Environment and Natural Resources Trust Fund

Research Addendum for Peer Review

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Project Title: Assessing the Cumulative Impacts of Shoreline Development

Project number: 024-A3

1. Abstract - Human structures related to shoreline development, such as docks, boatlifts, and other structures, and disturbance from recreational activity may have a cumulative impact on aquatic ecosystems. Near-shore areas (less than 4 meters deep) often contain most of the vegetation and are generally the spawning area for fish. Several studies have addressed the effects of incremental changes on lake ecosystems despite ongoing concerns about the rate and extent of near-shore, in-water habitat alterations, and expansion of in-lake structures. However, there is a lack of scientific knowledge on the cumulative effects of human activities on aquatic habitat, water quality, and fish populations, which has hindered regulatory authorities and lake managers who need better information to guide landowners toward lower impact practices. To address this lack of information, we will assess the extent of near-shore vegetation, fish, and macroinvertebrates along a gradient of shoreline development and develop a framework to assess cumulative impacts on whole lake systems. We will use aerial photos and existing DNR data to measure whole lake disturbances of ~100 lakes in the Northern Lakes and Forests Ecoregion. We will also conduct assessments of a subset of lakes (~30) at the individual lot scale, to quantify impacts to vegetation, fish, and macroinvertebrates along a gradient of shoreline development and shoreline types. We will use our research to develop a model to predict the cumulative impact of development on aquatic ecosystems, providing a tool to guide lake managers toward sustainable near-shore, in-water development.

2. Background - Aquatic plant communities are important for the health of fisheries and aquatic ecosystems (Becker 1983, Engel 1985, Janecek 1988). Aquatic vegetation provides critical habitat for fish and other aquatic organisms, providing spawning and juvenile rearing areas, and refuge from predators. Other benefits include stabilizing soft sediments, trapping suspended particulates, and absorbing wave energy that contributes to shoreline erosion (Garrison et al. 2005). Development of lakeshore properties (Kelly and Stinchfield 1998) and subsequent alterations may negatively effect fish populations. Shore alterations may include removing submergent and emergent aquatic vegetation, hard-armoring shoreline with rip-rap or retaining walls. In addition, in-water structures, such as docks, piers, boat lifts, and other structures added for recreation may have a site specific and cumulative effect on aquatic vegetation and the functions they provide (Engel and Pederson 1998, Bryan and Scarnecchia 1992, Jennings et al 2003). In-water structures have been related to declines in aquatic vegetation (Radomski and Goeman 2001, Radomski 2006), as well as reduced fish growth rates (Schindler et al. 2000, Scheuerell and Schindler, 2004). Despite concerns about the rate of shoreline development, the extent of near-shore, in- water habitat alterations, and expansion of in-lake structures, few studies have addressed the effects of these incremental changes on lake ecosystems simultaneously. The lack of scientific knowledge on the cumulative effects of human activities on aquatic habitat, water quality, and fish populations has hindered regulatory authorities and lake managers who need better information to guide landowners toward lower impact practices. Our goal is to understand the ecological consequences of development and associated activity on near-shore lake ecosystems. We have three objectives (Results): (1)

Assess near-shore, in-water habitat across lake ecosystems, (2) Assess impacts of shoreline development on near-shore habitat, and (3) Develop a framework to evaluate cumulative impacts.

3. Hypothesis – We hypothesize that local near-shore, in-water habitat alterations will contribute to changes in species richness and other metrics for aquatic macrophytes, fish, and macroinvertebrates. These alterations will result in gradient of habitat complexity (*sensu* Jennings et al. 1999) that will provide evidence for a cumulative effect for near-shore development.

