ASSESSING ECOSYSTEM-BASED MANAGEMENT IN THE GREAT LAKES BASIN

By

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ABSTRACT

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Ecosystem-based management incorporates biotic, abiotic, and social components into natural resource management decisions to promote natural resource sustainability. Fishery management in the Great Lakes basin has been facilitated by the Great Lakes Fishery Commission (GLFC) as the GLFC has taken a lead role in supporting ecosystem-based management for Great Lakes fisheries. The GLFC hosts Lake Committee meetings which began in the 1960s. Additionally the GLFC sponsored the Salmonid Community on Oligotrophic Lakes (SCOL) workshop in 1971 that furthered understanding about anthropogenic stressors on fish communities, advancing management and research discussions in the basin.

I explored 1) the role of the GLFC in developing ecosystem-based management principles in 1970-1975 through Lake Committee Meetings, and 2) how the structure of the Lake Committee meetings and SCOL influenced fishery management agency views towards ecosystem-based management principles. I confirmed that the GLFC facilitated management agencies to share fisheries management decisions and concerns across jurisdictions. SCOL was found to influence fishery management agencies to view management through a more comprehensive ecosystem perspective leading to a community and ecosystem perspective. Overall, ecosystem-based management principles were developing in the basin in 1970-1975 primarily through a fisheries perspective as resource managers moved from a single species type approach to an ecosystem perspective which was facilitated by the GLFC activities.

To Mom, Dad, Aubrey, and Nick
for always supporting me and
encouraging me to pursue my dreams.

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KEY TO ABBREVIATIONS

EBM..ecosystem-based management

GLFC..Great Lakes Fishery Commission

GLWQA...Great Lakes Water Quality Agreement

IJC..International Joint Commission

TVA...Tennessee Valley Authority

SCOL...Salmonid Communities of Oligotrophic Lakes

SPC..Scientific Protocol Committee

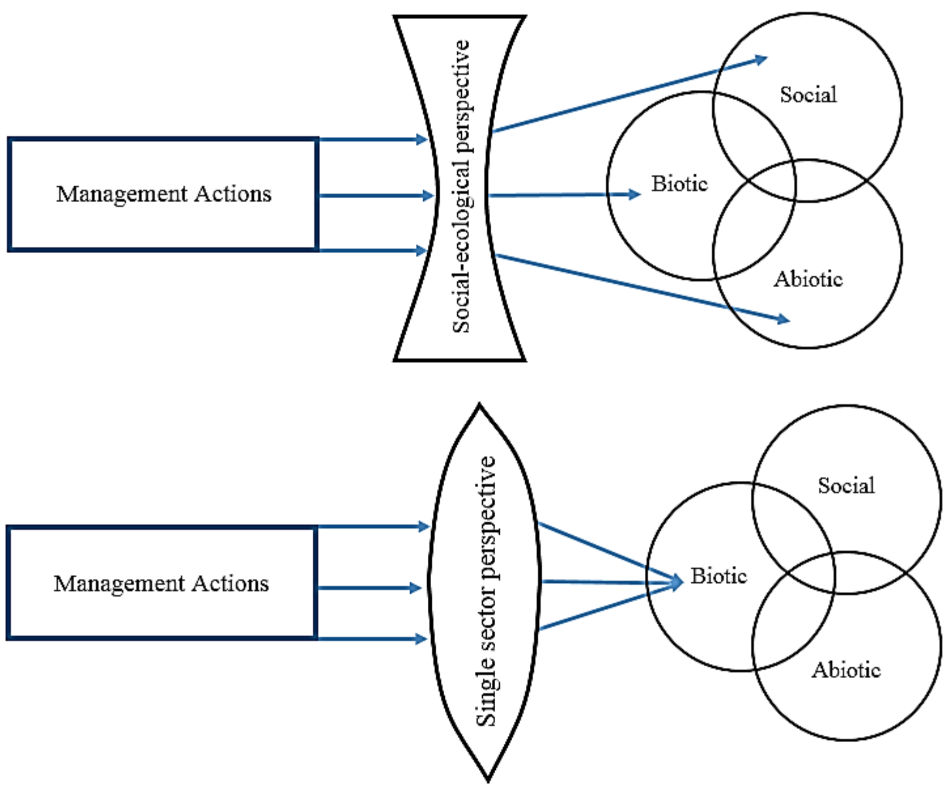
THESIS INTRODUCTION

DEFINING ECOSYSTEM-BASED MANAGEMENT

Interest in ecosystem-based management in the Great Lakes basin was largely derived from the recognition that historical management approaches (e.g., single species maximum sustainable fishery yield targets) were inadequate to mitigate collective environmental degradation compounded by multiple sources (e.g., toxins, eutrophication, and overexploitation) in the Great Lakes (Christie et al. 1986). Ecosystems are environmental systems comprised of exchanges among abiotic and biotic processes and are considered to be basic units of nature (Tansley 1935). Ecosystem-based management (EBM) incorporates abiotic (e.g., physical, chemical), biotic (e.g., species, communities), and social (e.g., economy, human values) components in decision making, aiming to increase natural resource sustainability (Grumbine 1994; Slocombe 1998; Curtin and Prellezo 2010). Specifically, ecosystem-based management incorporates 12 different principles to encompass a social-ecological management perspective into applied research and decision making about natural resource use and conservation: (1) adaptive management, (2) data collection, (3) dynamic ecosystems, (4) ecological boundaries, (5) ecological integrity, (6) hierarchical context, (7) human values, (8) humans embedded in nature, (9) interagency cooperation, (10) management evaluation, (11) organizational change, (12) sustainability, refer to Table 1 in Chapter 1 for definitions (Grumbine 1994; Christensen et al. 1996).

EBM was innovative because it incorporated interactions among humans and the environment as components of an overarching social-ecological system (Christie et al. 1986; Folke et al. 2005). A social-ecological system unifies human actions with biotic and abiotic processes as one interacting system, and contends the difference between social and ecological systems is arbitrary (Folke et al. 2005). Additionally, EBM strives to bridge multiple resource sectors (e.g., limnology, fishery, economy) to collectively manage ecosystems rather than treating them as independent sectors (Slocombe 1993). Ecosystem-based management can be viewed as natural resource management decisions filtered through a diverging social-ecological lens focused on the whole ecosystem (i.e., biotic, abiotic, social components). Single sector, conventional management is too narrow in scope to capture the dynamics of ecosystems and focuses on one component of the ecosystem, discounting ecological interrelationships and dependencies among sectors (Figure 1).

Figure 1. Schematic showing the delineation between ecosystem-based management (EBM) and single-sector natural resource management. EBM focuses on all components while single-sector management focuses on one component (e.g., the biotic component) of ecosystems.



Ecosystem-based management originated decades after we began to understand ecosystems as systematic units of the natural world. Forbes (1887) characterized lakes as a microcosm: a small, self-contained unit where all the "elemental forces" were interacting within a system. Forbes viewed lakes as a system of complex species inter-relationships. Before the 1910s, European lakes were characterized as either alpine or baltic (Moss et al. 1994). August Thienemann and Einar Naumann recognized similarities between geography, chemistry, oxygen, and plankton across lakes which were related to lake characteristics (Moss et al. 1994). Therefore Theinemann and Naumann expanded terms developed by Karl A. Webber, oligotrophic and eutrophic lakes, to include biological and physical factors in lake categorizations (Moss et al. 1994). Creating consistent terminology to define lake productivity allowed comparisons among lakes across regions (e.g., Lake Superior, Great Slave Lake, Lake Vättern) (Hutchinson 1969). Tansley (1935) was the first to codify the term "ecosystem" which highlighted environments as systems of interactions (e.g., biological, physical, chemical) that included organisms.

