Social-ecological institutional fit in volunteer-based organizations: A study of lake management organizations in Vilas County, Wisconsin, U.S.A.

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ABSTRACT

Lake organizations around lakes in North America can be seen as a natural experiment of volunteer-based organizations conserving and managing lakes. This enables us to study social, institutional and environmental attributes that correlate with performance of common pool resource governance. In the summer of 2019, we performed an in-depth comparative study of thirty-one lake organizations in Vilas County, Wisconsin using data collected through semi-structured interviews, websites, and agency databases. We systematically compared the cases using crisp-set qualitative comparative analysis, specifically analyzing how the eight Ostrom institutional design principles lead to different outcomes for the lake social-ecological system. We found that different combinations of design principles, and social and environmental attributes led to the same lake S.E.S. outcomes. Although we expected that there were no panaceas for lake governance, we were surprised by the high diversity in organizational goals and the relative low diversity of rules in use.

INTRODUCTION

Environmental governance regimes often ignore the institutional, social, and environmental conditions known to be pivotal to social-ecological system (SES) sustainability (Leslie et al., 2015). Ostrom observed an overuse of one-size-fits-all SES governance solutions, and called for the study of the institutional, social, and ecological conditions of systems to understand what works contextually and move beyond panaceas (Ostrom, 2007). She argued the goal of sustainability science research is to understand the combinations of conditions that more often lead to sustainable outcomes preventing disastrous results (Ostrom, 2007).

Institutional fit is conditions' congruence with the rules and norms governing a system. There are three types of institutional fit—ecological, social, and social-ecological (Epstein et al., 2015). Ecological fit is evaluated by asking whether the rules and norms effectively address the biophysical challenges. Social fit occurs when the rules and norms align with the preferences, values, and needs of the people involved. Social-ecological fit combines these two to ask which institutions are likely to lead to sustainable social-ecological systems (Epstein et al., 2015). In other words, the combinations of institutions and social and ecological conditions that lead to success in a social-ecological system. Assessments made solely on ecological or social data may lead to divergent conclusions (Leslie et al., 2015).

SES fit is used to help understand the conditions in which an institution leads to greater SES sustainability. To do this, a measure or measures of success and the conditions that contribute to that success must be defined (Epstein et al., 2015). The challenges of SES fit include how the system and success are defined, the conditions that are included or not, and success defined based on one set of criteria (Epstein et al., 2015). Most studies rely on the researcher to define success and only focus one measure of success, missing the multiple uses that emerge in SES and differing drivers of outcomes (Agrawal & Benson, 2011; Epstein et al., 2015). In our study we compare the conditions that lead to various outcomes as defined by the people who are part of the SES.

Large-n comparisons and meta-analyses are needed to understand how institutions influence SES outcomes (Cumming et al., 2020). These studies help to identify trends in the conditions and institutional arrangements that lead to SES sustainability, or SES fit. In large-n secondary case comparative studies, there are three types of bias that are common: investigator bias introduced by missing conditions, procedural bias stemming from coding errors, and substantive bias from the way individual conditions are weighted or alternative explanations (Barnett et al., 2016). Conducting standardized fieldwork is an approach for generating complete, consistent, comparable data to advance our understanding of common pool resource governance (Barnett et al., 2016). We compare organizations—using crisp-set qualitative comparative analysis as recommended by Epstein et al (2015)—that manage the same resource type but operate with different goals in different conditions. We integrate qualitative and quantitative datasets (Leslie et al., 2015) and explore different outcomes (Agrawal & Benson, 2011) to understand SES fit.

Traditional commons research focuses on social-ecological systems where the resource users are reliant on the resource for their livelihoods. These user groups 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). Through a large-n secondary case comparison, Ostrom and her colleagues identified eight institutional design principles (IDPs) 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. Follow up studies support the IDPs role in SES sustainability (Agrawal & Chhatre, 2006; Baggio et al., 2016; Cox et al., 2010; Shin et al., 2020); however, additional, rigorous studies of the institutional design principles are needed to understand their validity and generalizability (Araral, 2014). Our study confirms that the design principles play a greater role in some SES outcomes than others, explores their impact on SES outcomes volunteer-based organizations without high resource dependence, and addresses data completeness and consistency concerns through primary data collection.

