to sites away from docks. The lower amount of macrophyte habitat under docks lead to a corresponding reduction in macroinvertebrates. In addition, juvenile centrarchid and minnow species showed preference for abundant macrophyte cover found in non-dock areas.

While few dock studies exist, there are numerous studies that have investigated lake habitat or fish use associated with developed shoreline. Docks are often the loci for human activities resulting in altered shoreline and aquatic habitat loss in their vicinity and they often serve as a potential marker for human disturbance on lakes; for example, Radomski and Goeman (2001) found that emergent and floating-leaf vegetation was reduced in areas associated with these structures. In an Iowa lake, Byran and Scarnecchia (1992) found significantly lower aquatic macrophyte abundance and lower fish species richness in near-shore areas of developed shorelines than in undeveloped shorelines. Christensen et al. (1996) found significantly less riparian woody habitat along developed compared to undeveloped shorelines in Wisconsin and Michigan. Brazner (1997) evaluated fish diversity in Green Bay of Lake Michigan and documented lower fish richness along developed shorelines compared to undeveloped shorelines. Jennings et al. (2003) also found that the amounts of littoral woody habitat and emergent and floating-leaf vegetation were lower at developed sites and at lakes with greater development density. Finally in a lake comparison study, Scheuerell and Schindler (2004) noted a significant decrease in fish aggregation with increased shoreline development likely due to loss of near-shore habitat and a reduction in water clarity.

Since dock areas may have less structural complexity than undisturbed areas, such as fallen trees along undeveloped shorelines (Newbrey 2005), fish may alter their activity around docks. Barwick (2004) observed that largemouth bass (Micropterus salmoides) abundance in the spring was generally higher along natural shore with fallen trees (wood) than along developed shore. Wagner et al. (2006) found that largemouth bass nest success was negatively related to lakeshore development for a set of Michigan lakes, and Reed and Pereira (2009) noted that developed shoreline might have reduced nesting locations for largemouth bass and black crappie (Pomoxis nigromaculatus) for a set of Minnesota lakes.

There are concerns about the rate of dock development, size of structures, and the associated impact on aquatic habitats for northern glacial lakes. The cumulative effect of having primarily developed shorelines may not be conducive to habitat diversity. Development pressure is increasing, as evidenced by increases in the number of docks per lake each year (Radomski 2006). We are unaware of any estimates regarding their ecological footprint. In an effort to understand the potential impacts of docks on lake shoreline habitat, an inventory of docks across north-central Minnesota was undertaken. This area has similar development patterns, land development ordinances, and dock regulations to many other northern lake-rich regions of North America. The objective of this study was to determine the ecological footprint of docks in north-central Minnesota lakes and, more importantly, to project the potential future ecological footprint based on full development build-out under existing regulations.

Methods

Our study site was a five-county area in north-central Minnesota, a lake-rich region currently experiencing high rates of shoreline development. Collectively, these five counties (Aitkin, Cass, Crow Wing, Hubbard, and Itasca) have more than 2,000 lakes on which shoreland development activities are regulated by Minnesota shoreland rules. Under these rules, lakes are classified into three types: general development (GD), recreational development (RD) and natural environment (NE) lakes, with increasingly restrictive development requirements moving from GD to RD to NE. We generated a sub-sample of 174 lakes across the study area using a stratified random sampling scheme to assure proportional representation of lakes from each county and lake class. Using ESRI Arcview 3.3 software, we then digitized 9,284 docks on the sub-sample lakes from summer 2003 and 2004 U.S. Department of Agriculture, Farm Service Agency, georeferenced aerial imagery. Each dock was categorized into one of seven classifications based on size and complexity (Table 1).

Digitized docks were buffered with a 25-foot (7.62-m) buffer to simulate the zone of impact (i.e., habitat impact zone) around a dock structure. Width of the buffer was based on one-half the median shoreline footage of aquatic vegetation removal permits granted to shoreline owners in the

Table 1. Description of the dock class used in the analysis, and the median, mean, and standard deviation of the dock size by dock class.