The first natural resource policy document in the Great Lakes basin to formally include an ecosystem-based approach to management was the 1978 Great Lakes Water Quality Agreement (GLWQA) (*Great Lakes Water Quality Agreement* 1978; Imperial et al. 1993; Slocombe 1998). The GLWQA articulated the connection between the Great Lakes watershed and ecosystem components, including toxic water affecting fish and therefore human health (*Great Lakes Water Quality Agreement* 1978; Christie et al. 1986; Imperial et al. 1993). The Agreement demonstrated that the United States and Canada jointly agreed on the need for the development of interdisciplinary collaboration for natural resource management, and the incorporation of humans and ecosystems under one management framework.

Understanding the processes and mechanisms that stimulated the conceptualization of EBM in the Great Lakes basin can provide a deeper understanding of ecosystem-based management values and principles, and can support a more thorough evaluation and implementation of ecosystem-based management principles in natural resource management plans and research. Additionally, examining fishery and water management in the Great Lakes basin demonstrates the importance of binational management and documents the progressive decisions of natural resource managers in the Great Lakes basin. Current and future natural resource management policies are often amendments or modifications of past management decisions (e.g., Great Lakes Water Quality Agreement), demonstrating a need to evaluate historical decisions that created the foundation for recent and current natural resource management agreements and decisions in the Great Lakes basin. The goal of this study was to investigate the historical development of ecosystem-based management in the Great Lakes basin to demonstrate how the transition to ecosystem-based management supported Great Lakes fisheries.

HISTORY AND DEVELOPMENT OF ECOSYSTEM-BASED MANAGEMENT IN THE GREAT LAKES BASIN

Ecosystem-based management concepts arose during the 1970s in the Great Lakes basin in response to increased awareness of the links between anthropogenic toxins and pollution, water quality, fish contamination, and human health (Christie et al. 1986). The region was highly polluted and degraded by industrialization (Murphy et al. 2013). Dichlorodiphenyltrichloroethane (DDT), polychlorinated biphenyls (PCBs), and other toxins were present in Great Lakes waters (Baumann and Michael Whittle 1988; Murphy et al. 2013), accumulating in fish and transferred to humans through fish consumption, ultimately resulting in fish consumption regulations in the basin (Busch et al. 1975; Bhavsar et al. 2011).

The Great Lakes have been significantly altered since European settlement during the late 1700s and early 1800s (Koelz 1926; Gaden 2007). Settlers introduced non-native fishes, altered basin ecology through using new technology (e.g., dams), changed chemical and nutrient cycling due to logging, wastefully extracted fish, polluted the Great Lakes watershed with lumber sawdust and steamboat ash, and depleted fish stocks by commercial fishing (Koelz 1926; Smith 1972; Mandrak and Cudmore 2013; Murphy et al. 2013). Lake Ontario was the first lake to be settled by Europeans and consequently was the first to experience dramatic ecosystem changes (Francis et al. 1979). Lake Ontario fishers began seine fishing in 1807 followed by fishing on Lake Erie in 1815, Lake Huron in 1935, and Lake Superior in 1960 (Koelz 1926). The year fishing started on Lake Michigan is unknown, although it is presumed to have occurred before Lake Huron (Koelz 1926). Additionally, settlers dug canals for easier access to the Atlantic Ocean, thereby opening the lakes to invasive species (Smith 1972) which resulted in dramatic ecological and fish community changes in the basin.

During the New Deal Era (1933-1937) in the US, waterways were highly developed which fueled economic growth (MacKenzie 1996). During the 1940s, World War II created a demand for industrialization and the development of war materials (e.g., rubber, steel) in the Great Lakes basin (Murphy et al. 2013). Demand for industrialization and economic growth led to unconstrained development and chemical pollution causing environmental degradation which led to ecological disturbance. Excessive contamination and pollution (e.g., DDT) led to an increased environmental awareness (e.g., Silent Spring by Rachael Carson, 1962) that sparked a revolutionary period in the 1970s that focused on natural resource conservation and rehabilitation. Awareness of environmental concerns influenced natural resource management as there was public and political desire to collectively manage our Great Lakes resources across disciplines, ultimately contributing to the conceptualization of ecosystem-based management in the basin (Christie et al. 1986; Harris et al. 1987).

Cross-jurisdictional fisheries management in the Great Lakes basin, since 1955, is facilitated by the Great Lakes Fishery Commission (GLFC). The GLFC was established by the *Convention on Great Lakes Fisheries* (1954) to bring managers and scientists together to mitigate sea lamprey (*Petromyzon marinus*) invasions, to develop a vibrant research program, and to coordinate essential joint management efforts to rehabilitate fisheries in the Great Lakes and connecting waterways, with the ultimate goal of maintaining a healthy, sustainable Great Lakes fishery (*Convention on Great Lakes Fisheries* 1954). The formation of the GLFC did not alter the jurisdictional powers of the state, provincial, or federal management agencies, which was a stipulation of the agencies as they did not want to lose their jurisdictional control (Gaden et al. 2013). During the 1960s, Lake Committees, annual lake-specific management meetings, were formed to report on management actions and concerns across the basin. The meetings ultimately fostered a collaborative environment in the Great Lakes basin culminating in A Joint Strategic Plan for Management of Great Lakes Fisheries (1981), henceforth called "Joint Strategic Plan" (GLFC 1981; Gaden 2007; Gaden et al. 2008).

The Canada-United States 1972 Great Lakes Water Quality Agreement provided authority for the International Joint Commission (IJC) to coordinate water quality management (e.g., limiting phosphorus inputs) (Hartig and Kelso 1998). The International Joint Commission was established between Canada and the United States through the *Boundary Waters Treaty of 1909* to jointly manage transboundary waters between the two countries. Additionally, in 1972, the United States passed the US Federal Water Pollution Control Act, known as the Clean Water Act (US EPA 2013a, 2013b), which developed federal standards for water quality that were enforced by the US Environmental Protection Agency (MacKenzie 1996; Murphy et al. 2013). Both the Great Lakes Water Quality Agreement and Clean Water Act demonstrated the political awareness and initiative that resulted in more stringent water quality regulations.

In 1977, the IJC Great Lakes Science Advisory Board completed a 5-year review of the implementation of 1972 GLWQA and realized water quality conditions continued to deteriorate because of non-point source pollution. Additionally, the Canada-United States University Seminar in 1976-77, comprised of academics and civic servants, suggested interpreting water quality goals through ecological restoration and rehabilitation (Francis et al. 1979). Through the recommendations from the IJC Science Advisory Board and the University Seminar, IJC recognized the need to manage water quality using a broader perspective, ultimately conceptualizing an ecosystem approach to water management (Francis et al. 1979). The new natural resource management philosophy was presented to and accepted by the Great Lakes Fishery Commission in 1977, and the GLFC and IJC agreed to work together under an ecosystem approach (Francis et al. 1979).

Lake Committee attendees suggested the Great Lakes Fishery Commission work with the International Joint Commission to include fisheries in their water quality management even before the GLWQA was created. In Lake Erie Committee Meeting Minutes (1970) , it was documented that:

> *"Mr. Baldwin stated that the Commission had drawn the attention of the International Joint Commission (IJC) to the problem of pesticides and urged that the welfare of fish and other aquatic life be given greater consideration in*

> *controlling pollution. The Commission might proceed further by more closely coordinating the environmental work of fishery agencies and submitting more detailed recommendations"*

The link between fish and water quality was legally realized in the 1978 Great Lakes Water Quality Agreement as the purpose of the agreement was to cooperatively

> *"restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes basin Ecosystem."*

The agreement defined the "Great Lakes basin Ecosystem" as

> *"the interacting components of air, land, water and living organisms, including man, within the drainage basin of the St. Lawrence River at or upstream from the point at which this river becomes the international boundary between Canada and the United States"* (*Great Lakes Water Quality Agreement* 1978).

