COLLECTIVE ACTION AT THE SHORELINE:
A COMPARISON OF LAKE MANAGEMENT ORGANIZATIONS
IN VILAS COUNTY, WISCONSIN, U.S.A.

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by
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ABSTRACT

Community-based volunteer organizations are critical to natural resource management in the United States. However, due to volunteer involvement, these organizations struggle with collective action problems: coping with free riding, solving commitment problems, arranging for the supply of new institutions, and monitoring individual compliance with sets of rules. In this study, we explore how volunteer organizations can overcome these challenges. To explore how they overcome these challenges, we use the Institutional Analysis and Development framework and the Institutional Design Principles. These frameworks help us understand the impact of natural resource conditions, community attributes, and the rules in use impact volunteer organizations. For this research, we focused on lake organizations in Wisconsin. We collected our data through semi-structured interviews with thirty-one lake organizations and public data. The data were analyzed using constant comparison and linear regression, followed by qualitative comparative analysis (QCA). We reinforce the importance of considering the system holistically when managing a resource—the natural resource conditions, the community attributes, and the rules in use. Our study shows the importance of graduated sanctions and low-cost conflict resolution on social-ecological system outcomes. Volunteer-based resource management are an effective way to tailor management strategies to the natural resource condition and the community attributes.

TABLE OF CONTENTS

1. Introduction
    1.1. Overview
    1.2. Wisconsin Lakes and Lake Organizations
2. Methods & Data
    2.1. Case Selection
    2.2. Data Collection
    2.3. The Outcomes: Seven Lake Organization Goals
    2.4. The Conditions: Environmental, Social, and Institutional
    2.5. Analytical Approach: Linear Regression Analysis
    2.6. Analytical Approach: Crisp-Set Qualitative Comparative Analysis (csQCA)
3. Results & Discussion
    3.1. Basic Regression Analysis
    3.2. Necessary Conditions
    3.3. Sufficient Conditions
4. Conclusion
5. Acknowledgments
6. References
7. Appendices

1. INTRODUCTION

1.1 Overview

The majority of natural resource management responsibilities in the United States belong to federal and state agencies. These federal and state agencies, however, are increasingly relying on volunteer-based resource management groups to achieve conservation and restoration goals (Armitage, 2005; Bruyere & Rappe, 2007). Volunteer-based resource management encourages participation of communities and resource users in decision-making through the incorporation of local knowledge and institutions in management, regulatory, and enforcement practices for more sustainable resource management outcomes (Armitage, 2005). Local participation and knowledge accumulation occur in volunteer organizations comprised of people who live around or rely on a resource for their livelihoods (Ostrom, 1990). When changes threaten a community's natural resource, resource users often respond by forming volunteer organizations to address the challenge (Gabriel & Lancaster, 2004; Korth & Klessig, 1990; Ostrom, 1990). These organizations emerge from the community with a goal for the resource in mind; they design their rules based on the cultural and biophysical context (Ostrom, 2009). These volunteer-based organizations play a critical role in resource management as federal and state agency budgets shrink, and resource usage increases.

The budgets of federal resource management agencies have either remained constant or declined for the past several decades (Bruyere & Rappe, 2007). Although budgets shrank, outdoor recreation participation has increased, creating a gap in maintenance and services. Agencies rely on volunteers to fill this gap (Bruyere & Rappe, 2007). In 2012, the US Fish and Wildlife Service reported that 2.2 million volunteer hours, equivalent to 1,036 full-time employees, supplemented their 9,000-employee workforce by over ten percent (US Fish & Wildlife Service, 2013). The contributions from volunteers go beyond saving money for natural resource managers. Volunteers are deeply committed to the resources they help manage. They provide services like observing changes in natural resources and providing environmental education. As agencies recognize that "one size fits all" solutions are a poor match to the complexity of social-ecological systems (SES), volunteer-based organizations can help adapt rules to the needs of the resource and the community using the resource (Ostrom, 1990).

Volunteer involvement in resource management comes with challenges. Volunteer-based organizations struggle with collective action problems such as: "coping with free-riding, solving commitment problems, arranging for the supply of new institutions, and monitoring individual compliance with sets of rules" (Ostrom, 1990). With these challenges—and no formal authority to overcome them—volunteer-based organizations struggle to meet their goals. Goals themselves present a challenge to community-based natural resource management organizations. People's different uses of natural resources result in diversity in goals for resource management (Gabriel & Lancaster, 2004; Peterson et al., 2003). Collective action problems and variety of use are common issues faced by communities managing shared resources.

There is a reasonable understanding of how a community of resource users overcomes the collective action problems experienced by volunteer-based organizations. Ostrom and her colleagues identified eight institutional design principles (IDPs), through a systematic case study review, that are associated with the persistence of community-based resource management (Ostrom, 1990). The design principles are: 1) clearly defined boundaries, 2) congruence between appropriation and provision rules and local conditions, 3) collective-choice arrangements, 4) monitoring, 5) graduated sanctions, 6) conflict-resolution mechanisms, 7) minimal recognition of rights to organize, and 8) nested enterprises (Ostrom, 1990). Follow up studies support the IDPs with minor adaptations (Baggio et al., 2016; Cox, Arnold, & Villamayor Tomas, 2010). We separate the first design principle 1) clearly defined boundaries into 1A) user boundaries—the boundaries between who can and cannot use the resource—and 1B) resource boundaries—clear boundaries defining the resource system as suggested by Agrawal and Cox et al. (Agrawal, 2002; Cox et al., 2010).

Ostrom and her colleagues proposed the Institutional Analysis and Development framework (IADF) to analyze the outcomes of repetitive interactions by diverse people. The IADF is used to explore how institutions—the rules humans use to structure repetitive interactions—persist, dissolve, and evolve (Ostrom, 2005). According to the IADF, people with diverse interests interact in a social space; the context shapes the interactions and social space (Ostrom, 2005). The external contexts that influence the social interactions include the rules in use, the attributes of the biophysical world, and the structure of the community where the interactions occur (Ostrom, 2005). These three types of factors affect the actions that people can take, the benefits and costs of the actions, and the potential outcomes. We call these environmental, social, and institutional conditions and situate the eight institutional design principles in the IADF as the institutional conditions or rules in use.

In this study, we explore how the combinations of external factors and rules in use lead to different outcomes in lake SESs. To do this, we collect primary data about the goals and contextual factors—using the institutional design principles and the IADF—for volunteer-based organizations managing lakes in a small geographical area. Most studies of the institutional design principles rely on secondary case study analysis, which presents data completeness and variable consistency challenges (Ratajczyk, 2016); there are few examples of studies that collect primary data (Agrawal & Chhatre, 2006; Shin et al., 2019). We collected our data during the summer of 2019 in Vilas County in the Northern Highland Lakes District of Wisconsin, U.S.A., which is home to more than 1,300 lakes and 115 lake organizations (University of Wisconsin - Stevens Point, 2019; Vilas County Tourism and Publicity, 2020). Vilas County's rare geology and geography—a high concentration of lakes and organizations in a small area—enable the study of institutional arrangements and their impact on various social and environmental outcomes for lake SESs.

This study of lake organizations in Wisconsin resulted in insights about the conditions of lake SESs that experience desired social and environmental outcomes. Like Agrawal & Chhatre and Shin et al., we found the eight institutional design principles played a key role in these outcomes—even as the desired outcomes varied by the organization. Further, we saw that there are multiple causal pathways to success, which would mean that the design of management institutions, or rules in use, should consider the environmental and social conditions in contrast to uniform policies. In this study, we ask lake organizations about the rules they use and combine the rules in use data with ecological and social data sets. We first provide an overview of lakes in Wisconsin and the multi-level management structure before reviewing the methods, results, and findings of our study.

1.2 Wisconsin Lakes and Lake Organizations

1.2.1 Freshwater lakes in Wisconsin

Wisconsin is home to 15,000+ freshwater lakes (Wisconsin DNR, 2019). Most of the lakes are in the Northern Highland Lakes District, which has an area of 5330 km^2 and includes Vilas, Oneida, and portions of Forest, Iron, and Price counties. The area has been repeatedly glaciated, leaving a flat and lake-filled landscape when the glaciers retreated 12,000 years ago. These lakes range in area from small, temporary lakes to well over 1000 hectares and range in depth from one to more than thirty meters (Peterson et al., 2003).

Freshwater lakes play an important role in SESs. They provide permanent and migratory habitat for terrestrial and aquatic biodiversity. They offer recreational opportunities, including but not limited to fishing, skiing, paddling, swimming, and wildlife watching. Lakes are also central to economies created by lakefront property, tourism, and the freshwater recreational fishing industry. The recreational fishing industry was estimated to be worth $29.9 billion in 2016 (U.S. Department of the Interior, U.S. Fish and Wildlife Service, U.S. Department of Commerce, & U.S. Census Bureau, 2018).

Despite their important role, changes in recent years are threatening lake SESs. Climate change is changing temperature and precipitation patterns, thus affecting lake productivity and water level (Magee, McIntyre, Hanson, & Wu, 2019). Fish population and biomass changes have been observed in northern temperate lakes as a result of warmer water (Embke et al., 2019). Land-use change around lakes is also increasing. Lakefront property owners are removing the natural buffers created by trees and grasses in favor of agriculture, houses, and lawns. These landscape-scale land-use changes are affecting nutrient cycling and soil erosion, which impact water clarity (Jennings, Emmons, Hatzenbeler, Edwards, & Bozek, 2003; Johnston & Shmagin, 2006). Boaters moving from one lake to another often carry water, animals, and plants between lakes, increasing the risks of aquatic invasive species like zebra mussels, spiny water fleas, and Eurasian Watermilfoil. These aquatic invasive species are hard to eradicate once they are introduced and can permanently alter the biodiversity and community structure within lakes (Rothlisberger, Chadderton, McNulty, & Lodge, 2010).

There are also political and cultural threats. Regulatory changes related to resource use and zoning impact lakes. In 2015, Wisconsin updated their zoning codes so that townships and counties could not set more restrictive zoning ordinances than those set by the state legislature. This change in regulation impacted the ability of local government to tailor their codes to protect shorelines and fish habitats (Wisconsin Shoreland Alliance, 2019). New technology can also have effects on culture and resource use. Boats used for wake surfing can cause shoreline erosion in small lakes through the wakes they create and the repetitive paths they take in the lake. Additionally, rental property platforms like Airbnb and HomeAway attract new lake users that use lakes intensely and are unfamiliar with the cultural norms and ecology of the lakes.