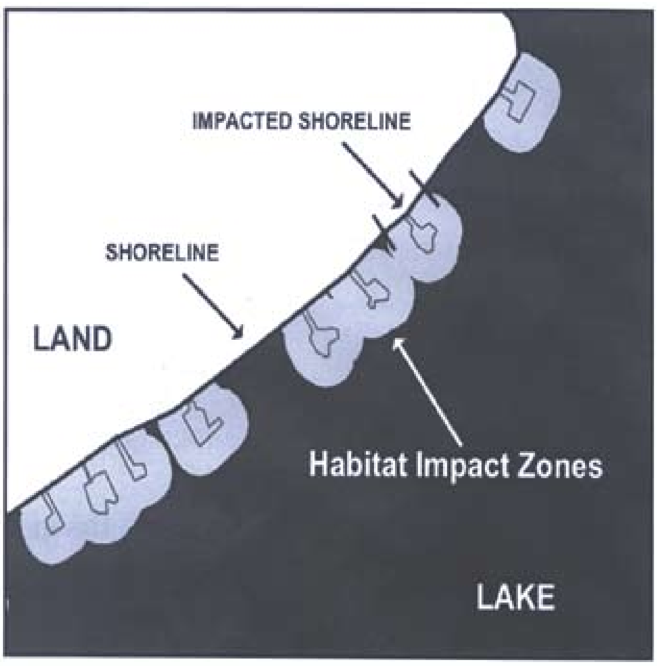
Dock Class	Dock Description	Number of Accessory Structures	Median (ft^2)	Mean (ft^2)	SD	Number Sampled
0	Simple dock with no boat lifts, slips or platforms	0	231	270	173	2201
1	Simple dock with one slip, lift or platform	1	404	450	234	3115
2	Complex dock with two slips, lifts, or platforms	2	603	665	300	2392
3	Complex dock with three or more slips, lift, or platforms	3	958	1075	523	1297
4	Marina (multiple adjacent docks)	multiple	3452	3671	1774	49
5	Swim platform (detached)		120	147	91	228
6	Other type of structure (e.g., atypical structures, fishing piers)		2614	2614	1466	2
All classes			449	560	173	9284

On many developed Minnesota lakes, docks are prominent features along the shore.
(Photo: Minnesota Department of Natural Resources)]

study area. The portion of buffered docks that overlapped with the shore was removed, decreasing the buffered areas by approximately 25%. The resulting buffered areas were dissolved together to form a cumulative habitat impact zone for each lake (Figure 1).

To quantify impacts on lake shoreline, we intersected the habitat impact zones with the shoreline linear features for each lake. Segments of shoreline where the buffered areas overlapped the shore were coded as "impacted shoreline," and were summed to obtain the total footage of impacted shoreline. To describe the current extent of impact by dock structures on lake shoreline, total lake acreage, and littoral zones across the study area, we calculated a series of statistics. The littoral zone was defined as the in-lake area from the shoreline to the 15-foot (4.6-m) depth contour, where aquatic vegetation is most prevalent. As digitized littoral zone data were available only for a subset of 31 lakes, the quantification of littoral zone impacts was constrained to this data set. The 31-lake subset was significantly more developed than the remaining 111 lakes in the randomly selected 142-lake set (mean number of docks per mile; t-test, $P < 0.05$); therefore, estimates of change in potential impacts with full build-out are likely to be underestimated.

Figure 1. A schematic showing habitat impact zones, which consisted of a 25-foot (7.62-m) buffer around docks and structures. The habitat impact zone was used to estimate associated impacts of dock structures on shorelines and littoral zones.



Build-out Scenario

After describing the impact under current conditions using the statistics above, we extrapolated the results to simulate a full development scenario as would be allowable under current Minnesota shoreland rules. We obtained GIS parcel layers for four of the five counties (142 lakes). We intersected the parcel polygons with the lake shorelines to transfer parcel attributes to the linear shoreline features. The percentages of public, private, and tribal-owned shoreline footage for each lake, county, and lake class were summed. We then selected all privately-owned, non-impacted shoreline segments and divided each by the minimum lot size allowed for the corresponding lake class. This generated the number of potential new lots available for development on each lake. Assuming that one dock would be built on each new lot, we multiplied the number of lots/docks by the mean shoreline impact (i.e., 2x the buffer width) to calculate the total footage of impacted shoreline.

To calculate the in-lake impacts on lake acreage and littoral zones, we performed full build-out analyses based on two scenarios. The first scenario assumed that new docks would be built in proportion to the percentages of dock class types that currently exist. In this case, we multiplied the frequency of each dock class by the total number of projected docks to get the number of projected docks in each class. Then we multiplied each dock by the median buffered size for its class. The second scenario assumed that all new docks would be of the largest basic type (class 3), consistent with the current trend towards larger and more complex dock types. In this case, we multiplied the projected number of docks by the median buffered size for dock class 3. In both scenarios, we summed the projected dock areas to obtain the total acreage of habitat impact zone by lake under the full build-out conditions.