The Great Lakes Water Quality Agreement of 1978 linked humans and ecology as one interacting system and took a large-scale, watershed-based approach to water quality management which is directly comparable to a social-ecological system perspective in ecosystem-based management (Lynch 2001).

Furthermore, the mechanism underlying the development of EBM principles in the basin can partially be attributed to the Great Lakes Fishery Commission institutional support (Francis 1988). In 1964, as the Lake Committees were formalized, the Great Lakes Fishery Commission requested senior representatives from fishery management agencies to attend Lake Committee meetings (Gaden 2007), thus creating continued interactions among senior staff members across jurisdictions. The fishery management network facilitated through the Lake Committee structure, permitted high-level agency representatives to develop relationships across jurisdictional borders through expected and continued attendance at annual meetings. The interactions at Lake Committee meetings likely fostered trust between jurisdictions and laid the groundwork for ecosystem-based management.

The Great Lakes Fishery Commission formally accepted the role of coordinating fishery management agencies under "lakewide-basinwide perspectives" for an ecosystem approach to management in A Joint Strategic Plan for Management of Great Lakes Fisheries (1981). In addition to the Great Lakes Fishery Commission, the Joint Strategic Plan was signed by federal (i.e., Canada, US), state, provincial, and later tribal management agencies that have jurisdiction in the Great Lakes basin, demonstrating the commitment of Great Lakes basin fishery management agencies to collaborative, ecosystem-based management. Cross-jurisdictional collaboration is necessary for EBM to be implemented as ecosystems can span multiple jurisdictions (Grumbine 1997; Post et al. 2007).

Further supporting the development of ecosystem-based management in the Great Lakes basin was the Salmonid Community of Oligotrophic Lakes (SCOL) workshop, held by the Great Lakes Fishery Commission (Loftus and Regier 1972). This workshop was held in 1971 for invited European and North American researchers. Attendees used European and North American cold water oligotrophic lakes as study replicates to assess anthropogenic stressors on salmonid communities, notably assess stressors from fishing practices, eutrophication, and nonnative species (Loftus and Regier 1972; Regier 2013). The SCOL workshop presented a hierarchical context for fisheries as it viewed salmonids as components of interacting communities, and viewed ecological integrity as a necessary consideration for fisheries by examining the relationship of eutrophication on fish, promoting concepts (e.g., ecological integrity, hierarchal context) that underlie ecosystem-based management.

THESIS PURPOSE

The 1970s were marked by an era of environmental awareness in North America and were hypothesized to be critical in the development of EBM for natural resources in the Great Lakes basin. In 1972, the US Clean Water Act and the Great Lakes Water Quality Agreement were enacted, demonstrating a binational commitment to stringent water quality standards (*Great Lakes Water Quality Agreement* 1972; US EPA 2013b). A special journal issue in Canadian Journal of Fisheries and Aquatic Sciences published the proceedings from the Salmonid Community on Oligotrophic Lakes workshop (Loftus and Regier 1972). SCOL was a novel workshop as attendees assessed anthropogenic stressors on fish communities, not on species, and thus was an advancement from conventional single species perspectives.

My goal was to understand how the Great Lakes Fishery Commission facilitated the development and the spread of ideas that supported ecosystem-based management for Great Lakes fisheries. The three primary objectives of my thesis were to: i) evaluate the conceptualization of ecosystem-based management in the Great Lakes basin from 1970-1975, the formative years of the North American environmental movement, ii.) determine if and how ideas about ecosystem-based management flowed through the Great Lakes basin fishery management networks from 1970-1975 as a result of Lake Committee meetings and the GLFC-sponsored workshop on Salmonid Community of Oligotrophic Lakes, and iii.) identify key agencies that assisted the spread of knowledge to support ecosystem-based management principles across jurisdictions in the Great Lakes basin.

This thesis is comprised of an introduction, two chapters, and a synopsis. The first chapter presents an evaluation framework that was used to assess the development of ecosystem-based management principles in the Great Lakes basin (objective i). The second chapter evaluates the spread of such principles via fishery management networks and how ideas were altered due to attendance by jurisdictional managers at Lake Committee meetings and the Salmonid Community of Oligotrophic Lakes workshop (objective ii, objective iii). The thesis is concluded by a synopsis that highlights the role of institutional structure and function for multijurisdictional natural resource management.

CHAPTER 1: A FRAMEWORK FOR EVALUATING ECOSYSTEM-BASED MANAGEMENT PRINCIPLES IN THE GREAT LAKES

INTRODUCTION

Ecosystem-based management (EBM) occurs when decisions about natural resource use and conservation practices are based on the interrelationships of the entire social-ecological system (Grumbine 1994; Christensen et al. 1996; Leech et al. 2009). Ecosystem-based management has been heralded as a radical shift for management processes in natural resource systems where conventional, single-species management practices (e.g., single species maximum sustainable yield fishery targets) have been implemented, often without success (Pikitch 2004; McClanahan et al. 2015; Long et al. 2015). EBM principles have been implemented by natural resource managers, policy makers, and professionals in recent years (Jennings et al. 2014) because EBM is accepted as a superior means to sustainably manage natural resources. EBM more accurately accounts for ecological interrelationships, dependencies, and stressors in natural resource management decisions than traditional management techniques (Curtice et al. 2012).

Science, management, and policy evolutions develop through a process of knowledge accumulation leading to a rapid change, but the impact of the "revolutionary" transition is only fully recognized retrospectively (Kuhn 1970; Rotmans et al. 2001). Management and policy revolutions face strong resistance to change through institutional inertia (Rotmans et al. 2001) and changes commonly occur during short time periods with increased opportunities to influence policy, termed policy windows (Kingdon 1984; Rotmans et al. 2001). Ecosystem-based management has been considered a revolutionary natural resource management paradigm that has evolved as the understanding of the importance of ecosystems developed (Hartig et al. 1996;

Berkes 2012). For new management principles to be implemented in natural resource policy there needs to be an opening in a policy window to allow policy changes to occur.

Ecosystem-based management has become a commonly recommended natural resource management paradigm, yet there are few assessments evaluating the success or failure of implementing ecosystem-based management principles. Developing an EBM plan occurs via eight steps: (1) set goals, (2) assess natural and social resources, (3) diagnose problems, (3) create a plan, (4) adopt actions to address the problems, (5) organize agencies and actions, (6) implement the plan, (7) evaluate progress towards goals, and (8) maintain and/or update the plan (Taylor et al. 1995). Evaluation is an essential step in the natural resource management process as evaluations can be used to assess the effectiveness of management decisions. Borgström et al. (2015) developed a matrix to evaluate the extent ecosystem-based management was being implemented in management plans and applied the assessment matrix to coastal management plans in Sweden. The assessment matrix is comprised of rows itemizing ecosystem aspects: Biodiversity, Relations and Ecological Processes, Changes and Uncertainty, Scales, Anthropogenic Processes. The matrix columns are ecosystem-based management phases: system description, goals, strategies/measures, and monitoring evaluation. The extent of each of these concepts (e.g., system description and biodiversity) is categorized as low, medium, high which are uniquely defined for each matrix relationship (Borgström et al. 2015). The assessment matrix is generalizable to other natural resource plans due its broad categories, yet it cannot be used to assess small changes in EBM principles as conceptualization and implementation of EBM principles evolved and progressed through time.