We explore SES fit and the validity and generalizability of the institutional design principles by comparing thirty-one Vilas County, Wisconsin, USA volunteer-based lake organizations using data collected through semi-structured interviews, websites, and agency databases. Vilas County is home to more than 1,300 lakes and 115 lake organizations providing an opportunity to compare conditions and outcomes across a landscape of lake SESs (Stedman, 2006). In this study, we explore how the combinations of ecological, social, and institutional conditions lead to different outcomes in lake SESs. To do this, we collected primary data about the goals and conditions through semi-structured interviews with lake organization leaders. Few studies collect primary data about the institutional design principles (Agrawal & Chhatre, 2006; Shin et al., 2020).

In the next section, we explain the methods used to collect primary data to compare thirty-one lake organizations in Vilas County, Wisconsin, USA. We then present a systematic comparison of the thirty-one organizations using crisp-set qualitative comparative analysis and conclude with a discussion of our findings.

METHODS & DATA

We conducted semi-structured interviews during the summer of 2019 to collect data about thirty-one lake organizations that conserve thirty-nine lakes in Vilas County, Wisconsin, USA. We integrated primary qualitative data with primary with secondary quantitative data derived from multiple sources. These sources included the Wisconsin Department of Natural Resources (WI DNR), University of Wisconsin Extension lakes program (UW-Ext), 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 used constant comparison to analyze the goals mentioned in the summer of 2019 interviews. After processing the data, we used crisp-set qualitative comparative analysis to assess SES institutional fit.

Case selection

The lakes and organizations in this study are in Vilas County, Wisconsin, USA (Figure 1). Vilas County is in the Northern Highland Lakes District, which is characterized by a patchwork of lakes and wetlands. Vilas County is home to more lakes than any other county in Wisconsin. It has 1,320 of Wisconsin's 15,000 lakes (Gabriel & Lancaster, 2004; Wisconsin Lakes Partnership, 2018), and there are 115 lake conservation organizations in Vilas County.

Additionally, there is extensive existing data about both the social and ecological conditions in Vilas County and the Northern Highland Lakes District as they have been studied for decades by the WI DNR, UW-Ext, USGS, NTL LTER, and Jones Lab. The number of Vilas County lake SESs with available data afforded us a set of comparable cases with a variety of institutional arrangements, social and ecological conditions, and outcomes.