Table 2. A summary of attributes by lake class for 174 north-central Minnesota lakes. HIZ represents habitat impact zone. Build-out analyses were based on a 142-lake subset. Percent shoreline ownership does not add to 100% due to a small amount of tribal ownership.

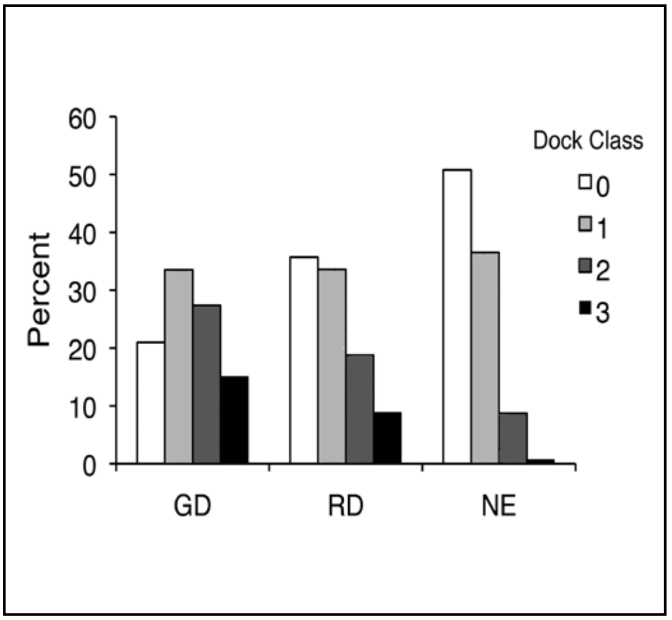
Attribute	General Development	Recreational Development	Natural Environment
Number of lakes	42	41	91
Number of docks (% of total)	7693 (83%)	1465 (16%)	126 (1%)
Mean number of docks/lake (N/lake)	183.2	35.7	1.4
Mean number of docks per lake surface acre (docks per ha)	0.141 (0.057)	0.083 (0.034)	0.018 (0.007)
Mean dock coverage in acres per lake (ha per lake)	2.4 (0.97)	0.4 (0.16)	0.0003 (0.0001)
Mean HIZ acres per lake (ha per lake)	16.96 (6.86)	3.35 (1.36)	0.12 (0.05)
Proportion of HIZ to lake surface area (% lake area)	1.37%	1.08%	0.13%
Build-out Analyses			
Shoreline ownership: private (existing % of total length)	89%	84%	52%
Shoreline ownership: public (existing % of total length)	11%	16%	47%
Increase in number of docks (N projected/N existing)	3.6x	4.8x	19x
Shoreline impacts (projected % of total length)	53%	36%	13%

Results

The average dock sizes by dock class type are summarized in Table 1. The median size of docks increases from dock class 0 to class 3. Dock classes 4, 5 and 6 were rare and not representative of typical structures seen in the study area. The mean number of dock structures per lake was 183.2 for GD, 35.7 for RD, and 1.4 for NE lakes (Table 2). The mean number of docks per lake acre (hectare) was 0.141 (0.057), 0.083 (0.034) and 0.018 (0.007), respectively. Across the study area, dock class 1 was the most common type of dock (34%), followed closely by dock classes 2 (26%), 0 (24%), and 3 (14%). Dock classes 4, 5 and 6 were much less prevalent, at less than 3% each. For GD lakes, the most common type of dock was class 1. For RD lakes, dock classes 0 and 1 were approximately equal. For NE lakes, dock class 0 was the most prevalent. The results show that moving from the less developed lake class (NE) to the most developed class (GD), there was a decrease in the percentage of simple docks and an increase in docks of greater size and complexity (Figure 2). GD lakes on average had 2.4 acres of dock structures along their shorelines.

The mean habitat impact zone size was 16.96 acres/lake (6.86 ha/lake) for GD lakes, 3.35 acres/lake (1.36 ha/lake) for RD, and 0.12 acres/lake (0.05 ha/lake) for NE lakes (Table 2). GD lakes accounted for 83 percent of the total habitat impact zone area, with dock class 1 being responsible for nearly one-third of that total. Across the study area, 1.2%

Figure 2. The percentage of docks in each dock class for general development (GD), recreational development (RD), and natural environment (NE) lakes. See Table 1 for dock class descriptions.



of the total lake surface area was impacted by dock structures. More importantly, 3.1% of the littoral zone habitat was impacted.