In this study I developed an ecosystem-based management framework based on literature definitions of EBM and applied the necessary framework to Great Lakes fishery management discussions from 1970-1975. In order to analyze the extent that ecosystem-based management principles were considered by fishery managers during the formative years of ecosystem-based management in the Great Lakes basin, I chose the Great Lakes basin as a study region because fisheries and aquatic resource managers in the basin developed international policies that formally endorsed ecosystem-based management in the 1970s. The endorsement of EBM in the basin is demonstrated by the principles included in the binational water resource management plan, the Great Lakes Water Quality Agreement (GLWQA) of 1978 that was enacted by the United States and Canada (*Great Lakes Water Quality Agreement* 1978). The GLWQA of 1978 was the first amendment to the Great Lakes Water Quality Agreement of 1972 and the GLWQA included ecosystem considerations linking water quality with ecosystem implications (e.g., fish production) and humans (e.g., human health).

As the 5-year review of the 1972 Great Lakes Water Quality Agreement was commencing in 1977, there was an awareness based on the International Joint Commission (IJC) Great Lakes Research Advisory and the Canada-United States University Seminar in 1976-77 that water quality restoration was linked with ecological rehabilitation (Francis et al. 1979). This abiotic-biotic connection, an underlying principle in the ecosystem approach, was proposed to the Great Lakes Fishery Commission (GLFC), a US-Canada Commission established to facilitate fisheries management, support and conduct fishery research, recommend policy and management changes, and reduce sea lamprey populations (*Convention on Great Lakes Fisheries* 1954). The GLFC instructed its Scientific Advisory Committee (i.e., researchers that counsel Commissioner and fishery managers; currently the GLFC Board of Technical Experts) to review the practicability of an ecosystem approach for implementation in the Great Lakes. The GLFC endorsed the ecosystem approach and accepted a “lead agency” role where applicable (Francis et al. 1979). The comprehensive approach to water management was considered novel in the basin because the GLWQA included ecosystem rehabilitation that focused on the linkages between water quality, fish production, contaminants, and human health.

At the same time, another endeavor to integrate basin-wide water management was occurring in the Tennessee Valley Authority (TVA) as the TVA adopted a basin-wide approach to water management by including economic considerations on water management. The TVA was not implementing an ecosystem-based approach as the primary management focus was navigation and flood control, not ecosystems (McKinley 1950; Mackenzie 1997). Past natural resource management plans or agreements chiefly focused on improving water quality or benefits of water without purposely integrating ecological and socio-economic-political linkages into decisions or actions.

Examination of the development and implementation of EBM principles can provide insights about how management evolves and potentially how best to facilitate an ecosystem-based approach to management by considering the political and natural environment that stimulated concept development. Applying the ecosystem-based management framework developed herein to historical fishery management discussions and decisions in the Great Lakes basin can elucidate the public, managerial, and political environments necessary (e.g., environmental awareness, policy windows) for enactment of new management paradigms into plans and policy. Management policies and agreements (e.g., Clean Water Act, Great Lakes Water Quality Agreement) have been amended since their original implementation in the 1970s, and the original formulation of those policies still influences natural resource management and policies today.

In the Great Lakes basin, bottom-up decisions were needed as top down management control was not effective (e.g., fish populations were crashing); fishery management jurisdictions would not revoke their control of fishery jurisdictions (Gaden et al. 2013). The effectiveness of the Great Lakes Fishery Commission is founded upon their non-regulatory, yet federally supported, binational treaty-based mandate. Understanding when, how, why, and the contexts in which ecosystem-based management developed and assessing its successes or failures can improve our understanding of the importance of ecosystem-based management for current and future implementation of natural resource management regimes.

The goal of this paper was to understand the development of ecosystem-based management for Great Lakes fisheries preceding the implementation of the first Great Lakes ecosystem-based management policy, the Great Lakes Water Quality Agreement in 1978. The objectives were to document and evaluate the conceptualization of ecosystem-based management in the Great Lakes basin from 1970-1975, the beginning of an era of environmental awareness and change in natural resource management. For this study, an ecosystem-based management principle evaluation framework was created to assess the development and evolution of ecosystem-based management principles in the Great Lakes basin through studying the six years of discussions from 1970-1975 among fishery managers at Great Lakes Fishery Commission Lake Committee meetings.

METHODS

Data

Since the 1960s, the Great Lakes Fishery Commission hosted annual Lake Committee meetings for natural resource management agency representatives from the various jurisdictions to discuss the status of fisheries, past management actions, future management decisions, and research (Gaden 2007; "GLFC" 2017). The Lake Committee meetings were used for agencies to convene on a regular basis and arrange for joint management of Great Lakes natural resources, namely supporting economically desirable species (e.g., lake trout, *Salvelinus namaycush*), and reducing the invasive sea lamprey (*Pekorngzon marinus*) population that hindered the production of the species of common concern. Minutes were recorded for each meeting and are maintained by the Great Lakes Fishery Commission in Ann Arbor, Michigan, USA (http://www.glfc.org/).

Meeting minutes from 1970-1975, the formative years of the North American environmental movement, were used for data collection to understand the processes and developments that occurred before a formal natural resource management and policy shift towards ecosystem-based management through the enactment of the Great Lakes Water Quality Agreement of 1978 and A Joint Strategic Plan for Management of Great Lakes Fisheries (1981). The duration of annual Lake Committee meetings ranged from 3 to 11 hours. Median meeting durations were 8.5 hours for Lake Erie, 3.4 hours for Lake Huron, 6.9 hours for Lake Michigan, 6.3 hours for Lake Ontario, 6.4 hours for Lake Superior. Meeting duration was used as a standardizing metric to compare meetings across lakes and time. Each lake hosted its annual meeting in March at different locations across the basin.

Document Content Analysis

Content analysis is a systematic method used to capture concepts in documents through the use of coding rules (Rourke et al. 2001). Code rules are a classification system to capture distinct content within a document (e.g., topics in a discussion: ecological integrity or adaptive management). The purpose of content analysis is to concisely and reproducibly analyze the underlying principles of a message (Stemler 2001). I developed code rules to use as a framework to evaluate discussions about ecosystem-based management principles. Code rules were based on literature definitions of EBM (Grumbine 1994; Christensen et al. 1996) that were iteratively adapted through discussions with another researcher to improve clarity of the final definition and reduce coding bias (Stemler 2001).

Each Lake Committee meeting was coded based on *a priori* literature definitions of ecosystem-based management; twelve principles were derived from (Grumbine 1994; Christensen et al. 1996)) and were used to develop reproducible ecosystem-based management code rules. EBM principles were: (1) adaptive management, (2) data collection, (3) dynamic ecosystems, (4) ecological boundaries, (5) ecological integrity, (6) hierarchical context, (7) human values, (8) humans embedded in nature, (9) interagency cooperation, (10) management evaluation, (11) organizational change, (12) sustainability (see Table 1 for explanations).

Table 1. Ecosystem-based management (EBM) principles and explanations as adapted from Grumbine (1994) and Christensen et al. (1996).

EBM Principle	**Explanation**
Adaptive management	Adaptive management takes the approach of management as a natural experiment and accepts uncertainty as a component of natural resource management decisions.
Data collection	Data should be collected across multiple scales (e.g., lake-wide, stream-specific) and sectors (e.g., fisheries, water quality, habitat) to assess patterns and processes occurring across a region.
Dynamic ecosystems	Ecosystems may have multiple states and large temporal fluctuations, and should not be forced into one state, nor should managers assume an ecological state is stable.
Ecological boundaries	Ecological boundaries can be defined structurally (e.g., geomorphic boundaries) or functionally (e.g., species interactions) and connectivity (e.g., species dispersal) should be assessed to understand the temporal and spatial scales of management (Post et al. 2007).