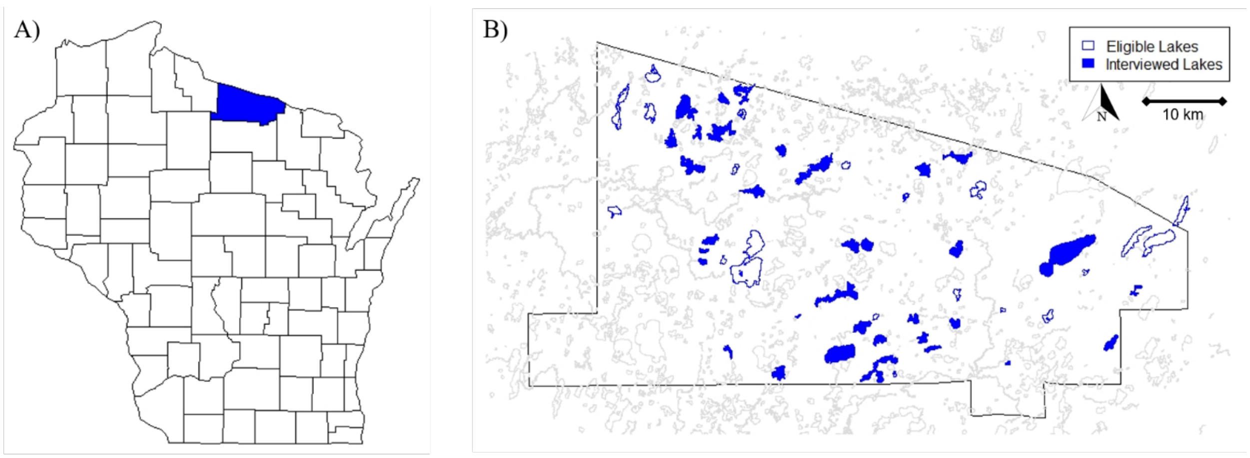

Figure 1. Our sample lakes in Vilas County, Wisconsin. A) Vilas County is in the Northern part of Wisconsin on the border of Michigan. B) The sixty-two Vilas County lakes outlined in blue were eligible for our study. The lakes filled in blue are the thirty-nine lakes managed by the thirty-one organizations we interviewed. Source: County Boundaries 24K and 24K Hydro Waterbodies (Open Water) published on dnrmaps.wi.gov.

Lake organizations, formed by lake users, 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). Lake organizations are one of two types: lake associations or lake districts. Lake associations are voluntary organizations made of lake property owners that range from informal, social organizations to incorporated non-profit organizations (Stedman, 2006). A lake district is a specialized unit of government designed to protect and rehabilitate a lake or group of lakes. They can tax property in the district to levy funds for lake protection and rehabilitation, own public infrastructure or expensive equipment (Stedman, 2006)(Glaser & Strauss, 1967). Collective action problems are common in lake organizations since a small number of highly committed individuals do most of the work. These challenges are exacerbated in regions where people live part-time. In Vilas County, 57.5% of lakefront houses are used “for seasonal, recreational, or occasional use” (Gabriel & Lancaster, 2004).

Vilas County lake organizations were eligible for our study (Figure 1B) if they fit three criteria. First, we selected lakes with public access. Public access lakes 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 and free-riding by non-residents who are less susceptible to the negative effects of over exploitation. Second, we included lakes with lake organizations that manage three or fewer lakes to select organizations managing similar SESs. Finally, we selected lakes that are managed by the WI DNR for their data availability. After applying these filter criteria, there were fifty-two eligible volunteer-based lake organizations that manage sixty-two lakes.

Primary data collection

We interviewed thirty-one of the fifty-two eligible organizations, which manage a total of thirty-nine lakes. We contacted the primary contact listed on the UW-Extension Lakes Program website, lake organization websites, or provided by partners at the Vilas County Land & Water Conservation Department. Contacts from forty-one of the organizations responded. We asked the contact to invite one to four other members of the organization to the interview. The interviews lasted one to two hours and were conducted in community centers, homes, and once on a boat.

We used a semi-structured interview methodology. Each interview started with the participants signing a letter of consent approved by the REDACTED Internal Review Board. Next, each participant filled out a questionnaire about changes to the lake (Appendix 1), and then the group was asked a series of questions about their use of the IDPs (Appendix 2). The questions asked were consistent, but their order and wording varied slightly following the flow of the conversation. 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 the two notetakers 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 were procedural, stemming from unclear definitions (Barnett et al., 2016). We refined the definitions for more consistency during the first week.

Social-ecological outcomes

As noted by Agrawal and Benson (2011), people living around the lakes have different uses and desired outcomes for the SES. As a result, lake organizations have a range of social and ecological goals. Figure 2 shows the goals stated during interviews by the lake organization leaders. We used constant comparison, a method whereby each statement is compared with the other statements to determine whether it is the same or different (Ragin, 1987). Using constant comparison, we identified eleven goals in the lake organization leaders' responses.