Regarding shoreline ownership, the ratio of private to public ownership for GD lakes was 89%:11%, for RD it was 84%:16%, and for NE lakes it was 52%:47% (Table 2). In a direct relationship with the number of docks and the amount of private shoreline ownership, the percentage of shoreline frontage impacted by dock structures was 19.7% for GD lakes, 9.4% for RD lakes, and 0.8% for NE lakes.

The build-out scenario added more than 25,000 docks to 142 study lakes in the four-county study area where we had GIS parcel data layers (Table 2). Under the full build-out scenario, the total number of docks increased 3.6-fold for GD lakes, 4.8-fold for RD lakes, and 19-fold for NE lakes. Although the total increase in number of docks is much higher for GD lakes than for NE lakes, the percentage increase for NE is five times higher due to the relatively undeveloped condition of NE lakes currently. The overall projected shoreline impact from dock structures under full build-out was 42%. The projected shoreline impacts by lake class were 53% for GD lakes, 36% for RD lakes, and 13% for NE lakes.

The projected impact on lake surface area by habitat impact zone increased overall from 1.2% to 4.8% under the full build-out Scenario 1 (i.e., new docks built in proportion to current percentages) and to 6.2% for Scenario 2 (i.e., all new docks are Class 3; Table 3). For the 31 lakes included in the littoral zone impact analysis, the shoreline impact under full build-out increased from 20.3% to 53.3% (Table 3). The lake surface area impacted by the habitat impact zone increased from 1.4% to 4.7% for Scenario 1 and to 6.0% for Scenario 2. The overall impacts on littoral zones increased 3.5-fold from 3.1% to 11.0%, and 4.4-fold from 3.1% to 13.8% for Scenarios 1 and 2, respectively.

Discussion

Dock placement into public waters is a riparian right common to Minnesota and elsewhere, and it is pervasive for most developed lakes. Because docks serve as a focal point for a host of human activities that result in lakeshore perturbations (e.g., shallow water boating, sand blankets for swimming beaches, chemical and mechanical removal of aquatic macrophytes, clearing of riparian vegetation for viewing corridors or lawns), quantifying docks is a sensible proxy for estimating these in-lake and near-shore habitat impacts from human development in shorelands. This study quantified the area impacted by these shoreline facilities in north-central Minnesota. Human development effects on near-shore aquatic habitats are only somewhat understood (Jennings et al. 1999; Radomski and Goeman 2001). Cumulative effects at the whole-lake scale are even less known, though some efforts to quantify impacts at these larger scales have been attempted (Radomski 2006; Sass et al. 2006; Smokorowski and Pratt 2007). Development along shorelines is known to result in reduced habitat complexity with consequent negative implications for aquatic species.

While this study did not provide insight into an acceptable or appropriate level of dock impact, it demonstrated that dock placement in lakes can potentially have significant impacts on aquatic habitats and recreational surface use. This study found that dock structures could be considerably larger at the site-scale than previous studies (Radomski and Goeman 2001; Garrison et al. 2005). Furthermore, the cumulative footprint of dock structures can occupy a substantial portion of the near-shore area. Near-shore aquatic habitats are patchy and individual lakes differ in the amount, type, and quality of habitat (Valley et al. 2004). This analysis made generalized assumptions about impacted habitat; thus, the estimates on habitat impact zones may be best considered upper bounds of habitat loss. However, lake development pressure in recent years in Minnesota has been increasingly directed toward shallow lakes and shallow lake embayments. This trend may make these estimates relevant for predicting future in-lake habitat impacts from new development. Since Minnesota has dock policies and regulations similar to other northern lake-rich regions of North America, comparable invasive near-shore impacts are likely elsewhere.