Table 1 (cont'd)

Ecological integrity	Desired species should be viewed as a component of ecological patterns (e.g., habitat characteristics, species distributions) and processes (e.g., species restoration, natural reproduction, and disturbance) that are necessary components of sustainable ecosystems.
Hierarchical context	A hierarchical context incorporates a systems view that accounts for the relationships across levels (e.g., habitats, stocks, populations, communities) in ecosystems.
Human values	Human values influence the priorities and goals of management and actions of resource users.
Humans embedded in nature	Humans are components of the ecosystem and their actions affect biotic and abiotic ecological relationships.
Interagency cooperation	Collaboration should occur across jurisdictional boundaries to reflect ecological boundaries, and among sectors (e.g., limnology, fisheries) and institutions (e.g., state legislature, non-governmental organizations) involved in the region. Actors should be aware of the broader political environment.
Management evaluation	Management decisions about resource conservation and use should be monitored and linked to the effect of these changes in the management region.
Organizational change	Natural resource management organizations should have their structure and operations reflect and adapt to current and emerging values and partnerships.
Sustainability	Management decisions and goals incorporate a long term focus that supports resource use for future years.

The coding unit, the base unit for content analysis, was determined based on the messages (e.g., EBM principles, Table 1) and syntax (e.g., bullets, paragraphs) in the documents (Rourke et al. 2001). If there was a shift in the topic discussed within a paragraph, subcategories were marked (e.g., numbered points), or the speaker changed, the segment was split into separate coding units based on these shifts. These separations were done to systemically and accurately capture the discussions about EBM principles at the meeting between different management agencies. The principle that best captured the statement was assigned to each unit. Statements without sufficient context ("*Mr. Wright reported on lake trout research"* Lake Superior Committee 1975), or relevant details (*"The tentative agenda was adopted with no changes*" Lake

Huron Committee 1970) were excluded. Appendices were omitted in the content analysis as appendix details were not explicitly linked to the meeting minutes ("*Mr. Byrne summarized plantings made by Ontario in 1972 and listed plantings proposed for 1973 (Appendix XIV)"* Lake Ontario Committee 1972*)*. In total, 30 Lake Committee meetings were analyzed resulting in 3,182 sections that were coded based on ecosystem-based management principles.

Additional code rules were developed to capture the emphasis of each unit analyzed. Emphasis of each statement was assessed to determine the fisheries context (i.e., focused solely on fishery considerations [sea lamprey wounding, fish stocking]) or alternatively, an environmental context (i.e., ecological components other than or in addition to fishery considerations) of EBM principle in that discussion. Linking social-ecological components (e.g., human values about shoreline development) with fisheries components (e.g., fish predator-prey dynamics) in discussions and management decisions is a major element in ecosystem-based management (Link and Browman 2014). Understanding the emphasis (i.e., fisheries or environmental) of each coded discussion can demonstrate the transition between classical single-species fishery management and ecosystem-based management (Link and Browman 2014).

Intercoder reliability

Two researchers independently coded the same content (n=100) and the results were compared to assess reproducibility of coding. Each unit (i.e., discussion segment) was coded using the twelve EBM principles and two emphasis categories (i.e., fisheries or environment), resulting in each coded segment linked to one of the twelve EBM principles and one emphasis. All code rules (12 ecosystem-based management principles and fisheries versus environment emphasis) were verified to be systematic interpretations of the message through intercoder agreement. Cohen's Kappa was calculated to evaluate intercoder reliability as it is a rigorous test that accounts for probability of agreement between coders due to chance (Cohen 1960). Cohen's Kappa was calculated using the following equation:

$$k = \frac{p_o - p_c}{1 - p_c},$$

where p_o is the proportion of units coded the same between coders, and p_c is the proportion of coding units that would be similar based on chance. Equal probability was assumed for coding each unit in any of the 12 ecosystem-based management categories (Table 1) or in either of the two emphasis categories (i.e., fishery or environmental) by each coder. Using Cohen's Kappa, intercoder agreement was determined to demonstrate substantial agreement if greater than 0.60 agreement was observed (Landis and Koch 1977).

ANALYSIS

Intercoder reliability and assumptions

Cohen's Kappa for the 12 EBM principles was 0.652 and for management emphasis (i.e., environment or fisheries) it was 0.625. Both are above the "substantial" agreement level (Landis and Koch 1977) indicating a reproducible coding scheme. To standardize data across meeting durations, I calculated the total proportion that each EBM principle was discussed per meeting. Additionally, I calculated the proportion that each EBM principle had an environmental or fisheries focus per meeting. I assumed that EBM principles that were discussed in greater proportion were considered a higher priority than other EBM principles and were a focus of the meeting as that concept was discussed more extensively. Discussions among management agencies were assumed to reflect fishery management concerns and decisions.

Assessing management priorities

To assess changes in the proportion that each principle was discussed over the study period (1970-1975), I used Repeated Measures Analysis of Variance (RM-ANOVA) in SPSS Statistics (IBM Corp. 2012; Gotelli and Ellison 2012). Proportion data was arcsine transformed to meet normality assumptions. Sphericity was not assumed, therefore Wilks' Lambda was used to assess significance of RM-ANOVA (Gotelli and Ellison 2012). Each of the five great lakes was assessed individually, resulting in five RM-ANOVAs. These RM-ANOVA allowed for multiple measurements to be evaluated at multiple time points (i.e., 1970, 1971, 1972, 1973, 1974, 1975). For this analysis, each EBM principle was considered an independent "subject" assessed over the 6 years evaluated and each year considered a repeated measurement, as described by the equation:

$$y_{ij} = \mu + \alpha_i + \tau_j + \varepsilon_{ij} \,,$$

where μ_k is the overall mean proportion that principle *i* was stated over 1970-1975

α_i is difference between the mean and principle *i* per year

τ_j is the effect of time *j* for all principles

ε_{ijk} is the error of principle *i* at time *j*.

To assess the prioritization of EBM principles discussed for each lake, the mean proportion that each principle was discussed was placed into low, medium, and high priority categories. Low priority EBM principles were the four least discussed proportions. High priority EBM principles were the four most discussed principles. Medium priority EBM principles were the middle four EBM principles that were discussed but were not a high or low priority.

Assessing the emphasis of EBM principles

Paired t-tests compared proportion of fishery emphasis to environmental emphasis within each principle, within each lake to assess if there was a difference in the emphasis (i.e., environmental or fishery) for each EBM principle, relating the principle to the structure and dynamics of each lake (IBM Corp. 2012; Sokal and Rohlf 2012). Proportions of EBM principles with an environmental emphasis and fishery emphasis were arcsine transformed to meet normality assumptions. Paired t-tests were used to evaluate the emphasis of EBM principles for each of the Great Lakes.

RESULTS

Management priorities

For all lakes no change over time was detected in the proportion that each EBM principle was discussed. Changes in the portions of EBM principles might have occurred during this time period although there is a potential that no change was detected due to the small sample size. A lack of a significant difference of EBM principle proportions during the study period suggested that management priorities may have remained constant through the study period and the proportions may be valid reflections of management priorities at that time.