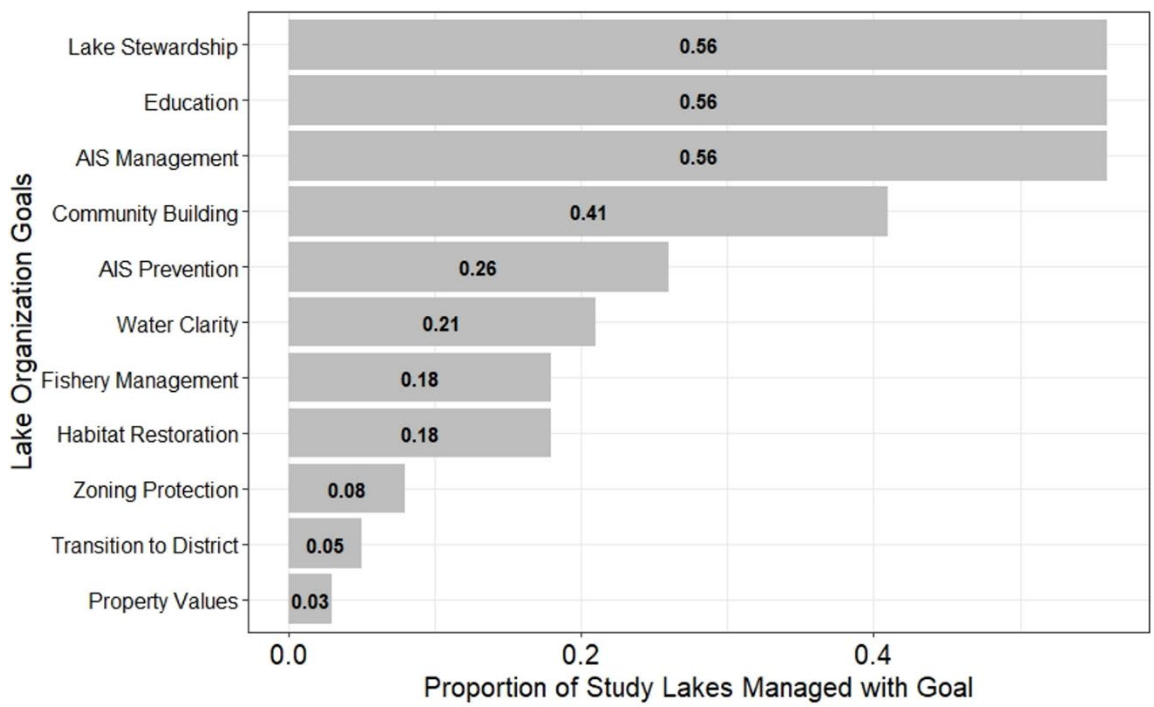

Figure 2. The eleven stated lake organization goals and the proportion of the thirty-nine lakes managed with each goal. Source: 2019 Interview Dataset.

Of the eleven goals, lake stewardship, education, and aquatic invasive species management were most common; organizations stated these goals for 56% of the thirty-nine studied lakes. The next three goals, stated for 20% or more of the lakes, were 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 transition to a lake district and 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 of lake organizations in Wisconsin.

In Table 1, we map the goals to measurable outcomes for each lake. The goals stated by the lake organizations were general. When the participants described the steps they take to achieve their goals, it was clear that the more general goals were established to reach a particular lake SES outcome. We used data available via the WI DNR, UW-Extension Lakes Program, and our 2019 Interview Dataset in this step, and mapped the seven most common of the eleven goals to outcomes in Table 1 (See Appendix 4 for details). Habitat restoration, zoning protection, transition to a lake district, and property value goals are not included 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 5 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 DNR
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

The outcomes in Table 1 are used in our analysis of the ecological, social, and institutional conditions that lead to lake SES outcomes. We thought we might find a strong relationship between stating the goal and the outcome, but we did not find stating the goal to have a significant impact on its own (REDACTED). In the next section, we explore the conditions evaluated for the lake SES outcomes. Although we cannot conclude anything about outcomes from goal setting alone, we include goal setting as a condition in our analysis.