Methodology – We will address near-shore, in-water habitat complexity at two scales (Result 1 and Result 2). At a broad scale (Result 1), we will select approximately 100 lakes for this study based on a number of criteria. We will control for differences in watersheds between lakes by selecting lakes that have primarily forested watersheds with no more than two upstream catchments from the Northern Lakes and Forests (NLF) ecoregion, excluding the low alkalinity lakes of northeast Minnesota. Lakes will be limited to mesotrophic waters, having total phosphorus levels from 12-30 ppb, which describes most lakes in this ecoregion (Heiskary and Wilson, 2005). Additional variables that will be considered in the selection include: size, shape, fetch, sediment, and depth. Over 700 lakes in the NLF ecoregion have two or fewer upstream catchments. Watershed land use will be at least 85% forest and wetlands, with no more than 10% consisting of agriculture (cultivated and pasture combined), and minimal urbanization typical for lakes in the NLF ecoregion (Heiskary and Wilson 2005). We plan to use a GIS tool that the DNR is developing to calculate land use by catchment for potential study lakes. Additional criteria may be used as the number of remaining lakes allows. After compiling a list of candidate lakes, we will select 100 lakes that represent a range of shoreline development conditions. Using the most recent available aerial photographs (currently 2009), we will use a similar approach to Radomski and Goeman (2001) and Radomski (2006) to categorize lakes by the amount of developed and undeveloped shoreline, choosing study lakes along a range from 100% undeveloped to 100% developed. Candidate lakes will be grouped by percentage of shoreline development in increments of 20%. Lakes will be drawn randomly from these groups in proportion to the numbers in each group. Additional variables, such as lakeshore landscaping, texture of the riparian bank, docks, and boat lifts used by Krysel et al. (2003) to reflect whether a parcel is likely to impact a lake may be used to categorize whether the shoreline is developed or undeveloped.

When the study lakes have been selected, all available data will be compiled for these lakes in cooperation with the DNR partners, including DNR lake surveys, fish IBI surveys, point-intercept plant surveys, sensitive shoreline surveys, and water quality data. Relevant GIS data, such as digitized docks, emergent vegetation maps, and land use data will also be compiled.

At a local scale (Result 2), we will select a sub-sample of approximately 30 lakes for intensive sampling, drawing these lakes from the 100 study lakes (Result 1) to ensure a gradient of habitat alteration. We will ground truth the GIS data and aerial photo analysis by collecting detailed aquatic habitat data for this subset of lakes. At each lake, a minimum of 15 lots (or locations where no development has taken place) will be selected for habitat assessment. We will assess a length of shoreline not to exceed 30m at each lot. For undeveloped areas, a transect 15 m on either side of a selected point will be surveyed. We will evaluate at least five dock sites per lake, plus an additional 10 sites beginning at a random starting point, and then evenly space sites around the lake to calculate a fish-based index of biotic integrity (Fish-IBI) (Drake and Pereira 2002). Although IBI scores and the coverage of macrophytes (and macrophyte composition) in relation to areas with extensive development and limited or no development within and across lakes will be evaluated, a motivating factor for including the IBI was because the protocol is well established and new sampling methods do not have to be developed for fish in water less than 0.75 m. The IBI sampling will yield information at the site level, and these data will be used to relate fish species (present/absent) to local habitat. The fish IBI will also be calculated for each lake and will be one of the lake-level response variables. We do not know if IBI will be sensitive to differing levels of development – the IBI was developed to respond to differences in watershed land use and human population density, but a working hypothesis is that because the watershed factor is controlled in this study, an IBI response to shoreline development may be detected. This project will be the first to evaluate IBIs and development.

At each site, all in-water features will be measured, mapped, and marked with GPS waypoints. These features may include docks, boat lifts, watercraft, rafts, or any other recreational structures in the water. The water depth at the corner of each dock or other structure will be recorded. We will note and estimate the linear distance of retaining walls or rip-rap along the shore, as well as the note vegetative cover type(s) adjacent to the wall or rip-rap. Coarse woody structure (CWS) will also be inventoried on each lot, using methods adapted from those used in other studies (Newbrey 2002, Newbrey et al. 2005, Marburg et al. 2006).

During our initial field season (July-August 2010), we will evaluate several potential sampling techniques for aquatic macrophytes, fish, and macroinvertebrates. Our goal for evaluating several techniques is to collect sufficient information in a time efficient manner for a limited number of lakes (5-10). For example, Jennings et al. (1999) used combined DC electrofishing and seining to sample fish in the near-shore zone after evaluating boomshocking, fyke nets, wading electrofishing, and seining. Based on these initial surveys, we will use the most efficient techniques in the summer of 2011 and 2012.

Initially, aquatic plant density and species composition will be measured along a transect parallel to the shoreline. Half meter diameter circular quadrats will be placed every 3 m along the length of this transect, and we will measure stem density and plant height in each quadrat. We will also compile a list of all aquatic plant species observed at each site along the sampling transect. Emergent vegetation will be marked with a GPS waypoint and its area measured. When *Chara* sp. is present we will record areal coverage and height. We will also measure areas substantially cleared of vegetation around each dock and the shoreline, and measure the distance from the dock or shoreline, to the weed line. A number of water quality variables will be collected at each site; including temperature, dissolved oxygen, turbidity, pH, and conductivity. Fetch, slope, and substrate will be characterized each site that may be included in data analyses as covariates.