The Wisconsin legislature has encouraged a collaborative natural resource management strategy to address these numerous changes. The collaboration includes the Wisconsin Department of Natural Resources, the University of Wisconsin system, local and county governments, non-profits, and volunteer-based organizations.

1.2.2 Wisconsin's public waters & their stewards

The public trust doctrine informs Wisconsin's navigable waters management; Article IX of the Wisconsin Constitution ensures public access and free use of the waters. In Wisconsin's interpretation of the public trust doctrine, Wisconsin's navigable waters must be maintained for particular types of uses. Wisconsin Statute 33 charges the Wisconsin Department of Natural Resources (WI DNR) with protecting and maintaining navigable waters (Wisconsin State Legislature, 1974).

The statute requires the WI DNR to form a multi-level collaboration that includes resource users, the WI DNR, the University of Wisconsin System (UW), other government agencies, and public and private organizations (Wisconsin State Legislature, 1974). This collaboration is known as the Wisconsin Lakes Partnership and includes the over 600 lake organizations, WI DNR, UW-Extension service, and many state, county, and local partners (Wisconsin DNR, 2019). The UW-Extension Lakes Program facilitates the Wisconsin Lakes Partnership through knowledge dissemination and by serving as an interface between residents (i.e., lake organizations), government agencies (i.e., WI DNR), and non-profits (Mandal & Lawrence, 2017). In this way, Statute 33 encourages lake users—those most invested in the resource—to form organizations, a necessary condition for successful common-pool resource governance (Mandal & Lawrence, 2017; Ostrom, 1990).

Lake users form lake organizations, which have a variety of goals, including preventing or treating aquatic invasive species, maintaining or enhancing their fishery, protecting water quality, and member education (Gabriel & Lancaster, 2004). As they mature, their goals may evolve; one lake organization had a goal to establish leadership continuity as the executive board ages. Lake organizations are one of two types: lake associations or lake districts. Lake associations are voluntary organizations made of citizens that range from social organizations to incorporated non-profit organizations. Lake associations have no regulatory power over lake or land use activities; they use informal influence and volunteer time and money to contribute to the management of lakes (Gabriel & Lancaster, 2004; Wisconsin Lakes Partnership, 2018). Lake associations undertake significant management activities in Wisconsin in partnership with the WI DNR and other formal management groups (Gabriel & Lancaster, 2004; Korth & Klessig, 1990). "Protecting environmental and water quality" is the primary goal and motivation for the formation of lake associations (Gabriel & Lancaster, 2004). Lake districts are specialized units of government designed to manage a lake or group of lakes. They can tax property in the district to levy funds for lake protection and rehabilitation. Lake districts have statutory responsibilities to the resource, local citizens, and taxpayers (Wisconsin Lakes Partnership, 2018). Lake districts manage projects that require a larger budget and can own public infrastructure or expensive equipment like weed harvesters and lake aerators (Gabriel & Lancaster, 2004).

The popularity of lake organizations has changed over time, as seen in Figure 1. The most notable event was the establishment of the Wisconsin Lakes Partnership in the 1970s. After the partnership was established, more than four hundred lake organizations were formed.

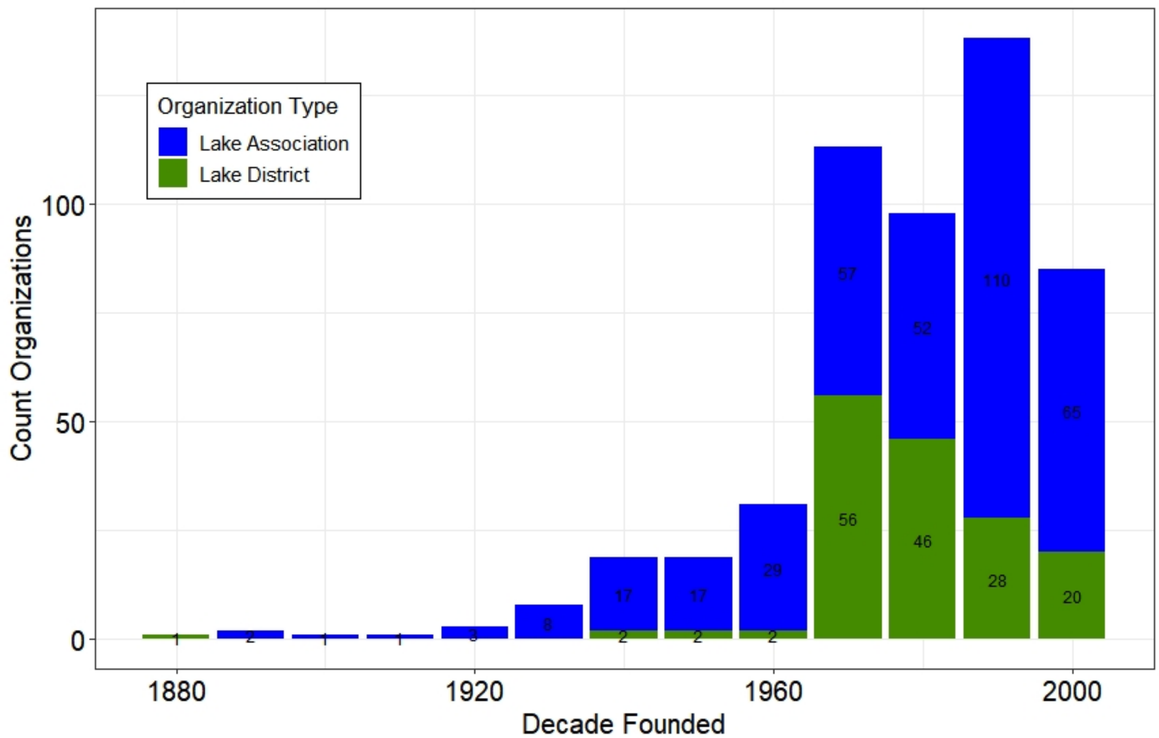

Figure 1. The number of lake organizations founded by decade through 2010.
Source**:** UW-Extension Lakes Program.

To achieve their goals, lake organizations use a combination of grants, partnerships, donations, and volunteer hours (Gabriel & Lancaster, 2004). The WI DNR has several types of grants for lake studies, treatments, enhancements, and monitoring (Wisconsin DNR, 2019). There are specific criteria that define a qualified lake association or district—including public access to the lake—to receive a grant (Wisconsin Lakes Partnership, 2018). The grants also require specific permits and partnerships. The funding, permits, and partnerships are how the WI DNR fulfills the administrative requirements of Wisconsin Statute 33. In addition to the resources available from the state, lake organization members contribute in the form of donations and volunteer hours. These contributions are required for lake organizations to receive grants from the WI DNR. The grants require a portion of the costs in-kind from the organization. Some grants require a volunteer hour match. Lake organizations meet their goals through a combination of state oversight and participation of those most affected.

Though it seems straightforward, garnering participation by those most affected is challenging. Collective action problems are common in community-based natural resource management groups like lake organizations. Like many volunteer-based organizations, a small number of highly committed individuals do most of the work. Lake organizations must design institutions that overcome these challenges and support the enforcement of rules without being perceived negatively by their neighbors. These challenges are exacerbated in settings where people only spend a portion of their time like Wisconsin's inland lakes where over half of all Vilas County lakefront housing is used "for seasonal, recreational, or occasional use" (Stedman, 2006). When these part-time residents are visiting their lake house, they want to relax. They do not want to contribute to management (Stedman, 2006).

This study explores the pathways to desired outcomes in lake SESs and how they compare. The remainder of the paper explains the unique dataset of thirty-one lake organizations collected in Vilas County during the summer of 2019, the pathways to different outcomes, and the implications and further research opportunities for volunteer-based resource management organizations.

2. METHODS & DATA

We conducted semi-structured interviews to collect data about thirty-one lake organizations and thirty-nine lakes in Vilas County during the summer of 2019. We supplemented the data we collected with data published by multiple sources. These sources included the WI DNR, UW-Extension lakes program, United States Geological Survey (USGS), the North Temperate Lakes US Long-Term Ecological Research Network (NTL LTER), and the Jones Lab at the University of Notre Dame. We analyzed the data using linear regression and crisp-set qualitative comparative analysis to identify the conditions that led to the outcomes for the lake SESs. We used constant comparison to analyze the goals mentioned in the summer of 2019 interviews. The conditions we used are the result of summer 2019 interviews and a review of articles about lake SESs.

2.1 Case Selection

The lakes and organizations in this study are in Vilas County, Wisconsin (Figure 2A). Vilas County is part of the territory that the Chippewa (Ojibwe) ceded to the United States in 1837 and 1842 (Riera et al., 2001). The southwest part of Vilas County is a reservation whose lakes and land are governed by the Lac du Flambeau band of Lake Superior Chippewa Indians.

We chose Vilas County for our study because of its geography and geology. Geographically it is very far North making the growing season short. Additionally, the soil is poor. These factors combined make the area uninteresting to the commercial agriculture industry. The absence of agriculture and the predominance of tourism results in support for conserving the lakes without much consideration of competing uses. It is the site of many studies like research by the NTL LTER, the National Ecological Observatory Network (NEON), the University of Notre Dame Environmental Research Center, and the University of Wisconsin Center for Limnology Trout Lake Station.

An interesting geological feature is the number of lakes. Vilas County is home to more lakes than any other county; it has 1,320 of Wisconsin's 15,000 lakes (Stedman, 2006). In addition to the 1,300+ lakes in Vilas County, there are roughly 115 lake organizations. With a high concentration of lakes and organizations, Vilas County was an attractive study site for the research questions we pursued.