Environmental, social, and institutional conditions

The ecological, social, and institutional conditions listed in Table 2 are the product of a three step selection process. First, we included the IDPs (Ostrom, 1990). Second, there were conditions that the lake organization leaders described in the interviews, like Eurasian water milfoil and participation in the organization. Finally, we sought input from a group of freshwater ecologists and a WI DNR fish biologist for more technical conditions like conductance and total phosphorous. Through an iterative process of analyzing different outcomes in dialogue with our cases and the experts, we identified the following variables as most useful to understand our outcomes.

Table 2. The dichotomized environmental, social, and institutional conditions and their data sources. The dichotomization of continuous variables uses the median value. See Appendix 5 for plots.

Condition	Present (1)	Absent (0)	Source
Ecological			
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 ecological, social, and institutional conditions we used are categorical. For the remaining seven conditions, we evaluated the distribution (see Appendix 5 for details). We used the median to convert them into dichotomous variables, which is essential for the analysis method we used, crisp-set qualitative comparative analysis. The condition "outcome as a goal" is drawn from the goals in Figure 2. A more detailed description and discussion of the conditions can be found in REDACTED (2020).

Analytical approach: crisp-set qualitative comparative analysis

We used crisp-set qualitative comparative analysis (QCA) to systematically compare the lake social-ecological systems. QCA is well-suited for evaluating conditions that lead to success in SESs (Baggio et al., 2016; Epstein et al., 2015). It is a mid-sized-n comparative method that uncovers the combinations of conditions that lead to SES outcomes. Charles C. Ragin developed QCA as a "synthetic strategy" to "integrate the best features of the case-oriented approach with the best features of the variable-oriented approach" (Cebotari & Vink, 2013). According to Ragin, a case-oriented approach (qualitative) assesses a case holistically, while a variable-oriented approach (quantitative) separates the case into its parts. While QCA combines features of both approaches, it is more clearly a case-oriented, qualitative method. The replicability of QCA is a significant asset of this approach when compared to qualitative techniques without formalized rules of logic (Ragin & Davey, 2016).

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. Based on our sensitivity analysis (Appendix 8), we do not have cause to believe that varying degrees of the remaining four factors, used in fuzzy set and multi-variate QCA, would have a significant impact on the outcomes.

Following the standards in the csQCA methodology, we conducted a two-step analysis using the fsQCA 3.0 software developed by Ragin and Davey. First, we identified the necessary conditions for each outcome. A necessary condition is always present when the outcome occurs (McCluskey, 1956). 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 and Vink, 2013). Second, we identified sufficient conditions. We used the default values in our sufficiency analysis where combinations with a consistency score equal to or greater than 0.80 are kept (Rihoux et al., 2009). fsQCA 3.0 uses the Quine-McCluskey algorithm to simplify combinations of sufficient conditions (McCluskey, 1956).

We take an unconventional approach in this study, repeating csQCA's identification of necessary and sufficient conditions for multiple, participant-defined SES outcomes. Most studies identify necessary and sufficient conditions for a single outcome. In the following section, we will explain the ecological, social, and institutional conditions that lead to seven lake SES outcomes for the cases we compared.

RESULTS

We evaluated the necessity of the causal conditions (Table 2) for the seven outcomes (Table 1) and found lake depth is a necessary condition for very high water clarity (Table 3). Lake depth explains 36% of the cases with very high water clarity. There are no other necessary conditions.

Table 3. 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 6

Lake depth (DEEP) is necessary for very high water clarity. Lake depth to be the single best predictor of water clarity (Johnston & Shmagin, 2006). Lake depth is tied to phosphorous cycling in the lakes and groundwater fluxes (Johnston & Shmagin, 2006). 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.

The analysis of sufficiency identifies the combinations of ecological, social, and institutional conditions that lead to the seven lake SES outcomes (Table 4). 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, showing contextual variables play an important supporting the theory of institutional fit. For each of the outcomes, there are multiple combinations of factors that lead to success.

Table 4. The combinations of ecological, social, and institutional 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 6.

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 SES outcome. The coverage ranges from 0.72 to 0.97; the pathways explain 72-97% of the studied cases with that outcome. The outcomes are somewhat 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 8).