An estimate of the cover that submerged aquatic vegetation provides larval and juvenile fish will be made using Weimer's modification (E. Weimer, ODNR, personal communication) of the Robel pole method (Robel et al 1970, citied in Litvaitis et al 1996). The Robel technique estimates both the height and density of vegetation with a significant correlation between height and density and the biomass of vegetation. Weimer took underwater photographs of a 3" diameter PVC pipe seen through submerged aquatic vegetation at a distance of 1 m, measured water depth, and plant height. The Robel technique will be used at regularly-spaced sites on a transect parallel to the shoreline. We will estimate plant density (stems/m^2) after photographing the amount of visual barrier to establish the relationship between the two variables.

We will assess species composition of macroinvertebrates using activity and light traps. Activity traps will be distributed along each transect at 5 m intervals. Light traps will be set near a dock or other structure and at the farthest point from a dock (including neighboring lots) for developed sites. For sites with no shoreline disturbance, the traps will be placed at the mid-point of the site and the end of the station having the most aquatic vegetation. Light traps have been used to assess macroinvertebrates in aquatic vegetation where shoreline restoration has been implemented (Cynthia Tomcko, Minnesota Department of Natural Resources, Personal Communication).

At each sampling station during summer 2010 (pilot study), we will also collect invertebrates associated with macrophytes from 0.1 m^2 quadrats spaced at 3 m intervals or at selected sites based on the distribution of aquatic macrophytes. All plant material in a quadrat will be clipped at the sediment interface and immediately placed in a sealable bag underwater, returned to a boat, and immediately placed on ice. The samples will be rinsed of invertebrates and will be picked with forceps from macrophytes at 2x magnification and from the wash water at 8x magnification following Newman and Biesboer (2000). If this procedure is cost effective, the protocol will be followed during the subsequent sampling periods in 2011 and 2012.

Nearshore fish communities will be sampled following the methods of the Fish-IBI of Drake and Pereria (2002). We will sample a shoreline, beginning at the edge of docks, lifts, or at the water access point for the lot, or at one end of the station for undeveloped lots. Some lots may not allow for a 30 m sample, and in those cases we will sample as much of the shoreline as possible. We will make two passes with a backpack electroshocker parallel to the shore, one near the shoreline and one at 75-100 cm depth. We will also complete one 30 m seine haul at each station parallel to the shoreline to the length of the seine from shore or maximum wadeable depth (Drake and Pereria 2002). Cynthia Tomcko (Minnesota Department of Natural Resources, personal communication) has found light traps used to sample macroinvertebrates also attract larval fish. When larval fish are present in a light trap, we will identify and record larval fish.

We will use a boat electrofisher along a transect parallel to shore at a depth of 2.0 m or 20 m from the shoreline, whichever is closer. The data collected with the boat electrofisher should complement the data collected for the Fish-IBI, because they will sample different areas.

We will use a technique developed by Radomski and Goeman (2001) and Radomski (2006) to evaluate the relationship between lakeshore development and emergent and floating-leaf plant abundance across the sample of 100 lakes in Result 1. Radomski and Goeman (2001) found there was more there was a 66% reduction in vegetation coverage with development relative to undeveloped shorelines in relation to frequency of occurrence of bulrush, water lilies, arrowhead, and cattails in 44 lakes. Radomski (2006) estimated loss of vegetation cover across lakes in north-central Minnesota was 15% across three categories (general development, recreational development, and natural environment) of lakes.

We will begin the analysis of the relationships among the development and biological variables for the second set of lakes (Result 2) with an evaluation of multiple regression/general linear models (GLM) or nonlinear models, where dependent variables will be the biological variables and independent variables will be the development variables. Multiple regression and GLM are often used for modeling species distributions (Guisan et al. 2000). These models can quantify individual species responses to near shore habitat disturbance. Each taxa will likely have a different response – some will benefit from the disturbance, others will be negatively affected, some might have a "dome-shaped" response (flourish at medium disturbances – i.e., benefit from patches), others may have a flat response (not affected by near shore disturbance). A flexible response model, such as a generalized additive model (GAM) will capture many of these different response shapes. GAM can also provide spatial predictions of species distribution under changing environmental conditions (Lehmann 1998).

The distribution of submerged macrophytes can also be modeled with a GAM. Lehmann (1998) modeled four submerged species (three *Potamogeton* species and *Chara*, representatives of these species are found in Minnesota) in the littoral zone of Lake Geneva (Switzerland) in relation to bathymetry, wave exposure, current strength, water quality, and soil type.