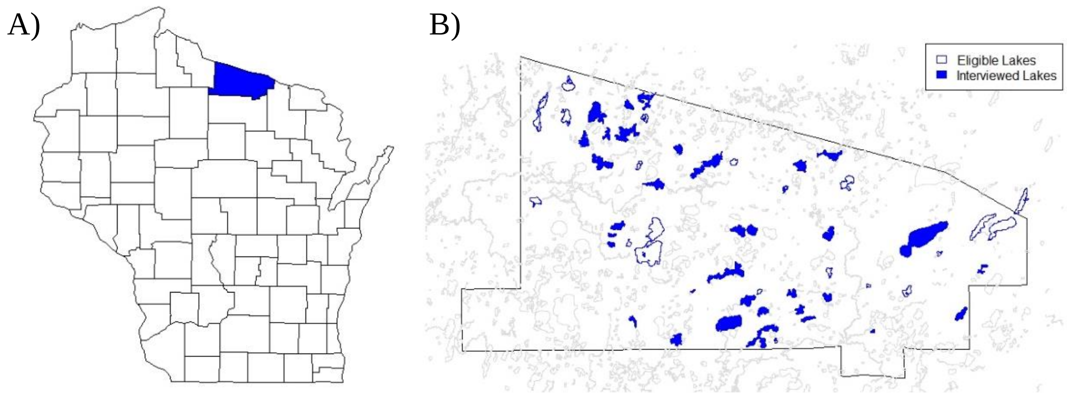

Figure 2. Our sample lakes in Vilas County, Wisconsin. A) Vilas County is in the Northern part of Wisconsin on the border of Michigan. B) The sixty-two Vilas County lakes outlined in blue were eligible for our study. The lakes filled in blue are the thirty-nine lakes managed by the thirty-one organizations we interviewed. Source: County Boundaries 24K and 24K Hydro Waterbodies (Open Water) published on dnrmaps.wi.gov.

We selected lakes and lake organizations (Figure 2B) using three criteria. First, we selected lakes with public access. Lakes with public access have a boat ramp or landing where non-residents can access the lake for recreation, fishing, and other uses. Lakes that have public access are faced with greater collective action problems because there is potential for over-use by non-residents who are less susceptible to resulting negative effects. Second, we included lakes with lake organizations that manage three or fewer lakes to study organizations that manage similar system complexity. For example, we exclude the Eagle River Chain of Lakes Association, which manages ten lakes and has 829 members (ERCOLA, 2020). Finally, we selected lakes that are managed by the WI DNR. After applying these filters, there were fifty-two organizations and sixty-two lakes eligible for our study.

2.2 Data Collection

We interviewed thirty-one of the fifty-two eligible organizations. The thirty-one organizations manage a total of thirty-nine lakes. Most organizations, in our study, manage one lake; five organizations manage more than one lake. To schedule the interviews, we contacted the president or primary contact listed on the UW-Extension Lakes Program website, listed on lake organization websites, or provided by partners at the Vilas County Land & Water Conservation Department. We received a response from forty-one of the organizations through email, online contact forms, phone calls, and in person. Once in contact with the president or primary contact, we asked them to invite one to four other members to the interview for a maximum of five interviewees. The interviews lasted one to two hours and were conducted in community centers, lake organization member homes, and once on a boat.

We used a semi-structured interview methodology. The interviews started with each attendee signing the letter of consent approved by the Arizona State University IRB. Next, everyone filled out Worksheet 1: Changes to the Lake (Appendix 1). Most of the interview was a guided discussion about the lake organization structure and rules (Appendix 2). Each interview had the same facilitator and two notetakers. The notetakers took independent notes on the discussion.

Following each interview, the notetakers immediately coded the institutional design principles as present or absent based on their notes. Each notetaker coded independently and then compared their decisions. When the notetakers disagreed, the facilitator made the final decision. The two design principles that had a high level of disagreement at the beginning of the data collection period were: monitoring and low-cost conflict resolution. The disagreements came from unclear definitions. Once we resolved to include informal monitoring, like lake organization members noting rule violations from their boats, and programmatic monitoring, like boat ramp inspections, in our definitions of monitoring, we did not have further issues with disagreement. For conflict resolution, the challenge was deciding what is considered rapid and low-cost. We included the use of lake organization meetings and science-based conflict resolution but excluded lawsuits and court-based conflict resolution. Once we reached an agreement, the notetakers entered the data into our database.

2.3 The Outcomes: Seven Lake Organization Goals

The people living around the lakes use the lakes in different ways. As a result, lake organizations have multiple social and environmental goals. Figure 3 shows the goals mentioned by the lake organizations during our interviews. We used constant comparison, a process in which each finding is compared with present findings to determine whether it is the same or different, to identify eleven themes in the lake organization goals recorded in our field notes (Glaser & Strauss, 1967). Lake stewardship, education, and aquatic invasive species management were most common; organizations managed 56 % of the thirty-nine lakes in the study with these goals. The next three goals, named by 20% or more of lakes, were focused on community building, aquatic invasive species prevention, and water clarity. These findings are consistent with Gabriel and Lancaster’s survey results (Gabriel & Lancaster, 2004). The least common goals were a) transition to a lake district and b) to enhance property values, which included 5% or less of lakes. We were surprised to find that the lake organizations that we interviewed did not mention fishery protection and zoning issues as often as lake organizations in the 2004 Gabriel and Lancaster study.

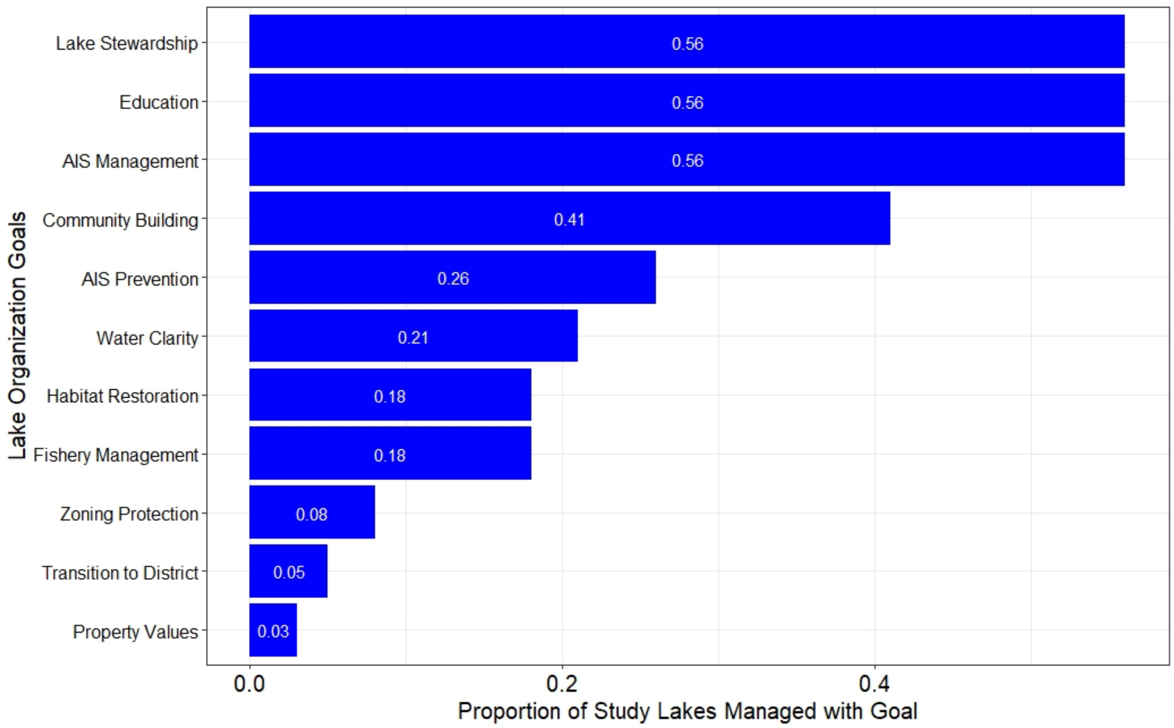

Figure 3. The eleven lake organization goals and the proportion of the thirty-nine lakes managed with each goal. Source**:** 2019 Interview Dataset.

In Table 1, we map the goals to outcomes for each lake. We use data available via the WI DNR, UW-Extension Lakes Program, and our 2019 Interview Dataset. We focus on the common goals; we mapped seven of the eleven goals in Figure 3 to outcomes in Table 1. We do not include habitat restoration, zoning protection, a transition to a lake district, and property values in this study.

Table 1. The mapped outcomes and dichotomization of seven of the goals mentioned by lake organizations during the 2019 interviews. The data for the outcomes come from several public sources. Appendix 4 shows the distribution of continuous variables.

Goal	Outcome	Present (1)	Absent (0)	Source
Lake Stewardship	Lake Management Grant	Received	Not Received	WI DNR
Education	Clean Boats, Clean Waters (2019)	Participated	Did Not Participate	UW-Extension Lakes
AIS Management	AIS Treatment Grant	Received	Not Received	WI DN R
Community Building	Participation in Organization	≥ 0.65	< 0.65	2019 Interview Dataset
AIS Prevention	Eurasian Watermilfoil (2019)	Present	Absent	WI DNR
Water Clarity	Very High Water Clarity	Very High	Moderate, Low	WI DNR
Fishery Management	Adult Walleye per Acre	≥ 1.42	< 1.42	WI DNR

We mapped goals to outcomes based on lake organizations' description of their goals. When talking about lake stewardship organizations mentioned general lake management and shoreline protection, lake organizations apply for lake management grants to understand and make improvements to the lake. Without a grant, they have no authority to make changes. AIS treatment grants are specific to AIS management; they allow lake organizations to apply chemical and manual treatments to the lake. Education of members and lake users happens in many different ways; however, Clean Boats, Clean Waters (CBCW) is the most widely adopted and recorded approach. Through CBCW, volunteers educate lake users about the risks of AIS. When lake organizations talked about community building, they mentioned increasing membership and neighborhood connections. Organization participation is a function of membership that controls for variations in the number of houses around a lake. Lake organizations are very concerned about EWM. When they talked about AIS prevention, it was most often about EWM. Water clarity is the only goal that is the same as its outcome. Fishery management like AIS prevention could be general, but lake organizations mentioned walleye most often as the fish they care most about; this is also a fish that the WI DNR manages through habitat improvement and by stocking—adding juvenile fish to a lake. While lake organizations stated general goals, the way they described the steps they take to meet them made mapping a measured outcome straightforward.