Management discussions at Lake Committee meetings prioritized similar management principles. The ecosystem-based management principles, data collection, and management evaluation were considered high priority EBM principles among all lakes. Adaptive management, organizational change, and sustainability were commonly low priority EBM principles rarely discussed for most of the lakes. All low, medium, and high prioritizations for EBM principle per each lake are listed in Table 2.

Table 2. Priority level for each of the 12 ecosystem-based management (EBM) principles (Grumbine 1994; Christensen et al. 1996) for Lakes Erie, Huron, Michigan, Ontario, and Superior, as determined by the standardized proportions of the discussions at Great Lakes Fishery Commission Lake Committee meetings during 1970-1975. The EBM principle humans embedded in nature was shortened to humans in nature. Within each priority category, principles are alphabetized and do not denote rank order.

Lake	Low Priority	Medium Priority	High Priority
	Adaptive Management	Ecological Integrity	Data Collection
	Dynamic Ecosystems	Ecosystem Boundaries	Humans in Nature
	Organizational Change	Hierarchical Context	Interagency Cooperation
Erie	Sustainability	Human Values	Management Evaluation
	Dynamic Ecosystems	Adaptive Management	Data Collection
	Interagency Cooperation	Hierarchical Context	Ecological Integrity
	Organizational Change	Humans in Nature	Ecosystem Boundaries
Huron	Sustainability	Human Values	Management Evaluation
	Dynamic Ecosystems	Ecosystem Boundaries	Data Collection
	Adaptive Management	Human Values	Ecological Integrity
	Organizational Change	Hierarchical Context	Humans in Nature
Michigan	Sustainability	Interagency Cooperation	Management Evaluation
	Adaptive Management	Hierarchical Context	Data Collection
	Dynamic Ecosystems	Humans in Nature	Ecological Integrity
	Ecosystem Boundaries	Human Values	Interagency Cooperation
Ontario	Sustainability	Organizational Change	Management Evaluation
	Adaptive Management	Human Values	Data Collection
	Dynamic Ecosystems	Interagency Cooperation	Hierarchical Context
	Organizational Change	Ecological Integrity	Humans in Nature
Superior	Sustainability	Ecosystem Boundaries	Management Evaluation

Typical focus of EBM principles

EBM principles discussed at Lake Committee meetings typically had a stronger fishery focus than environmental focus. For example, the following statement was coded as ecological boundaries with an environmental focus:

> *"Coho movement and recapture studies would be increased. Greater amounts of gillnet would be fished and different methods of sampling tried. The direction and strength of water currents would be studied in relation to water temperature in an attempt to predict where major concentrations of Coho would be at different times in the year." (Lake Erie Committee meeting 1970).*

The following statement was coded as ecological boundaries with a fishery focus:

> *"Electrophoresis techniques to distinguish sub-species of walleye or walleye of different origin were being tested and one year's collection of data as being assessed". (Lake Erie Committee meeting 1970).*

The former statement included considerations of the boundaries of coho salmon (*Oncorhynchus kisutch*) movement in relation to water characteristics. The latter statement focused on defining fishery stocks and boundaries based only on the fish species, walleye (*Sander vitreus*).

Data collection, dynamic ecosystems, ecological boundaries, human values, and humans embedded in nature were often discussed with a fishery emphasis in the Lake Erie Committee meetings. There was a significantly higher environmental emphasis than fisheries emphasis during Lake Erie Committee meetings for ecological integrity (Figure 2). Lake Erie Committee meetings were the only Lake Committee meetings to have an EBM principle with a higher environmental emphasis than fisheries emphasis. Adaptive management, data collection, ecological boundaries, interagency cooperation, and management evaluation were discussed with a fishery emphasis in the Lake Huron Committee meetings (Figure 3). Data collection, ecological boundaries, human values, humans embedded in nature, interagency cooperation, and management evaluation were most often discussed with a fisheries emphasis in the Lake Michigan Committee meetings (Figure 4). Lake Ontario Committee meetings had a significantly higher proportion of principles with a fishery focus for adaptive management, data collection, ecological boundaries, human values, humans embedded in nature, and management evaluation (Figure 5). Lake Superior Committee meetings had a significantly higher fishery emphasis than ecological emphasis for data collection, ecosystem boundaries, hierarchical context, interagency cooperation, and management evaluation (Figure 6). Across all lakes, two EBM principles, organizational change and sustainability (refer to Table 1 for explanations), were similar between a fisheries and environmental emphasis. Sustainability was discussed infrequently during the Lake Committee meetings and therefore was not a focus of discussions.

Figure 2. Mean proportion (y-axis) of ecosystem-based management principles (x-axis; refer to Table 1 for definitions) with a significant difference in the fishery versus an environment emphasis discussed during Great Lakes Fishery Commission Lake Erie Committee meetings from 1970-1975 (all P<0.05; the other six EBM principles not displayed did not differ significantly in emphasis).

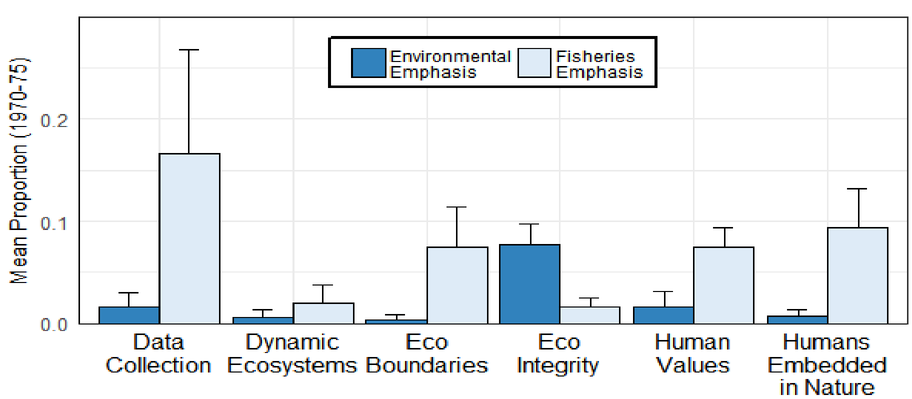


Figure 3. Mean proportion (y-axis) of ecosystem-based management principles (x-axis; refer to Table 1 for definitions) with a significant difference in the fishery versus an environment emphasis discussed during Great Lakes Fishery Commission Lake Huron Committee meetings from 1970-1975 (all P<0.05; the other seven EBM principles not displayed did not differ significantly in emphasis).

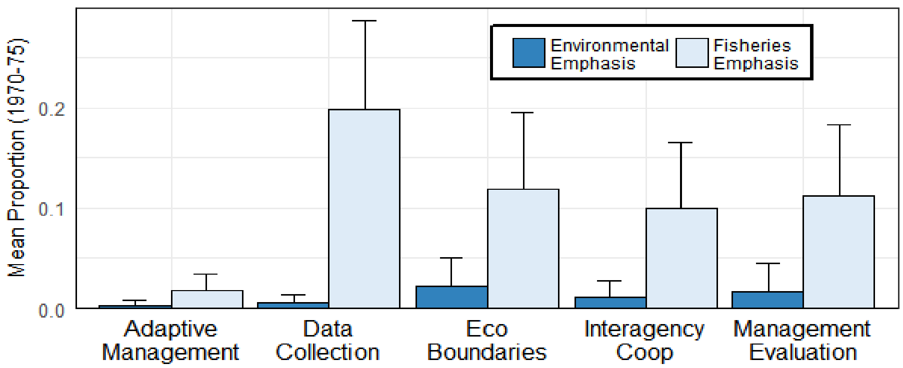


Figure 4. Mean proportion (y-axis) of ecosystem-based management principles (x-axis; refer to Table 1 for definitions) with a significant difference in the fishery versus an environment emphasis discussed during Great Lakes Fishery Commission Lake Michigan Committee meetings from 1970-1975 (all P<0.05; the other four EBM principles not displayed did not differ significantly in emphasis).