This study suggests several research and policy recommendations. First, additional research comparing near-shore habitat conditions and fish use at the scale of a typical lake lot may be needed. Specifically, it would be beneficial to determine which fish species are most affected due to shoreline disturbance around docks. Second, additional research needs to be conducted to determine if these small-scale, near-shore effects are sufficient to cause measurable shifts in whole-lake assemblage structure. Determining those species populations that are reduced by near-shore human structures and activity would provide fisheries managers with a better understanding of the consequences of predicted build-out scenarios across a region. Information obtained from these two research approaches would also aid managers in prioritizing places and habitat to protect. Third, policy recommendations that may serve to protect near-shore aquatic habitats while maintaining access rights for riparian landowners could be explored and tested. In addition, lost recreational surface use for

Table 3. Estimates of percent of lake habitat impacted by docks for two lake sets: 142-lake set and the 31-lake subset. For the 142-lake set, the current condition (2003-2004) was based on 8,642 docks, and full build-out scenarios were based on a projected 25,155 additional docks on the sampled lakes. For the 31-lake subset, the current condition (2003-2004) was based on 6,393 docks, and full build-out scenarios were based on a projected 16,114 additional docks on the sample lakes. NA indicates that data were not available.

Condition	% shoreline impacted	% lake surface area impacted	% littoral zone impacted
142-lake set			
Current	14.0	1.2	NA
Build-out Scenario 1	41.9	4.8	NA
Build-out Scenario 2	41.9	6.2	NA
31-lake subset			
Current	20.3	1.4	3.1
Build-out Scenario 1	53.3	4.7	11.0
Build-out Scenario 2	53.3	6.0	13.8

Aerial photograph of the near-shore area of one of the randomly selected lakes in the five-county area of north-central Minnesota.
(Photo: U.S. Department of Agriculture, Farm Service Agency)

the general public caused by dock structures placed in public waters may also need to be considered and addressed. We recognize that dock ownership and use is highly guarded by riparian landowners. Social values certainly are important in formulating public policy, but the natural resource manager is also charged with ensuring sustainable aquatic habitats, water quality, aquatic biota, and in many instances, recreational opportunities for future generations. To be sound, policy decisions must weigh the individual interests of riparian property owners with the common interest and public trust responsibilities of regulatory authorities. Policies may be most effective when addressing the size and placement of dock structures and less so when addressing the intended use, therefore managers might consider regulations restricting size of dock structures, requirements to use decking materials that allow transmission of light, restrictions on the placement of dock structures to areas with existing authorized disturbance, prohibitions on placement of docks in sensitive habitats or where essential fish habitats will be fragmented, incentives for sharing of dock structures among multiple riparian landowners, and comprehensive lake plans that apportion habitat impacts analogous to land use zoning.

An important issue for consideration may be the application of the precautionary principle for placement of docks and alteration of the near-shore littoral area given the existing uncertainties of the consequences to lake biota. This principle is already in use in Minnesota for a similar circumstance. Under Minnesota regulations, a maximum threshold of 15% of the littoral area of a lake can be chemically treated to control aquatic plants for the benefit of riparian and non-riparian lake users. This threshold was established to provide a means to address the cumulative effect of many individual herbicide treatments in a given lake. Whether 15% is sufficiently protective to ensure sustainable lake habitats and ecosystem function is unknown; however, natural resource managers cited the precautionary principle in setting this limit for aquatic plant control (Valley et al. 2004). Herbicide applications to control extensive inshore and offshore growths of aquatic invasive species represent most instances where the 15% threshold is reached. This study indicates that, under future build-out scenarios, dock structures and the disturbance buffers around them could cover nearly 15% of the littoral area of study lakes. Unlike herbicide applications that may be somewhat dispersed throughout the littoral zone, dock and structure impacts to the littoral zone will be concentrated in the more ecologically sensitive near-shore transition area and cover up to half or more of a lake shoreline. Docks and other near-shore structures and alterations reduce fish habitat at multiple sites within lakes that can have whole-lake consequences to ecosystem functions, fish distributions, and aquatic plants (Engel and Pederson 1998; Scheuerell and Schindler 2004; Radomski 2006). In addition, near-shore structures and their associated alterations could disrupt habitat coupling and subsequent energy flow between near-shore and pelagic habitats, thereby affecting recreational fisheries (Schindler and Scheuerell 2002). Finally, the application of the precautionary principle to docks for biological concerns could also be expanded to include the social issues resulting from the private use of public areas that have emerged with high development densities (e.g., aesthetics and use conflicts). From the public perspective, these social issues are also of critical importance.

This is the shoreline of a popular Minnesota lake.
(©Regents of the University of Minnesota.
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References

Asplund, T. 2000. The effects of motorized watercraft on aquatic ecosystems. Wisconsin Department of Natural Resources, Publication PUB-SS-948-00, Madison.