Table 2 compares the outcomes for lake SESs with a goal to those without a goal related to the outcome. On the one hand, lakes with AIS management and AIS prevention goals receive more plant management grants and have a lower incidence of Eurasian Watermilfoil than lakes that do not state these goals. On the other hand, lakes with lake stewardship and community building goals receive fewer general grants and have lower participation than organizations that do not state these goals. We used the Mann-Whitney U test (Mann & Whitney, 1947) for significance and found all these significant to 0.1. For water clarity and fishery management, there was no significant difference in outcome between the two groups.

Table 2. Impact of Stated Goals on Success. This table shows the percentage of the lakes in our study managed under each goal. We then show the percent successful as measured by the metrics in Table 1. compare success between lakes that have stated the goal to lakes that have not stated the goal. Using the Mann-Whitney U test (Mann & Whitney, 1947), all group differences have at least a 0.10 significance level except water clarity and fishery management. Source: 2019 Interview Dataset, WI DNR.

Organizational Goal	**% Lakes**	**Metric**	**Stated**	**Not Stated**	**z-Score**
Lake Stewardship	56%	GRNT	73%	100%	-1.43[1]
AIS Management	56%	APM	55%	24%	1.63[1]
Education	56%	CBCW	31%	65%	-1.73[1]
Community Building	41%	PART	31%	61%	1.54[1]
AIS Prevention	26%	~EWM	90%	62%	1.29[1]
Water Clarity	21%	CLAR	25%	19%	-0.23
Fishery Management	18%	ABUN	47%	71%	-1.15

[1]Significance < 0.1

The outcomes in Table 2 are used in our analysis. In the next section we explore the combinations of conditions that lead to the outcomes. Although we cannot conclude anything about outcomes from goal setting alone, we include goal setting as a condition in our analysis.

2.4 The Conditions: Environmental, Social, and Institutional

The environmental, social, and institutional conditions listed in Table 3 are the product of a comprehensive, iterative selection process. First, we selected the theoretically relevant variables from the IADF and IDPs (Ostrom, 1990, 2005). We then included theoretically and empirically derived conditions from a literature review and the summer 2019 interviews, respectively. Through an iterative process of analyzing different outcomes in dialogue with our cases, we identified the following variables as most useful to understand our outcomes.

Table 3. The dichotomized environmental, social, and institutional conditions and their data sources. The dichotomization of continuous variables uses the median value, for plots see Appendix 4.

Condition	Present (1)	Absent (0)	Source
Environmental			
Eurasian Watermilfoil (2019)	Present	Absent	WI DNR
Lake Type	Seepage, Spring	Drainage	WI DNR
Lake Size (ac)	≥ 377	< 377	WI DNR
Lake Depth (ft)	≥ 32	< 32	WI DNR
Distance from Road (ln(m))	≥ 6.58	< 6.58	USGS
Conductance (uS/cm)	≥ 69	< 69	NTL LTER
Total Phosphorous (ug/L)	≥ 12.4	< 12.4	Jones Lab, NTL LTER, WI DNR
Stock Walleye (since 2000)	Yes	No	WI DNR
Social			
Participation in Organization	≥ 0.65	< 0.65	2019 Interview Dataset
Building Density	≥ 16.58	< 16.58	USGS
Lake Organization Type	Lake District	Lake Assoc.	2019 Interview Dataset
Institutional			
Graduated Sanctions	Present	Absent	2019 Interview Dataset
Accessible Conflict Resolution	Present	Absent	2019 Interview Dataset
Exclusion	Present	Absent	2019 Interview Dataset
Work with Consultant	Yes	No	2019 Interview Dataset
Town Lakes Committee	Member	Not Member	2019 Interview Dataset
Outcome as a goal	Yes	No	2019 Interview Dataset

The data we used for the conditions come from several sources, including the WI DNR, USGS, NTL LTER, Jones Lab, and our 2019 Interview Dataset. Ten of the environmental, social, and institutional conditions we used are categorical. For the remaining seven conditions, we evaluated the distribution (Appendix 4). We used the median to convert them into dichotomous variables, which is essential for the analysis method we used. The condition "outcome as a goal" is drawn from the goals in Table 2.

2.4.1 Environmental Conditions

Several environmental conditions affect lake SES outcomes. For our study, we considered Eurasian Watermilfoil, lake type, lake size, lake depth, distance from road, conductance, total phosphorous, and stock walleye.

Lake type, lake size, and lake depth are all morphological characteristics of the lake that affect the processes within the lake. Deeper lakes and spring-fed lakes are both clearer, which is tied to the phosphorous cycling in lakes and groundwater fluxes (Johnston & Shmagin, 2006). Drainage lakes, lakes that have an inlet or outlet, are more susceptible to aquatic invasive species (Smith, Smith, Barko, & Barko, 1990).

Conductance and total phosphorous are conditions that describe a lake's productivity or ability to support plant and animal life. Higher total phosphorous and conductivity indicate higher productivity (Johnston & Shmagin, 2006; Smith et al., 1990).

Eurasian Watermilfoil and the distance from the road are both environmental factors that may impact how people use the lake and the amount of investment from a lake organization. Eurasian Watermilfoil is an aquatic invasive species that is easily spread through fragments and can make lakes unnavigable (Smith et al., 1990). Distance from the road is a measure of the accessibility of a lake.

Stock walleye indicates where the lake has been stocked with juvenile walleye since 2000. The WI DNR stocks walleye to maintain a healthy fish population in the lake when fish mortality outpaces natural reproduction.

2.4.2 Attributes of the Community

There are three attributes of the community that we identified through interviews and literature review. These are building density, participation in organization, and lake organization type.

Building density is calculated as the number of buildings per unit of the perimeter. Building density reflects the lakefront property development, which affects the shoreline habitat. The shoreline development can affect runoff into the lake and fish reproduction. Additionally, it indicates the concentration of individuals living around the lake, which can affect cooperation.

Participation in organization is the percent of households who are members of the lake organization. Percent participation is different from volunteering. Many of the lake organization participants just pay dues or pay dues and attend the annual meeting. It is a much smaller group that contributes time to lake management.

Finally, we include the lake organization type (LDST). We only have a small sample of lake districts in our study, so we do not see this variable in our later causal combinations. The lake organization type, however, can play a role in solving collective action problems given a lake districts' mandatory participation and ability to levy taxes.

2.4.3 Rules-in-Use

Neither the biophysical conditions nor the attributes of the community—explained in the previous two sections—alone explain the benefits of a lake organization for a lake nor how differences between organizations impact their performance. We include the institutional design principles or rules-in-use, which Ostrom describes as "an essential element or condition that helps to account for the success of these institutions in sustaining the [common pool resources] and gaining the compliance of generation after generation of appropriators to the rules in use" (Ostrom, 1990). Figure 4 shows the proportion of the thirty-one, interviewed organizations that employ each of the eight design principles. We see that some design principles are present for most or all lake organizations and others that vary by organization.

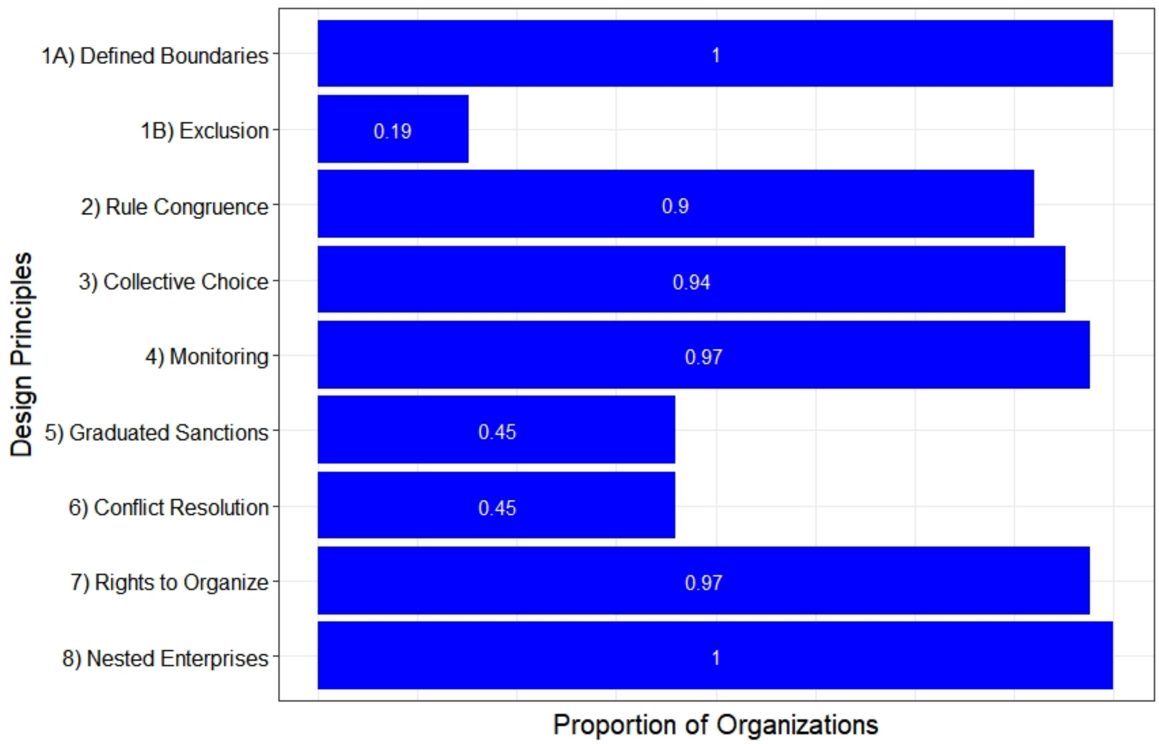

Figure 4. The proportion of Lake Organizations using each Institutional Design Principle (IDP). Source: (Ostrom, 1990), 2019 Interview Dataset

All lake organizations have 1A) clearly defined boundaries and 8) nested enterprises. Lake organizations are formed around lakes "for the purpose of undertaking a program of lake protection and rehabilitation" (Wisconsin State Legislature, 1974). It is inherent to this type of organization that the physical boundaries of the resource are clear to the organization.

Additionally, Wisconsin Statutes Chapter 33 establishes that the lakes will be managed in a partnership between the Department of Natural Resources, the University of Wisconsin system, other government agencies, and public and private organizations known as the Wisconsin Lakes Partnership (Wisconsin State Legislature, 1974). As a result, design principle eight—nested enterprises—is required by Wisconsin State law. Even though nested enterprises are present for all lake organizations, there are different types of partnerships formed by lake organizations.