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

There are three combinations of conditions present when lake organizations receive a lake management grant. These combinations explained 97% of the cases when lake organizations received grants. The first combination 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 developed best practices based on experience with a variety of lake organizations. The second combination 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, promoting learning. The third combination 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 protect and rehabilitate 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 one of four combinations of conditions were present. These combinations described 88% of the cases when an AIS treatment grant was received. The four combinations fall into two groups, lakes with high building density (DENS) and lakes with Eurasian Watermilfoil (EWM). The first high building density combination 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 combination includes lake organizations with aquatic invasive species management goals (AISMg) 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 (Smith & Barko, 1990), one combination 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 combination 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 (UW-Extension Lakes, n.d.). Three combinations explain 72% of the cases where lake organizations participated in CBCW during the summer of 2019. The first combination 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 combination 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 less free-riding. The third combination 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 developed institutions to address rule breaking and conflict. 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 combinations of conditions. 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 combination includes lake organizations that work with consultants (CONS) and are not close to a secondary road (ROAD). The third combination 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 combinations 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 combinations of conditions, which explain 96% of the cases where EWM was absent. The first combination 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 combination is shallow (deep) 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 combination 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 may be favorable to EWM, the rule enforcement may prevent

EWM. The fourth and final combination with moderate to low water clarity includes organizations that set AIS prevention goals (AISPg). The fifth combination 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 (Johnston & Shmagin, 2006), so low levels of phosphorous in combination with the other factors prevent EWM presence. The final combination 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 combination, 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 a 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 combinations of conditions. These combinations 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 combinations, 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 combination 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. The low density and lack of stocking may mean these lakes are out of the way, without much fishing pressure. The third combination 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 rules, like harvest limits, are enforced. The lakes with more adult walleye per acre tend to be environmentally favorable and either less developed or with graduated sanctions in place.

Comparing the combinations of conditions that lead to each SES outcome (Table 5), we found that the institutional design principles were necessary to explain success. In only one outcome, receiving a lake management grant, were they necessary and sufficient. For the other six out comes, the social and ecological conditions contributed to success. Four of the outcomes relied on both social and ecological conditions and two of the outcomes were ecologically determined. These results contribute to the validity of the institutional design principles, show their generalizability to low resource dependent SESs, and support the research on SES fit.

Table 5. The Institutional Design Principles were necessary but not sufficient to explain all seven SES outcomes. Four of the outcomes included social and ecological conditions to fit the institutions, two only ecological conditions, and one outcome was not context dependent.

SES Outcome	Institutional	Social	Ecological
Clean Boats, Clean Waters Participation	Yes	Yes	Yes
AIS Treatment Grant Received	Yes	Yes	Yes
Eurasian Watermilfoil Absence	Yes	Yes	Yes
Adult Walleye/acre ≥ 1.42	Yes	Yes	Yes
Participation in Org ≥ 0.65	Yes		Yes
Very High Water Clarity	Yes		Yes
Lake Management Grant Received	Yes		

DISCUSSION

Our mid-sized-n comparison of lake SESs for user defined outcomes, confirmed that institutional design principles play a role in SES outcomes for volunteer-based organizations whose resource dependence is low. csQCA was a useful method for understanding institutional fit by identifying the combinations of ecological, social, and institutional conditions that lead to various SES outcomes. We uncovered multiple combinations that lead to the outcomes, reinforcing the risk of panaceas and the value of institutional fit.

The institutional design principles (IDPs) were necessary but not sufficient to explain the seven user-defined SES outcomes we investigated. Graduated sanctions, conflict resolution, and nested enterprises were the design principles that played a central role for success in the lake SESs we studied. Araral (2014) calls for more research to confirm the generalizability and validity of the design principles, we contribute to the growing number of meta-analyses that show their validity (Agrawal & Chhatre, 2006; Baggio et al., 2016; Cox et al., 2010; Shin et al., 2020). Additionally, we tested whether the institutional design principles, emerging from community-based resource management groups who have high-dependency on the resource for their livelihood (Ostrom, 1990), apply to volunteer-based organizations with low resource dependency. In the thirty-one lake SESs we studied, they do.