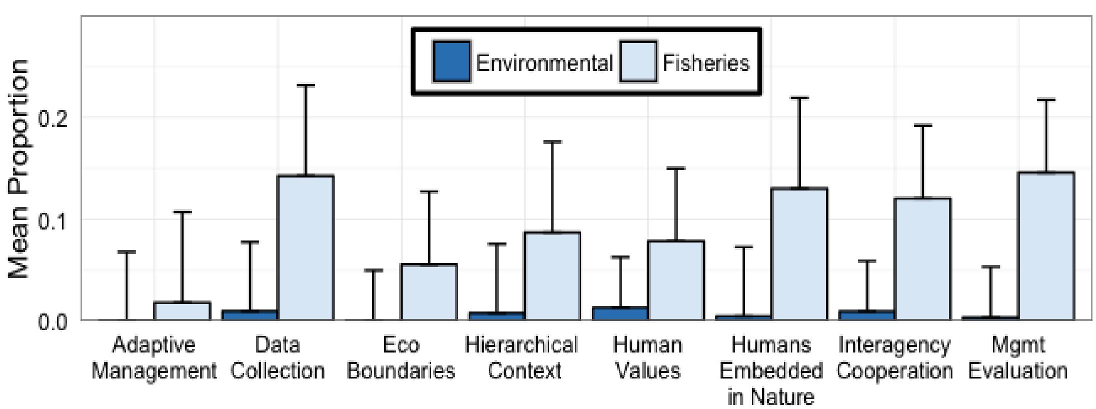


Figure 5. Mean proportion (y-axis) of ecosystem-based management principles (x-axis; refer to Table 1 for definitions) with a significant difference in the fishery versus an environment emphasis discussed during Great Lakes Fishery Commission Lake Ontario Committee meetings from 1970-1975 (all P<0.05; the other six EBM principles not displayed did not differ significantly in emphasis).

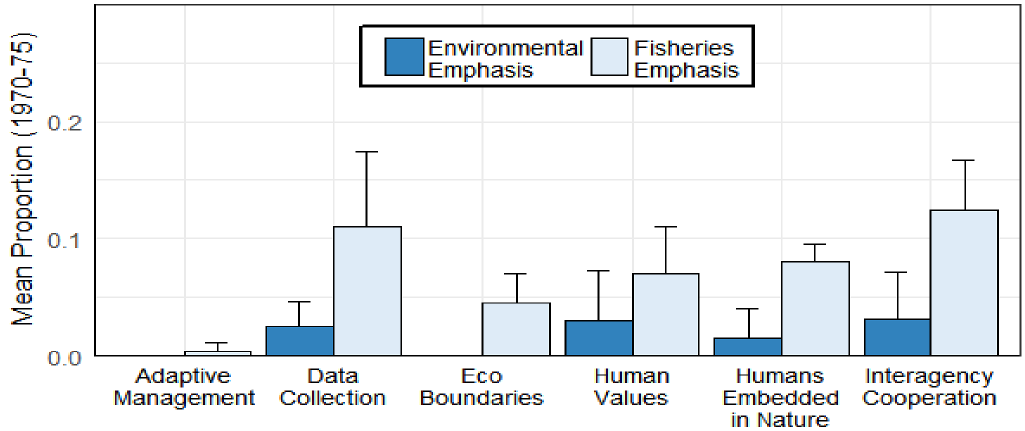
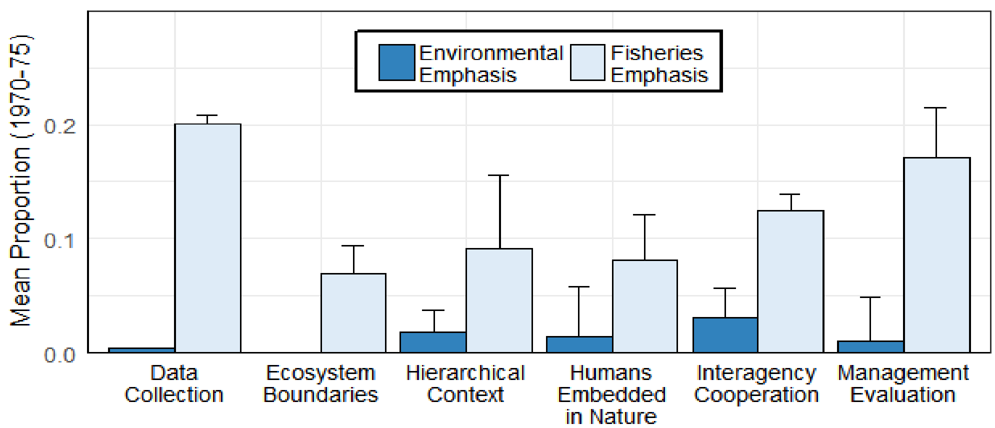


Figure 6. Mean proportion (y-axis) of ecosystem-based management principles (x-axis; refer to Table 1 for definitions) with a significant difference in the fishery versus an environment emphasis discussed during Great Lakes Fishery Commission Lake Superior Committee meetings from 1970-1975 (all P<0.05; the other six EBM principles not displayed did not differ significantly in emphasis).



DISCUSSION

All lakes

Cooperation across agencies was evident during all meetings as all Lake Committee meetings often engaged in discussions among members about data collection and management evaluation. Gaden (2007) determined that Lake Committee meetings facilitated cooperation among jurisdictions and natural resource management agencies. Cooperation was necessary for Great Lakes basin ecosystem-based management to occur as lake ecosystems span multiple jurisdictions and actions in one jurisdiction can influence the other jurisdictions. Developing a cooperative environment was a challenge that spanned decades as jurisdictions did not want to revoke their specific governance power to other agencies or jurisdictions (Gaden et al. 2013). The collective use of the Lake Committee meetings to discuss data collection and management evaluation demonstrated the role of the Great Lakes Fishery Commission as a non-binding, bi-national agency that brought natural resource jurisdictions together for discussion about Great Lakes fisheries. Lake Committee meetings facilitated cooperation among natural resource management agencies through routine interactions and fostered cross-jurisdictional cooperation (Gaden 2007), a necessity as ecosystem boundaries often do not coincide with human-delineated (i.e., jurisdictional) boundaries (Grumbine 1994; Post et al. 2007).

Across the Great Lakes basin, the ecosystem-based management principle, organizational change, was often a low priority yet evidence of organizational change occurred as management agencies were restructured during the study period. Numerous federal, provincial, and state fishery management agencies were renamed, separated or combined, which reflects changing priorities that were happening at the time. As an example, the Bureau of Commercial Fisheries was reorganized with most functions transferred to the National Oceanic and Atmospheric

Administration and some functions transferred to the newly established Environmental Protection Agency ("NOAA History" n.d.). Organizational change is an EBM principle because natural resource management institutions should reflect institutional values and partnerships and the institutions were adopting larger ecosystem perspectives. As organizations were restructuring (e.g., combining and dividing existing organizations) and changing their names to reflect the institutional focus, the organizations were adapting to the emerging ecosystem-based perspectives of the time.