These partnerships include partnering with other lake organizations, a town lakes committee, the DNR, Vilas County Land and Water Committee, or a consultant. We found that almost all organizations partner with the WI DNR or Vilas County Land and Water Conservation Department, most partner with a consultant or town lakes committee, and few organizations partner with other lake organizations. Lake organizations rely on funding, permits, and training from the WI DNR and Vilas County Land and Water Conservation Department, so they must partner with them if they take any management actions on the lakes. The lake management planning and lake study grants require lake organizations to partner with an approved consultant to be funded, so it is typical for lakes that are applying for grants to partner with a consultant.

Lake organizations do not have to work with a consultant; they can join a town lakes committee that applies for grants and commissions a consultant on behalf of the lakes in their township. These town lakes committees serve as a network of the lakes in their area. Finally, it is rare for lake organizations occasionally to collaborate with the lakes upstream or downstream from them.

Over 90% of the organizations had rules in practice that facilitate 2) congruence between appropriation and provision rules and local conditions, 3) collective-choice arrangements, 4) monitoring, and 7) minimal recognition of rights to organize. Qualified lake associations and lake districts are the two types of lake organizations that can apply for grants to carry out projects to protect or rehabilitate the lakes they are formed around. To be a qualified lake association, the organization must "allow any individual to be a member if they reside within one mile of the lake for at least one month each year, allow any individual to be a member if they own real estate within one mile of the lake, not have articles of incorporation or bylaws which limit or deny the right of any member or class of members to vote" (Wisconsin Lakes Partnership, 2018). The people who live around the lake have a voice in the proceedings of the lake association; people who visit the lake for day-use may not have a voice. Lake districts require any landowners within the border of the district to be a member and landowners; resident and non-resident, have the right to vote. Therefore, we were not surprised to see that 94% of the organizations interviewed had collective-choice arrangements.

Monitoring can be formal or informal. 97% of the lake organizations in Vilas County had one or the other. Often, they had both. Formal monitoring occurs through two programs facilitated by the University of Wisconsin Extension Lakes Program: Citizen Lake Monitoring Network and Clean Boats Clean Waters. Through the Citizen Lake Monitoring Network, "volunteers measure water clarity, using the Secchi Disk method, as an indicator of water quality. Volunteers may also collect chemistry, temperature, and dissolved oxygen data, as well as identify and map plants or watch for the first appearance of Eurasian Water Milfoil near boat landings" (Department of Natural Resources, 2019). Clean Boats Clean Waters "inspectors perform boat and trailer checks for invasive speciess, distribute informational brochures and collect and report any new water body infestations" (UW-Extension Lakes, 2019). Most lakes participate in Citizen Lake Monitoring Network; however, fewer participate in the Clean Boats Clean Waters (CBCW) program. CBCW requires a significant number of volunteer hours.

In addition to formal monitoring, the lake organization members also serve as informal monitors. As users of the lake, people will notice when people are complying with or breaking the rules. Many of the people we interviewed, for example, own pontoon boats. When they were cruising the lake in the evenings, they noticed if people were water skiing after the no-wake hours started. There is no formal program that assigns monitoring time to different pontoon owners; this informal monitoring is common in resource systems when the systems are small, and the users live or work nearby.

Finally, Wisconsin Statute Chapter 33 provides lake organizations the right to organize. Lake organizations are legitimized by Wisconsin law and supported through the Wisconsin Lakes Partnership.

The three design principles that were employed by lake organizations with more variation were 1B) the exclusion of non-permitted users, 5) graduated sanctions, and 6) conflict-resolution mechanisms. These are the three rules-in-use that we employ for qualitative comparative analysis. In our interviews, we found that exclusion was carried out through physical structures, like narrow or shallow entry to a lake, or through social pressure. An example of social pressure is encouraging homebuyers who intend to rent out their cabin to consider buying a property on another lake. Sanctions—verbal warnings and written notices—were employed by fewer than fifty percent of the organizations. The organizations that did use graduated sanctions decided against verbally warning their neighbors because members did not think it was their job—they are not the police. Finally, conflict resolution was rarely needed by organizations. For the organizations that had experienced conflict, most found low-cost ways of resolving the issue, such as inviting a DNR scientist to mediate. However, a couple cited going to court. These rules in use derived from the Ostrom institutional design principles complement the biophysical conditions and attributes of the community following the contextual variables outlined in the IADF.

The institutional conditions that we include in our analysis are the exclusion of non-permitted users, graduated sanction, and conflict resolution. We also included partnerships with a consultant and with town lakes committees. Lastly, we included organizational goals as a condition to understand the lake SES outcomes.

2.5 Analytical Approach: Linear Regression Analysis

Environmental and social conditions could explain the goals and outcomes defined by lake organizations. We used linear regression to explore the effect of social and environmental variables on water clarity and adult walleye per acre. We used a logit model to do the same for the presence of Eurasian Watermilfoil (EWM). We explored the three outcomes where data was available for many lakes across Vilas County; we were not able to test all outcomes.

2.6 Analytical Approach: Crisp-Set Qualitative Comparative Analysis (csQCA)

Charles C. Ragin developed qualitative comparative analysis (QCA) as a "synthetic strategy" to "integrate the best features of the case-oriented approach with the best features of the variable-oriented approach" (Ragin, 1987). According to Ragin, a case-oriented approach (qualitative) assesses a case holistically, while a variable-oriented approach (quantitative) separates the case into its parts. QCA combines features of both approaches, but it is more clearly a case-oriented, qualitative method used to compare cases systematically.

In QCA, each case is a combination of conditions that as a whole comprises the case (Rihoux et al., 2012). QCA draws from set theory and Boolean algebra, the rules of logic—creating logical sets using "and" and "or" operators—established by these approaches make it an easily replicable method of case comparison (Ragin, 1987). The replicability of QCA is a significant asset of this approach when compared to qualitative techniques without formalized rules of logic (Rihoux et al., 2012). Additionally, QCA is transparent about the choice of cases, variables, and the tools for analysis.

There are three types of QCA analyses: crisp set, fuzzy set, and multi-variate. Crisp set QCA (csQCA), the method we employ, uses dichotomized variables; all continuous and categorical variables are coded as present or absent. csQCA is most appropriate for our analysis because eight of the twelve factors we employ are dichotomous. Based on the sensitivity analysis we conducted, we do not have cause to assume that varying degrees of the remaining four factors would have a significant impact on the outcomes.

csQCA analysis has two steps: identification of necessary conditions and generation of sufficient causal conditions for an outcome. In QCA, a condition is necessary for an outcome if it is always present when the outcome occurs; a condition is sufficient for an outcome if the outcome always occurs when the condition is present (Rihoux & Ragin, 2009). We used the fsQCA 3.0 software—developed by Charles Ragin and Sean Davey—for both of these steps (Ragin & Davey, 2016).

Using the software, we analyze the consistency of an outcome for a given set of conditions; we follow the convention where combinations with a consistency score equal to or greater than 0.80 are kept (Ragin & Davey, 2016). We then use the Quine-McCluskey algorithm, also called the tabulation method, to simplify the combinations to their minimal number of conditions (McCluskey, 1956).

When using QCA, the researcher views causation as context and conjecture specific; the researcher does not specify a single causal model that best fits the data. The researcher, instead, identifies the multiple models that exist within comparable cases (Ragin, 1987). QCA, therefore, allows for "multi conjectural causation" across cases; there can be more than one combination of factors that lead to a given outcome called equifinality (Rihoux et al., 2012).

The results from a systematic comparison of cases, QCA, may be used in "modest generalization." We can form propositions to apply to similar cases with due caution (Rihoux et al., 2012). QCA, as suggested before, does not assume some of the key ideas in mainstream statistics. These ideas include permanent causality, uniformity of causal effects, unit homogeneity, additivity, and causal symmetry (Rihoux et al., 2012).

We take an unconventional approach in this study, repeating csQCA's identification of necessary and sufficient conditions for multiple outcomes. Most studies identify necessary and sufficient conditions for a single outcome. In the following sections, we will explain the outcomes and conditions used in our analysis.

3. RESULTS & DISCUSSION

We use linear regression analysis to identify environmental and social conditions that influence success on water clarity and Eurasian Watermilfoil prevention. We then use crisp-set qualitative comparative analysis (csQCA) to compare the thirty-nine lakes whose lake organizations we interviewed. Following the standards in the csQCA methodology, we used a two-step analysis. First, we identified the necessary conditions for each outcome. Second, we identified sufficient conditions using the Quine-McCluskey algorithm for solution simplification.

3.1 Linear Regression Analysis

We start with linear regression analysis (Table 4) of certain environmental and social conditions on three lake SES outcomes. We explore water clarity, adult walleyes per acre, and the presence of Eurasian Watermilfoil. WI DNR data is widely available for Vilas County lakes for these outcomes. We examined whether having a lake organization, having a public landing, the size, the depth, the lake type, the distance to a secondary road, and building density have a significant effect on these outcomes.

Table 4. The WI DNR has data available on the water clarity, walleye abundance, and Eurasian Watermilfoil (EWM) presence for 1,136 lakes in Vilas County. We examined whether having a lake organization, having a public landing, the size, the depth, the lake type, the distance to a secondary road, and building density has a significant effect on these goals through regression analysis.
Source: WI DNR, USGS, NTL LTER

Goal Metric	**Water Clarity**	**Adult Walleyes per Acre**	**EWM**
Model Type	Linear Regression	Linear Regression	Logit
constant	+++	+++	
Lake organization			+
Public landing	–		
Size (acres)			
Max depth	+++		––
Drainage	–––		
Drained			
Seepage			
Spring	–		
Distance secondary road			
Building density		–	++
N	342	82	148
R^2	0.4767	0.1492	0.2708

Significance: +++/––– p<0.001 | ++/–– p< 0.01 | +/– p< 0.1

As expected, we see that water clarity is explained by the depth of the lake (Johnston & Shmagin, 2006). Drainage lakes have lower water clarity. A drainage lake has an inlet and outlet and often have higher nutrient loads than other lakes, leading to water with lower clarity. Lakes with a public landing and spring-fed lakes have a modest negative effect on water clarity. Lakes with a public landing give access to boaters and swimmers, which can stir up sediment that has settled on the bottom of the lake. Groundwater flows into spring lakes from the bottom of the lake.