Asking the lake organization leaders how they define success exposed a greater variety of desired SES outcomes than we anticipated. Most studies of the commons have not considered the multiple outcomes that emerge in renewable resource management (Agrawal & Benson, 2011). Agrawal & Benson's observation was evident in the lake SESs we studied, which have multiple uses like boating, fishing, swimming, and biodiversity conservation. Because most studies only consider one measure of success, the SES outcomes may not be successful if a different set of criteria were used (Epstein et al., 2015). We found that the conditions that lead to success differed and that there was equifinality, or multiple pathways to success, for a given SES outcome.

SES fit was critical to explaining four of the seven outcomes we studied. Without including both the social and ecological conditions in which the institutions were set, we would not have been able to explain the outcomes. For two outcomes, ecological fit was sufficient and for receiving a grant the rules were enough. Epstein et al.'s SES approach to institutional fit, though more intensive to study, provides a better understanding of a system. Our results show that context is critical to the outcomes of the system, and that context differs depending on the outcome.

Qualitative comparative analysis is a well-suited method for evaluating conditions that lead to success in SESs (Epstein et al., 2015), and thus evaluating SES fit. QCA is a useful method for conducting structured comparison of similar cases to understand the components of the cases that lead to different outcomes (Ragin, 1987). QCA considers combinations of conditions and allows for equifinality, which is consistent with the concept of institutional fit where the context is critical to the outcome.

Primary data collection through semi-structured interviews helped gather comparable, consistent data, whose availability can stymie secondary data analysis (Araral, 2014; Barnett et al., 2016). We also used selection criteria for lakes in the county that provided a mix of successful and not successful cases. We compared SESs dominated by the same resource—lakes—in close proximity to each other, and thus used more granular and specific variables than may be used to compare across regions or resource types. Consistent with Dressel et al's study (2018), our regional comparison exposed social and ecological challenges to fit that would not have been visible at a coarser resolution. A synthetic approach, like that employed by Leslie et al (2015), to integrate quantitative social and ecological data to qualitative outcome and institutional data is useful when evaluating SES fit and IDP validity and would serve future researchers well.

CONCLUSION

Institutions are critical to the sustainability of natural resource systems, facilitating cooperation and helping the systems adapt to change (Cumming et al., 2020). We have learned that these systems are not social or ecological, but integrated social-ecological systems (Liu et al., 2007; Ostrom, 2007). To understand what leads to sustainable social-ecological systems, we must consider the institutional, social, and ecological conditions that lead to various outcomes (Dressel et al., 2018; Epstein et al., 2015; Leslie et al., 2015; Ostrom, 2007). We found that not only must the social-ecological fit be considered, but that multiple pathways may lead to the same outcome and important contextual variables vary based on the outcome. As we learn more about the institutions that lead to SES sustainability, we must be careful to consider the conditions in which those institutions are successful.

ACKNOWLEDGMENTS

We appreciate the input and ideas from REDACTED. We are exceptionally grateful to the Vilas County lake organizations who participated in this study and all the community-based organizations that contribute to resource management. We thank the Wisconsin DNR, UW-Extension Lakes Program, and the wonderful team at the Vilas County Land and Water Conservation Department for sharing data and stories. This work was supported by the National Science Foundation under Grant No. REDACTED.

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APPENDICES

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? Would you stock/not stock in the future?