Where possible the models will be compared using AIC statistics to determine the best fitting model to describe each response (Burnham and Anderson 1998; Johnson and Omland 2004). AIC statistics have proven better than best subset regression and forward/backward regression for multiple variable models. Technically, models should be developed *a priori* for AIC statistics to be valid; however, there are little prior data on which to base model selection *a priori* for shoreland development models and biological responses.

After determining the whether measures of development predict habitat disturbance, we will return to the variables in the data set for the 100 lakes and compute a measurement for each lake. Using the models of local ecological processes generated in the previous lot-scale analysis (Result 2), we will generate hypotheses regarding potential whole lake and fish population responses to littoral disturbance. We will then examine the lake-wide data for the 30 lakes for responses of fish populations relative to development and determine whether our hypotheses explain the responses. Several fish variables that may be impacted by littoral habitat disturbance include: fish IBI (Drake and Pereira 2002), bluegill growth rate (Schindler et al. 2000), largemouth bass growth rate and yellow perch abundance (Sass et al. 2006). Fish data will largely be gathered from existing DNR Fisheries Lake Survey Data and DNR Ecological Resources fish IBI surveys, although the 30 lakes sampled for habitat will have fish IBIs and species lists for this study.

A likely candidate for Result 3 (the cumulative impacts model) is the Bayesian Belief Network (BBN), since these models can incorporate different spatial scales, they can use the important relationships developed from Results 1 and 2 to evaluate changes to shoreland, to near-shore habitat and fish, and to lake-wide fish populations. Baysian Belief Networks have been widely used to model species-habitat relationships of aquatic organisms and in resource management and have also been used in a decision-support framework to facilitate decision-making (McCann et al. 2006). These models can also reflect uncertainty about underlying relationships. Baysian Belief Networks can depict the influence of alternative development practices on key environmental predictors to guide decisions about shoreline development. Among the benefits to the BBN approach is that the models can be easily presented graphically and understood by stakeholders and decision makers. Likely the most useful feature of BBNs is that they can be used to infer the most likely set of causal conditions by backward calculation (McCann et al. 2006). Thus, BBNs can generate correlative and causal relationships. These models are also interactive and flexible, allowing for refinement of the model structure and probabilities as new data becomes available, making the BBN an ideal tool for decision-making and analysis in an adaptive management process.

4. Results and Deliverables - Result 1: Assess near-shore, in-water habitat on lake ecosystems.

Using aerial photographs, we will estimate emergent and floating-leaf coverage in relation to development for lakes in the NLF region. Working with our DNR partners we will compile all available data for these lakes, including DNR lake surveys, fish IBI surveys, point-intercept plant surveys, sensitive shoreline surveys, and water quality data. Other relevant GIS data, such as digitized docks, emergent vegetation maps, and land use data will also be assembled. Our DNR partners will document all visible landscape and development features will be identified and digitized, including buildings, roads, driveways, decks, lawns, fields, forests, and wetlands. Our DNR partners will also correlate the occurrence of emergent and floating-leaf plant species with fish population characterized following Radomski and Goeman (2001). Thus, additional information could potentially be used to increase the usefulness of the BBNs in Result 3.

Result 2: Assess impacts of shoreline development on near-shore habitat

We will provide detailed aquatic habitat data for 30 lakes that can also confirm or “ground truth” the information from the aerial photographs. For these 30 lakes, we will quantify in-water features, such as docks, lifts, watercraft, rafts, or any other recreational structures, retaining walls or rip-rap along the shore, vegetative cover type(s) adjacent to the wall or rip-rap, and aquatic macrophytes, fish, and macroinvertebrates along a development gradient that will help refine the information from Result 1. These data on the biological characteristics will be correlated with the extent of rip-rap, CWS, and in-water structures. In addition, correlations among fish community characteristics and macrophtye characteristics and macroinvertebrate characteristics and macrophtye characteristics will be evaluated. For example, correlations will be evaluated between IBI scores and the coverage of macrophytes (and macrophyte composition) in relation to areas with extensive development and limited or no development within and across lakes. Statistical models (multiple regression/general linear models and generalized additive model) will be used to quantify species responses to near shore habitat disturbance.