Barwick, D. H. 2004. Species richness and centrarchid abundance in littoral habitats of three southern U.S. reservoirs. North American Journal of Fisheries Management 24:76-81.

Beachler, M. M., and **D. F. Hill.** 2003. Stirring up trouble? Resuspension of bottom sediments by recreational watercraft. Lake and Reservoir Management 19:15-25.

Brazner, J. C. 1997. Regional, habitat, and human development influences on coastal wetland and beach fish assemblages in Green Bay, Lake Michigan. Journal of Great Lakes Research 23:36-51.

Bryan, M. D., and **D. L. Scarnecchia.** 1992. Species richness, composition, and abundance of fish larvae and juveniles inhabiting natural and developed shorelines of a glacial Iowa lake. Environmental Biology of Fishes 35:329-341.

Engel, S., and **J. L. Pederson.** 1998. The construction, aesthetics, and effects of lakeshore development: a literature review. Wisconsin Department of Natural Resources, Research Report 177, Madison.

Garrison, P. J., D. W. Marshall, L. Stremick-Thompson, P. L. Cicero, and **P. D. Dearlove.** 2005. Effects of pier shading on littoral zone habitat and communities in Lakes Ripley and Rock, Jefferson County, Wisconsin. Wisconsin Department of Natural Resources PUB-SS-1006 2005.

Jennings, M. J., M. A. Bozek, G. R. Hatzenbeler, E. E. Emmons, and **M. D. Staggs.** 1999. Cumulative effects of incremental shoreline habitat modifications on fish assemblages in north temperate lakes. North American Journal of Fisheries Management 19:18-27.

Jennings, M. J., E. E. Emmons, G. R. Hatzenbeler, C. Edwards, and **M.A. Bozek.** 2003. Is littoral habitat affected by residential development and land use in watersheds of Wisconsin lakes. Lake and Reservoir Management 19:272-279.

Newbrey, M. G. M. A. Bozek, M. J. Jennings, and **J. E. Cook.** 2005. Branching complexity and morphological characteristics of coarse woody structure as lacustrine fish habitat. Canadian Journal of Fisheries and Aquatic Sciences 62:2110–2123.

Payton, M. A., and **D. C. Fulton.** 2004. A study of landowner perceptions and opinions of aquatic plant management in Minnesota lakes. U.S. Geological Survey, Minnesota Cooperative Fish and Wildlife Research Unit, University of Minnesota, Department of Fisheries, Wildlife, and Conservation Biology, St. Paul.

Radomski. P. 2006. Historical changes in abundance of floating-leaf and emergent vegetation in Minnesota Lakes. North American Journal of Fisheries Management 26:932-940.

Radomski, P., and **T. J. Goeman.** 2001. Consequences of human lakeshore development on emergent and floating-leaf vegetation. North American Journal of Fisheries Management 21:46-61.

Reed, J. R., and **D. L. Pereira.** 2009. Relationships between shoreline development and nest site selection by black crappie and largemouth bass. North American Journal of Fisheries Management 29:943-948.

Sass, G. G., J. F. Kitchell, S. R. Carpenter, T. R. Hrabik, A. E. Marbury, and **M. G. Turner.** 2006. Fish community and food web responses to a whole-lake removal of coarse woody habitat. Fisheries 31:321-330.

Scheuerell, M. D., and **D. E. Schindler.** 2004. Changes in the spatial distribution of fishes in lakes along a residential development gradient. Ecosystems 7:98-106.

Schindler, D. E., and **M. D. Scheuerell.** 2002. Habitat coupling in lake ecosystems. Oikos 98:177-189.

Smokorowski, K. E., and **T. C. Pratt.** 2007. Effect of a change in physical structure and cover on fish and fish habitat in freshwater ecosystems--a review and meta-analysis. Environmental Review 15:15-41.

Valley, R. D., T. K. Cross, and **P. Radomski.** 2004. The role of submersed aquatic vegetation as habitat for fish in Minnesota lakes, including the implications of non-native plant invasions and their management. Minnesota Department of Natural Resources, Special Publication 160, St. Paul.

Wagner, T., A .K. Jubar, and **M. T. Bremigan.** 2006. Can habitat alteration and spring angling explain largemouth bass nest success. Transactions of the American Fisheries Society 135:843-852.