Adult walleye abundance is modestly impacted by building density around the lake. Walleye require certain conditions in shallow water to spawn; lakefront property development may impact this (Jennings et al., 2003; Sass et al., 2006). Additionally, there may be higher fishing pressure on lakes with more development.

The presence of Eurasian Watermilfoil (EWM) is lower for deeper lakes and higher for lakes with high building density and lakes with lake organizations. EWM grows on the bottom of lakes and is often transported by boat into a lake. Nutrients may be limited in deeper lakes, negatively impacting EWM growth (Johnston & Shmagin, 2006). Building density around the lake probably means more lake traffic providing more opportunities to transport EWM. It may seem counter-intuitive that a lake having a lake organization is slightly positively correlated with EWM. It is common for lake organizations to form in response to a threat—aquatic invasive species appearance is a common cause (Gabriel & Lancaster, 2004).

Our basic regression analysis suggests that lake organizations have an insignificant role in these outcomes and that there may be multiple factors influencing the outcomes. The complexity of SESs makes them a good fit for csQCA, which allows multiple pathways to the same outcome through combinations of environmental, social, and institutional conditions.

3.2 Necessary Conditions

A necessary condition is always present when the outcome occurs (Rihoux et al., 2012). We evaluated whether each condition is necessarily present, necessarily absent, or not necessary for each outcome. For a condition to be considered necessary, it should have a consistency score of greater than or equal to 0.90 (Cebotari & Vink, 2013). This score means that the condition is present or absent in 90% of the cases with that outcome.

We evaluated the necessity of the causal conditions in Table 3 for the seven outcomes and found lake depth is a necessary condition for very high water clarity. During the analysis of necessity, one considers the presence and absence of the conditions (Cebotari & Vink, 2013). We only find necessary conditions for very high water clarity, and lake depth only explains 36% of the outcome. These findings support our hypothesis that lake SES outcomes depend on combinations of factors and that there are multiple pathways to an outcome.

Table 5. Necessary conditions by outcome. UPPERCASE means the variable is present; lowercase means the variable is absent. Conditions are considered necessary if they have a consistency value of 0.90 or higher.

Outcome	Necessary Conditions[1]	Consistency	Coverage
Very high water clarity	DEEP	1.00	0.36

[1]For abbreviations see Appendix 5

Lake depth (DEEP) is necessary for very high water clarity. This finding is consistent with a study by Johnston and Shmagin, where they found lake depth to be the single best predictor of water clarity. Lake depth is tied to phosphorous cycling in the lakes and groundwater fluxes (Johnston & Shmagin, 2006). These processes both affect the prevalence of algae and vegetation in the lake and thus the water clarity. Because the necessary conditions only start to explain lake SES outcomes, we next explore the sufficient conditions whose combinations lead to success in our sample.

3.3 Sufficient Conditions

The analysis of sufficiency identifies combinations of the environmental, social, and institutional conditions that lead to the seven outcomes (Table 6). In this analysis, the conditions sufficient to explain an outcome vary by the outcome assessed. For example, the conditions that explain receiving a lake management grant differ from the conditions that explain very high water clarity. For each of the outcomes, there are multiple combinations of factors that lead to success. Each line in Table 6 represents a combination of variables that lead to the outcome.

Table 6. The combinations of environmental, social, and institutions conditions that lead to the seven outcomes studied. Following the conventions of Boolean algebra, UPPERCASE letters mean the condition is present and the value is "1"; lowercase letters represent absence and the value is "0". The operators used are the logical "AND" represented by the multiplication symbol "*" and the logical "OR" represented by the addition symbol "+" (Rihoux et al., 2009). Each line represents a combination of variables that lead to the outcome.

Outcome	**Combinations[1]**	**Consistency, Coverage**
Lake Management Grant Received	[CONS] + [TLC*SANC*(stewg+dens)] + [tlc*STEWg*dens]	1, 0.97
AIS Treatment Grant Received	[DENS*road]*[(cons*AISMg)+CLAR] + [DENS*ROAD*AISMg*clar] + [EWM*road*clar*AISMg] + [EWM*CONS]	1, 0.88
Clean Boats, Clean Waters Participation	[EWM*SANC*ROAD]*[DENS+(SIZE*CONF)] + [ewm*sanc*SIZE*dens] + [road*SANC*CONF*SIZE]*[ewm+DENS]	1, 0.72
Participation in Org ≥ 0.65	[CONS*commg]*[(SANC*road)+(SIZE*EWM)] + [CONS*ROAD]*[(sanc*commg)+(sanc*SIZE)+(size*EWM)] + [cons*road*COMMg*SIZE] + [cons*commg*ROAD*SANC]	1, 0.86
Eurasian Watermilfoil Absence	[clar*dens]*[AISPg+(SANC*cond)+(TP*DEEP)] + [clar*tp*deep*cond*aispg] + [clar*DENS*SANC*COND] + [clar*sanc*AISPg] + [CLAR*tp*DEEP]*[SANC+cond] + [dens*tp]*[(cond*DEEP)+(clar*deep)]	1, 0.96
Very High Water Clarity	[DEEP*SEEP*(ROAD+CLARg)]	1, 0.88
Adult Walleye/acre ≥ 1.42	[clar*DEEP]*[(sanc*dens)+(cond*SANC)+(COND*sanc*STOCK)] + [clar*cond*dens*stock] + [CLAR*DEEP*COND*SANC]	1, 0.75

[1] Abbreviations used are available in Appendix 5.

The combinations that lead to the seven outcomes range in complexity and number. For example, very high water clarity has one pathway comprised of four conditions. High participation in the lake organization has four pathways with six conditions. All of the pathways have a consistency of 1. A consistency score of 1 means the cases that exhibit the conditions in that combination have the same outcome. The coverage ranges from 0.72 to 0.97, which means the pathways explain 72-97% of the cases with the outcome. The outcomes are sensitive to the way the variables have been dichotomized. When the conditions are dichotomized on the mean, rather than the median, the same conditions explain 63-94% of the outcomes (Appendix 7).

Outcomes can also be conditions in SESs. Very high water clarity is an outcome that lake organizations care about; it influences the appearance of EWM and adult walleye abundance. The interconnected nature of SESs systems blurs the line between cause and effect.

There are three pathways by which lake organizations receive a lake management grant. These pathways explained 97% of the cases when lake organizations received grants. The first pathway is working with a consultant (CONS); consultants are paid through grants to conduct lake studies or prepare lake management plans for lake organizations. They provide scientific knowledge and have streamlined processes based on years of experience. The second pathway includes being a member of a Town Lakes Committee (TLC) and employing graduated sanctions (SANC) when there is no stewardship goal (stewg), or the building density is low (dens). Town lake committees can apply for grants on behalf of lake organizations and are forums for sharing information between organizations. Graduated sanctions (SANC) mean that organizations are sophisticated enough to enforce their rules and do it on a sliding scale, which promotes learning. The third pathway includes organizations that have a stewardship goal (STEWg), are not town lakes committee members (tlc), and have low building density (dens) around the lake. These organizations are focused on stewardship; lake management grants provided by the WI DNR are the best method to make changes to the lake. Receiving a lake management grant was achieved in three ways, which involve working with information aggregators—consultants and town lakes committees—and organizational sophistication shown through graduated sanctions and goal setting.

Lake organizations received aquatic invasive species (AIS) treatment grants when they fit one of four pathways. These pathways described 88% of the cases when an AIS treatment grant was received. The four pathways fall into two groups, lakes with high building density (DENS) and lakes with Eurasian Watermilfoil (EWM). The first high building density pathway is lakes that are close to a secondary road (road). These lakes are accessible, which may increase the non-resident traffic on the lake. Higher non-resident traffic would lead to a greater risk of the introduction of AIS during boat launching. The second high building density pathway includes lake organizations with aquatic invasive species management goals (AISMg) and that manage moderate to low clarity lakes (clar) that are not close to a secondary road (ROAD). These organizations need AIS treatment grants to reach their goals. For lake organizations with EWM, a rapidly spreading AIS that chokes out other plant life, one pathway includes organizations with aquatic invasive species management goals (AISMg) managing lakes moderate to low clarity lakes (clar) near secondary roads (road). These accessible, EWM-plagued lakes need AIS treatment grants to meet their goals and prevent the spread of EWM. The fourth pathway includes organizations who work with consultants to manage EWM-plagued lakes. Consultants help lake organizations carry out the AIS treatment activities funded by the grants. Lake organizations dealing with EWM that set AIS management goals or partner with consultants receive AIS treatment grants to manage lakes that have high building density or are close to secondary roads.

Clean Boats, Clean Waters (CBCW) is an AIS education program carried out by volunteers who inspect boats at launch ramps across the state of Wisconsin. Three pathways explain 72% of the cases where lake organizations participated in CBCW during the summer of 2019. The first pathway includes lake organizations employ graduated sanctions (SANC) to manage lakes with EWM (EWM) that are not close to secondary roads (ROAD). These conditions indicate that they already have an AIS, but they are committed to educating people about its spread through boat ramp monitoring and rule enforcement. The second pathway includes organizations that employ graduated sanctions (SANC), but do not have Eurasian Watermilfoil (ewm). These lakes are large and have a low building density. CBCW is a volunteer-based program; lakes with graduated sanctions have stronger rule enforcement and perhaps stronger organizations. The third pathway is large lakes (SIZE) near secondary roads (road) managed by organizations with graduated sanctions and conflict resolution. The size and accessibility of these lakes may put them at risk, so they participate in CBCW and have a sophisticated institutional structure. The lake organizations that participate in CBCW vary in structure as do the lakes they manage. Some organizations participate as a preventative measure; others have EWM and still participate. Some organizations supplement CBCW with graduated sanctions, and others do not.

High lake organization participation, ≥ 65%, is explained by four pathways. These pathways explain 86% of the cases where organization participation is high.

First, lake organizations that partner with consultants (CONS) and do not have a community-building goal (commg). Members participate in surveys and workshops, like aquatic plant identification, during lake management studies by consultants. The resulting products are exciting and serve as strategy documents for the organization. These organizations, which manage large (SIZE) or accessible (road) lakes, might not have a community-building goal because they have high participation. The second pathway includes lake organizations that work with consultants (CONS) and are not close to a secondary road (ROAD). The third pathway is large, accessible lakes that have community building goals (COMMg). Finally, organizations that are not close to a secondary road (ROAD) and employ graduated sanctions (SANC) have high participation. The pathways that lead to high participation differ by lake size and accessibility. Common strategies like sophisticated organizational practices, partnering with a consultant, and goal setting, lead to high participation.