Result 3: Develop a cumulative impacts model

Bayesian Belief Networks can incorporate different spatial scales and will be used to depict the relationships between a large number of variables and the potential interrelationships of development and aquatic organisms. Bayesian Belief Networks can be used to evaluate alternative development practices, i.e., different scenarios for key environmental predictors to guide decisions about shoreline development in easy to interpret graphical presentations. Thus, the impact of our research will provide shoreline owners and lake managers with information about the impacts of development on aquatic ecosystems. Lakeshore managers may use this information to guide shore land management practices and where to focus protection or restoration strategies.

5. Timetable

Year	Task	Summer	Fall	Winter	Spring
First	Acquire aerial photos Result 1	XXX			
First	Assess aerial photos Result 1		XXX		
First	Data analysis of aerial photos Result 1		XXX	XXX	XXX
First	Field work to assess techniques Result 2	XXX			
First	Data analysis of field work Result 2		XXX	XXX	XXX
Second	Data analysis of aerial photos Result 1		XXX	XXX	

Second	Field work Result 2	XXX			
Second	Data analysis Result 2		XXX	XXX	XXX
Third	Field work Result 2	XXX			
Third	Data analysis Result 2		XXX	XXX	XXX
Third	Develop cumulative impact model Result 3		XXX	XXX	XXX
Third	Write final reports & ms.		XXX	XXX	XXX

6. Budget –

Project Budget

PROPOSAL BY: ***Vondracek***

Assessing the cumulative impacts to near-shore, in-water habitat

IV. TOTAL PROJECT REQUEST BUDGET (*[3]* years)

BUDGET ITEM	**AMOUNT**
Personnel: One graduate student (masters) 2 years plus tuition and benefits	$70,337
One graduate student (Ph.D.) 3 years plus tuition and benefits	$105,787
one undergraduate student (fulltime in summer and 10 hours week during academic year)	$23,720
Contracts: one Specialist (6L) with the Minnesota Department of Natural Resources for 1.83 years	$81,439
Equipment/Tools/Supplies: Preservative for specimens	$500
Sample jars to preserve and store specimens	$2,717
Nets	$400
Acquisition (Fee Title or Permanent Easements):	$-
Travel: 10 trips to study areas per year 800 mi @0.60 mi for Federal vehicle	$11,600
Per Diem $50.00/day per person for graduate and undergraduate students for 30 days per year	$3,500
Additional Budget Items:	
TOTAL PROJECT BUDGET REQUEST TO LCCMR	$300,000

V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ Being Applied to Project During Project Period: /	$-	
Other State $ Being Applied to Project During Project Period:	$-	
In-kind Services During Project Period: Assistance from DNR as needed and use of electrofishing boat Partial salary for Bruce Vondracek	$-	
Remaining $ from Current Trust Fund Appropriation (if applicable):		
Funding History:	$-	

7. Credentials - Provide brief background of the principal investigators and cooperators who will carry out the proposed research and selected publications (targeted/abbreviated resumes are acceptable).

Bruce Vondracek is the principal investigator on the project. He has maintained an active research program focusing on aquatic ecology for 34 years, and is a specialist in the ecology of freshwater systems, specifically interactions of fish, macroinvertebrates, hydrology, water quality, and geomorphology. He is the Assistant Unit Leader-Fisheries for the US Geological Survey, Minnesota Cooperative Fish and Wildlife Research Unit (1991-2010) and an Adjunct Professor in the Department of Fisheries, Wildlife, and Conservation Biology at the University of Minnesota (2002-2010). He has published 68 peer-reviewed articles related to research he and graduate students have conducted across a spectrum of systems from small streams in California to the Great Lakes. He has been PI or Co-PI on 3.5 million dollars of grant-funded research projects since 2006, with current or past funding from the National Science Foundation, US Geological Survey, US Environmental Protection Agency, US Forest Service, and National Council for Air and Stream Improvement.

Donna Dustin will be an important collaborator on the project and will supervise the DNR employee on the project. She is a Senior Fisheries Biologist with the Fisheries Research Group of the Minnesota Department of Natural Resources. Over the past 11 years, her research has focused on aquatic habitat impacts on fish, including methods for improving walleye spawning habitat and stream restoration impacts on trout. She has recently been investigating large-scale stressors, such as climate change and watershed development in relation to aquatic vegetation and fish populations. Donna has a B.S. from Cornell University and M.S. from the University of Saskatchewan. Prior to coming to Minnesota, she worked for Cornell University and University of Wisconsin-LaCrosse in research programs studying lake ecology and zebra mussels.

8. Dissemination and Use – We will collaborate with people, such as Paul Radomski with the Minnesota Department of Natural Resources who works on a project "Score Your Shore", to disseminate the information to agency managers and lakeshore owners.

9. References

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