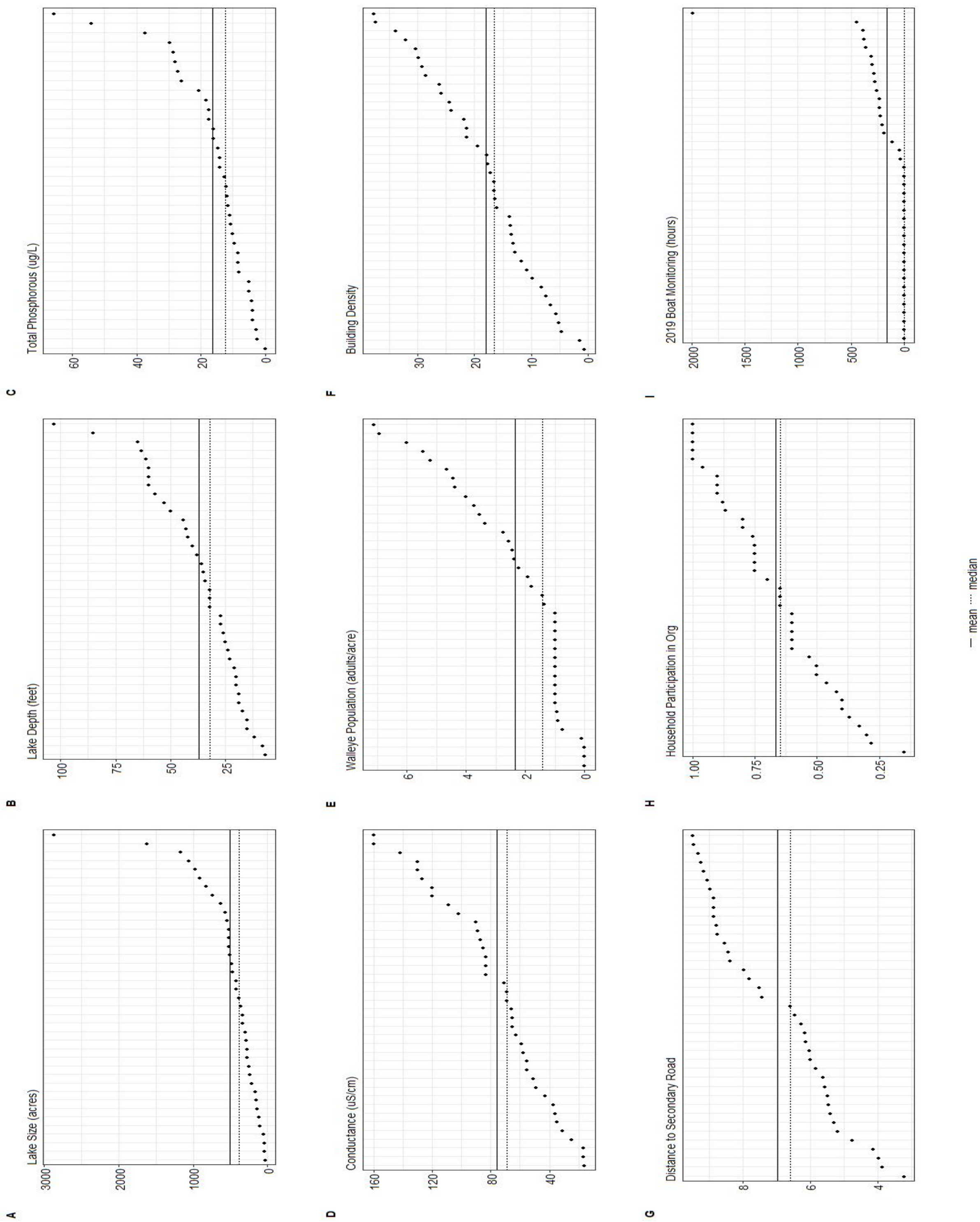
Appendix 3. Code Definitions for Organizational Goals

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. Goal to outcome mapping description.

We mapped seven lake organization goals to lake SES outcomes in Table 1 based on the interviewees' 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. Aquatic invasive species (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; this is also a fish that the WI DNR manages through habitat improvement and by juvenile fish stocking. While lake organizations stated general goals, the way they described the steps they take to meet them made mapping a measured outcome straightforward.

Appendix 5. Continuous Variable Dichotomization



Appendix 5. Continuous variables were dichotomized on the mean (solid line) and median (broken line).

Appendix 6. 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 Tables 3 & 4 and Appendix 7, 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 7. 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 8. 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