The absence of Eurasian Watermilfoil is the result of six pathways, which explain 96% of the cases where EWM was absent. The first pathway includes lakes that have moderate to low water clarity (clar) and low building density (dens). Less light penetrates water with lower clarity, which inhibits EWM growth (Smith et al., 1990). Additionally, some of these lakes are deep (DEEP), which inhibits EWM growth for the same reason. The next pathway is shallow (deeps) lakes with moderate to low water clarity (clar). These lakes have low conductivity (cond) and total phosphorous (tp). Conductivity and total phosphorous are different measures of lake productivity; low conductivity and low phosphorous indicate low lake productivity. The third pathway also includes moderate to low water clarity (clar) lakes managed by organizations with graduated sanctions (SANC) in place. These lakes also have high conductivity (COND) and high building density (DENS). Though the lake productivity and building density seem to be favorable to EWM, the graduated sanctions play a role in preventing EWM. The fourth and final pathway with moderate to low water clarity includes organizations that set AIS prevention goals (AISPg). The fifth pathway is very high water clarity (CLAR), low total phosphorous (tp), deep (DEEP) lakes that either have low conductivity (cond) or graduated sanctions (SANC). Phosphorous is a nutrient that promotes EWM growth (Smith et al., 1990), so low levels of phosphorous in combination with the other factors prevent EWM presence. The final pathway includes lakes with poor growing conditions for EWM that have low building density (dens). Eurasian Watermilfoil is prevented by unfavorable environmental conditions like low lake productivity and water clarity; graduated sanctions and goal setting also play a key role in preventing this aquatic invasive species.

Very high water clarity is the result of one pathway, which explains 88% of the cases where water clarity is very high. The lakes in this group are deep (DEEP) and either seepage or spring lakes (SEEP). Both of these conditions are associated with phosphorous cycling in the lakes; deep, seepage or spring lakes have less phosphorous and, therefore, slower algae and plant growth (Johnston & Shmagin, 2006). These lakes were also far from a secondary road (ROAD) or the organization had a water clarity goal (CLARg). The lakes far from a secondary road may have less traffic, churning less sediment, or have more natural watershed leading to fewer runoff nutrients. Very high water clarity is a function of the hydrology in the lake; very clear lakes are deep, seepage or spring lakes.

The proportion of adult walleye per acre is higher in three scenarios. These scenarios explain 75% of the cases where the number of adult walleye per acre was equal to or higher than 1.42. In two of the pathways, the water clarity is low to moderate (clar).

The first pathway is deep (DEEP), moderate to low clarity lakes. The low water clarity and depth make these good walleye lakes. Additionally, the walleye populations benefit from low building density (dens), graduated sanctions (SANC), high conductance (COND), and stocking (STOCK) in various cases. The second pathway is low conductance (cond) lakes with low building density (dens) and organizations that do not stock (stock). These lakes have low productivity and are not deep; this goes against the understanding of what makes a good walleye lake. The low density and lack of stocking may mean these lakes are out of the way, without much fishing pressure. The third pathway is clear (CLAR), deep (DEEP), high conductance (COND) lakes that employ graduated sanctions (SANC). The natural conditions in the lake are favorable to walleye, and the graduated sanctions mean that the harvest limits are probably enforced. The lakes with more adult walleye/acre tend to be environmentally favorable and either less developed or with graduated sanctions in place.

Trends across the seven outcomes show that some outcomes have a greater social and institutional impact, others have a greater environmental influence, and some are a blend. Receiving a lake management grant and having high participation are both heavily influenced by working with a consultant, graduated sanctions, and goal setting; these are social and institutional conditions. Adult walleye abundance and very high water clarity are influenced by environmental factors like lake productivity and lake depth, respectively. Finally, receiving an AIS treatment grant, CBCW participation, and EWM prevention are a cross over. These three cross-over outcomes are management activities carried out by lake organizations to prevent and manage AIS. Positive outcomes are a result of the natural conditions of the lake such as water clarity, social conditions like the building density, and institutional conditions like graduated sanctions.

4. CONCLUSION

We asked how the combinations of environmental, social, and institutional conditions lead to different outcomes for lake SESs with volunteer-based organizations. We found that multiple combinations can lead to an outcome; these combinations vary in number and complexity by the outcome. Social-ecological systems acknowledge the interactions between environmental, social, and institutional factors. Some lake SES outcomes were influenced by environmental factors, others by social and institutional, and others by a combination. Outcomes that were also conditions, like water clarity, blurred the relationship between conditions and outcomes. Social-ecological research, which focuses on systems as a whole, must acknowledge the complex interactions between different types of conditions and the outcomes in the system.

A case-based, systematic comparison presents challenges in preparing data, but it facilitates understanding the complex relationships in social-ecological systems. The approach we used to collect primary data for a moderate number of cases during one field season was effective for overcoming the challenges described by Ratajczyk with institutional design principle data completeness. With a sample of 31 organizations and 39 lakes, gathering secondary data on the environmental conditions of the lakes required compiling multiple data sources. The reward was seeing the similarities emerge. By examining a sample of similar organizations and geographically similar lakes, we identified the contextual nuances in the organizational structures and lakes. In a traditional case study, these would not have been identifiable as trends. In a traditional statistical approach, the combinations would not have emerged and the context would have been lost. Now that the pathways have been identified, other methods like case studies or statistical analysis can explore the nature and prevalence of these pathways.

We chose Vilas County for our study because of its geography and geology; these same factors make it different from many other US counties. There are only a few counties in Wisconsin, Minnesota, and New York that have the number of lakes found in Vilas County and the reduced competition between user groups. Vilas County, as a result, has unique networking opportunities between management organizations. The models developed in Vilas County, like town lakes committees and volunteer-based organizations, could inform policy in other parts of the US. We believe that an interesting next step is to explore the ways that lake organizations emerge and collaborate in the face of changes—like regulatory changes.

Our exploration of different goals focused on lake organizations. Lake organizations have numerous, diverse goals. Lake organizations are one of several groups that use lakes, and goals differ by user-group. Managing lakes for different outcomes is challenging. One approach is to identify the underlying drivers that could maintain system resilience, no matter how success is defined. For example, one person may want to continue catching walleye, another may want to swim in clear water, another may dream about having a nesting pair of loons on the lake, and a fourth may want to maintain the value of their lakefront property. Though goals are diverse and motivated by different uses, there are underlying processes like shoreline development that could impact all the outcomes.

Natural resource management is an essential and resource-intensive function. Innovative models of management are needed to adapt to increasing threats from climate change, land-use change, and invasive species to social-ecological systems. The lakes region in Vilas County, Wisconsin provides a collaborative model that relies on volunteer-based resource management; these solutions are not one size fits all. Conditions for success depend on the desired outcomes and the conditions present in the social-ecological system. Better understanding the dynamic nature of the environmental, social, and institutional context on outcomes is critical for designing social-ecological systems that remain resilient to the increasing challenges of the twenty-first century.

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7. APPENDICIES

Appendix 1. Lake Changes Worksheet

1. For which lake(s) are you answering the questions below?
2. Please summarize how your lake changed over the past 10 years in 3-4 sentences.

In the following questions please check the box that most accurately describes the current state of the lake attribute listed and indicate whether it has increased (+), stayed the same (=), or decreased (-) over the past 10 years.

Attribute	Very Low	Low	Moderate	High	Very High	Change (+, =, -)
Water Clarity						
Amount of fish						
Diversity of fish						
Invasive plant prevalence						
Invasive animal prevalence						
Wildlife diversity						
Pollution levels						
Natural shoreline						
Property values						
Watershed quality						
Personal watercraft presence						
Fishermen presence						
Local visitors						
Wisconsin visitors						
Out-of-state visitors						
Volunteer turnout						
Annual meeting turnout						
Social event turnout						
Lake organization membership						
Housing density						
Amount of stocking						

3. Please list and indicate the state and change of any other attributes that you find important.
4. How does your lake organization compare on the attributes above to the other lake organizations in Vilas County? Please include the names of the organizations.

Appendix 2. Semi-Structured Interview Questions

SECTION1

What were the biggest changes you noticed in the past decade?

What do you think has caused the changes? Has your organization influenced the changes?

SECTION2

When did your lake organization form? Why did it form?

Have you considered being a lake district?

How many people are on your board?

Who lives around the lake? How many homes? What % in the lake organization?

Is there other development around the lake besides homes?

Are there other organizations you work with to manage the lake? County? DNR? (polycentricity)

How do people use the lake? Residents vs. non-residents?

What do you consider the lake?

What is your public landing like? Do you manage it? Improve it? (exclusion)

Are there rules about who can or cannot use the lake? (exclusion)

Do you participate in CBCW? AIS monitoring? Stocking? Shoreline improvement? (provision)

Are lake association members involved in rule making? Non-members? (collective choice)

Are there no wake times, special zoning requirements or other ordinances on your lake?

Has the organization suggested new ordinances or requested different catch limits? (collective choice)

What happens when someone doesn't follow the rules of the lake? (monitoring, graduated sanc)

What happens when there is a conflict between lake users? DNR or township? (conflict)

What are the goals of the organization? How do you meet them?

Have you had any challenges carrying out your goals? (self-determination)

Are there ordinances or regulations that you'd like to change but haven't been able to?

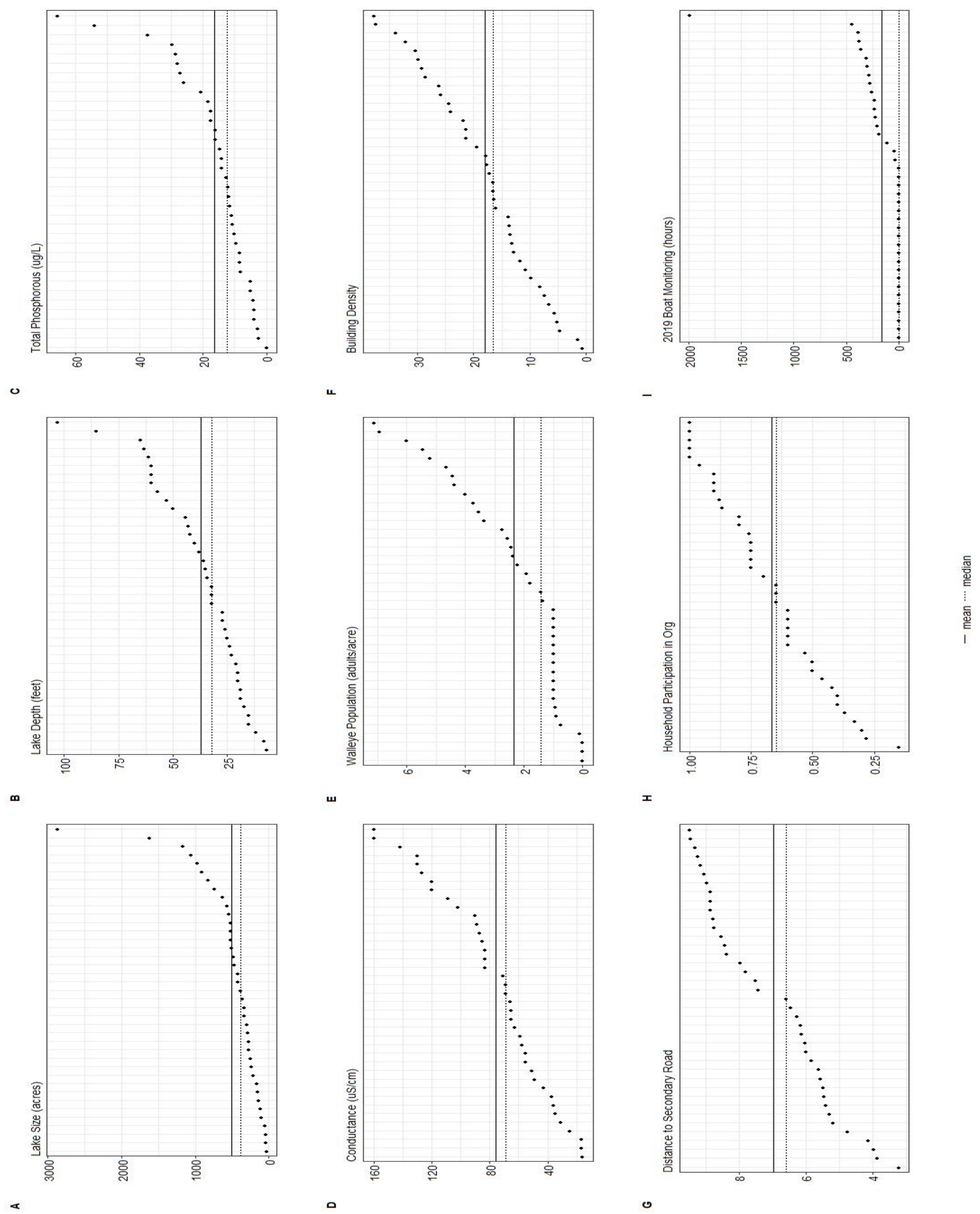
Have you been asked to perform certain activities by the DNR or your township?

Why do/don't you stock fish in your lake? Do you'd stock/not stock in the future?

Appendix 3. Code Definitions for Organizational Goals

Goal	Definition	Typical Exemplars	Atypical Exemplars
Lake Stewardship (STEW)	General lake, shoreline, and watershed protection, monitoring, and management.	stewards of the environment, protect the natural shoreline	keep the lake healthy, keep management plan updated, prevent runoff
AIS Management (AISM)	Managing or controlling existing AIS populations.	AIS Management	contain milfoil with available resources, control EWM, adequate funds for management
Education (EDU)	Education and outreach goals for lake organization members and lake users.	Education, outreach	communication on lake, update website with info
Community Building (COMM)	Goals focused on building the community, promoting connection between neighbors, and goodwill.	increase membership, community building, neighborhood connections	keep volunteers, good life, increase membership
AIS Prevention (AISP)	Goal specifically mentions preventing AIS or protection the lake from AIS. General lake protection is considered STEW.	AIS prevention, be alert for AIS	future camera installation
Water Clarity (CLAR)	Maintain, improve, or monitor lake water clarity.	preserve and maintain water quality and clarity, water clarity	water
Fishery Management (FISH)	Fishery improvement, monitoring, and management.	fishery management, fishery protection	good fishing
Habitat Restoration (HAB)	Habitat restoration or improvement. This can refer to wildlife or vegetation. Protection does not qualify.	habitat restoration, habitat improvement	helping the loons
Zoning Protection (ZONE)	Goals to prevent changes to zoning and land use activities.	zoning preservation	enforcing the deed restrictions
Transition to LD (T2LD)	Transition organization type from a lake association to lake district.	transition org from LA	
Property Values (PROP)	Maintain or improve property values around the lake.	property values	

Appendix 4. Continuous Variable Dichotomization



Appendix 4. Continuous variables were dichotomized on the mean (solid line) and median (broken line).

Appendix 5. Condition and Outcome Abbreviations

The conditions used to understand the combinations that lead to outcomes for lake SESs. The condition and outcomes, values for which they are present, abbreviation used in Table 6 and Appendix 6, and data source.

	Present (1)	Abbreviation	Source
Environmental Conditions			
Eurasian Watermilfoil (2019)	Present	EWM	WI DNR
Lake Type	Seepage, Spring	SEEP	WI DNR
Lake Size (ac)	≥ 377	SIZE	WI DNR
Lake Depth (ft)	≥ 32	DEEP	WI DNR
Distance from Road (ln(m))	≥ 6.58	ROAD	USGS
Conductance (uS/cm)	≥ 69	COND	NTL LTER
Total Phosphorous (ug/L)	≥ 12.4	TP	Jones Lab, NTL LTER, WI DNR
Stock Walleye (since 2000)	Yes	STOCK	WI DNR
Social Conditions			
Participation in Organization	≥ 0.65	PART	2019 Interview Dataset
Building Density	≥ 16.58	DENS	USGS
Lake Organization Type	Lake District	LDST	2019 Interview Dataset
Institutional Conditions			
Graduated Sanctions	Present	SANC	2019 Interview Dataset
Accessible Conflict Resolution	Present	CONF	2019 Interview Dataset
Exclusion	Present	EXCL	2019 Interview Dataset
Work with Consultant	Yes	CONS	2019 Interview Dataset
Town Lakes Committee	Member	TLC	2019 Interview Dataset
Outcome as a goal	Yes	*g	2019 Interview Dataset
Outcomes			
Lake Management Grant	Received	GRNT	WI DNR
Clean Boats, Clean Waters	Participated	CBCW	UW-Extension Lakes
AIS Treatment Grant	Received	APM	WI DNR
Participation in Organization	≥ 0.65	PART	2019 Interview Dataset
Eurasian Watermilfoil	Present	EWM	WI DNR
Very High Water Clarity	Very High	CLAR	WI DNR
Adult Walleye per Acre	≥ 1.42	ABUN	WI DNR

Appendix 6. QCA Models and Assumptions used in Sufficiency Analysis
Model: GRNT = f(CONS, TLC, SANC, STEWg, DENS)
Assumptions:
CONS (present)
TLC (present)
SANC (present)
STEWg (present)
DENS (present)
Model: APM = f(DENS, ROAD, CLAR, AISMg, CONS, EWM)
Assumptions:
DENS (present)
~ROAD (absent)
~CLAR (absent)
AISMg (present)
CONS (present)
EWM (present)
Model: CBCW = f(ROAD, EWM, SANC, CONF, SIZE, DENS)
Assumptions:
~ROAD (absent)
~EWM (absent)
SANC (present)
CONF (present)
SIZE (present)
DENS (present)
Model: PART = f(CONS, SANC, SIZE, COMMg, ROAD, EWM)
Assumptions:
CONS (present)
SANC (present)
EWM (present)
Model: ~EWM = f(CLAR, DENS, TP, SANC, DEEP, COND, AISPg)
Assumptions:
~CLAR (absent)
~DENS (absent)
~TP (absent)
SANC (present)
DEEP (present)
~COND (absent)
AISPg (present)
Model: CLAR = f(DEEP, SEEP, ROAD, CLARg)
Assumptions:
DEEP (present)
SEEP (present)
ROAD (present)
CLARg (present)
Model: ABUN = f(CLAR, DEEP, COND, SANC, DENS, STOCK)
Assumptions:

~CLAR (absent)
DEEP (present)
COND (present)
SANC (present)
~DENS (absent)
STOCK (present)

Appendix 7. Sensitivity analysis of the sufficient condition combinations.

Outcome	Combinations[1]	Consistency, Coverage
Lake Management Grant Received	[CONS] + [TLC*SANC*(stewg+DENS)]	1, 0.94
AIS Treatment Grant Received	[EWM*CONS] + [EWM*clar*AISMg] + [DENS*road*(cons+CLAR)] + [DENS*ROAD*AISMg*clar]	1, 0.88
Clean Boats, Clean Waters Participation	[ewm*sanc]*[(ROAD*SIZE)+(road*dens*CONF)] + [EWM*SANC]*[DENS+(ROAD*CONF)] + [SANC*conf*SIZE*DENS]	1, 0.73
Participation in Org ≥ 0.67	[CONS*COMMg]*[(SIZE*ROAD)+(size*road*EWM)] + [CONS*commg*road*EWM]*[SIZE+SANC] + [size*commg]*[(CONS*road*ewm)+(SANC*ROAD)] + [cons*COMMg*SIZE*road]	1, 0.84
Eurasian Watermilfoil Absence	[dens*tp]*[(cond)+(SANC*DEEP)] + [CLAR*tp*DEEP]*[(SANC*AISPg)+(cond)] + [clar*dens]*[(sanc*COND)+(SANC*cond)+(SANC*DEEP)] + [clar*sanc*cond*AISPg] + [clar*DENS*TP*SANC]	1, 0.93
Very High Water Clarity	[DEPTH*SEEP*(ROAD+CLARg)]	1, 0.75
Adult Walleye/acre ≥ 3	[clar*cond*stock]*[dens+SANC] [clar*DEEP*DENS*STOCK]*[COND+SANC] [clar*DEEP*dens*stock]	1, 0.63