Across all Great Lakes, low priority (i.e., not frequently discussed) EBM principles were sustainability, dynamic ecosystems, and adaptive management. Sustainability and dynamic ecosystem principles were developed after my study period ended as the concern during the 1970s for fisheries management was to recover fishery stocks since environmental conditions were extensively degraded (Moll et al. 2013), as opposed to a focus on the integration of fishery and environmental concerns in management decisions. Adaptive management was formally proposed by C.S. Holling (1978), after my study period (1970-1975), thus this was not a commonly known perspective at that time. It has been shown in the literature that these three principles were not recognized before the early 1970s and if there was detection of these principles, it might be due to incorrect interpretation of the statements. Therefore, the lack of sustainability, dynamic ecosystem, and adaptive management discussions validated the framework because these principles were not detected.

Environmental emphasis: Lake Erie

Management decisions or discussions for Lake Erie during my study period mostly had a fisheries emphasis with the exception that discussions about ecological integrity had an environmental emphasis. Two high priorities discussed at the Lake Erie Committee meetings, in addition to data collection and management evaluation, were humans embedded in nature and interagency cooperation. The humans embedded in nature principle, although with a fishery emphasis, is an incorporation of humans as components of ecosystems, not solely seen as external stressors. The inclusion of humans into ecological systems is one of the underlying principle for Great Lakes Water Quality Agreement of 1978, which is considered as the first EBM policy in the Great Lakes basin (*Great Lakes Water Quality Agreement* 1978). The view of humans as components of nature was developed in the basin before policies formally stated it, demonstrating a time lag between idea development and natural resource management policy implementation.

Lake Erie was at the forefront of developing ecosystem-based management principles. An ecosystem perspective of fishery management corresponds with the extensive anthropogenic pollution, contamination, and environmental degradation that occurred in Lake Erie. The Lake Erie walleye population crashed in 1957 and remained at low abundances due to environmental and fishing stressors (Hatch et al. 1987). In 1969, the Ontario Water Resources Commission tested walleye tissue samples for mercury concentrations and found them to be above the US Food and Drug Administration level of 0.5 μg/g, stimulating commercial fishing bans in Canada and the US beginning in 1970 (Leach and Nepszy 1976; Thomas and Jaquet 1976; Hatch et al. 1987). Due to fishery closures, Lake Erie walleye stocks increased resulting in the production of strong year classes and thus were able to rebound (Hatch et al. 1987).

In 1973, the Great Lakes Fishery Commission facilitated a meeting that developed a binational management plan and the Scientific Protocol Committee (SPC) to assess walleye population dynamics and abundance (Hatch et al. 1987). The Scientific Protocol Committee was binational and therefore matched the high prioritization of interagency cooperation during Lake Erie Committee meetings. Discussions and advice from the Scientific Protocol Committee was seen to have influenced the Lake Erie Committee meeting discussions. Attendees at the Lake Erie Committee meetings occasionally referenced work of the SPC:

> *"It was expected that procedures developed by the walleye SPC would provide essential guidelines for the development of perch management. It was generally agreed that for the moment it would be unwise for the walleye subCommittee to dilute any of its efforts, specifically towards yellow perch management. The general consensus reached was that objectives remained unchanged. Many pressing problems remained throughout the Lake Erie basin, and that the best that could be done for the present was to await development of an agreeable management plan for walleyes, and then attempt to apply this to yellow perch management"*("Lake Erie Committee Meeting Minutes" 1974).

The SPC, as a cross-jurisdictional committee, supported interagency collaboration as management agencies endorsed and supported SPC decisions.

Lake Erie Committee meeting attendees developed a unique perspective of ecological integrity through an environmental focus because of walleye mercury contamination, which indicated a large environmental change was needed to expand the perspectives of fishery managers to include environmental considerations in management decisions. The walleye mercury contamination illuminated the fish-water-humans link (Hatch et al. 1987) and, therefore, necessitated an integrated perspective of all ecological components in management decisions. Lake Erie fishery managers therefore adopted a novel ecological perspective which presumably led to further development of EBM principles with an ecological perspective beyond the study period.

Fishery emphasis: Lakes Michigan, Ontario, Huron, and Superior

Discussions during Lakes Michigan, Ontario, Huron, and Superior Committee meetings did not have any ecosystem-based management principles with a significant ecological emphasis. All principles with a detectable significant difference had a fisheries emphasis. The strong fishery emphasis during management discussions for Lakes Michigan, Ontario, Huron, and Superior can be attributed to fishery management considerations dependent upon each respective lake.

Lake Michigan fishery managers began stocking lake trout in 1965 (Muir et al. 2013), and successfully introduced pacific salmon to Lake Michigan before other lakes in the Great Lakes basin (Claramunt et al. 2013). As Lake Michigan is the only Great Lake entirely within US borders, stocking decisions in Lake Michigan were not subject to formal objections from Canada, whereas other lakes were binational and thus could be subject to stronger criticisms from Canada. Coho salmon were introduced in 1966 and chinook salmon (*Oncorhynchus tshawytscha*) in 1967 (Dettmers et al. 2012; Claramunt et al. 2013). Pacific salmon were introduced to Lake Michigan to reduce invasive alewife (*Alosa pseudoharengus*) abundance and to develop a recreational salmon sport fishery (Dettmers et al. 2012; Claramunt et al. 2013; Eshenroder and Lantry 2013). Fishery management was concentrated on stocking fish and developing a sport fishery, which explains the fishery emphasis in discussions about EBM principles for Lake Michigan during 1970-1975. Attendees at the Lake Michigan Committee meetings highly prioritized humans embedded in nature. Fishery managers realized there were anthropogenic stressors (e.g., pollution, contamination) influencing the Lake Michigan ecosystem, yet anthropogenic stressors were determined to be less critical than fishery stressors (e.g., overexploitation, nonnative species effects) (Wells and McLain 1972, 1973).

Lake Ontario, similar to Lake Erie, was strongly degraded due to anthropogenic stressors (e.g., dissolved solids, eutrophication, pollution), and was presumed to be the first lake to have dramatic changes in fishery stocks (Francis et al. 1979). Yet surprisingly, environmental concerns or awareness was not detected as a significant discussion emphasis at the Lake Ontario Committee meetings. Half of the ecosystem-based management principles discussed by the Lake Ontario Committee attendees had a strong fisheries emphasis showing the focus of the management discussions was often fishery focused and not fully encompassing the ecosystem and interactions.

Lake Huron fishery managers during the early 1970s were focused on fishery concerns rather than environmental concerns. Lake Huron lake trout fisheries were in decline since the early 1900s. Lake trout populations collapsed in 1935, years earlier than in Lakes Michigan and Superior due to overfishing (Muir et al. 2013). The rate of human settlement along Lake Huron coasts was comparably slower than Lakes Michigan, Erie, and Ontario; therefore Lake Huron had a comparably slower anthropogenic eutrophication process (Berst and Spangler 1972). Saginaw Bay water quality was poor, compared to other regions in Lake Huron and may have influenced the decline of *Coregonus* ciscoes (*Coregonus spp*) species in Lake Huron (Berst and Spangler 1972). As the anthropogenic impacts on regions in Lake Huron were spatially varied, the awareness of incorporating ecosystem consideration in management actions was likely also varied. Overall, the major stressors on lake trout populations in Lake Huron were overfishing and sea lamprey predation which explains why environmental issues were of lessor concern in comparison to fishery stressors (Berst and Spangler 1972; Muir et al. 2013). Fishery managers noted potential concerns for fisheries due to heated water and radioactive pollution emitted by electric generating power plants, but any potential effects were not measureable at that time due to the time lag between environmental stressors and any detectable effects (Berst and Spangler 1973). Therefore, there was preliminary evidence of ecosystem considerations for management actions but there was not data available at the time to influence management decisions. Fishery managers thus focused on fishery stressors, not environmental concerns, matching the fishery focus that was detected for EBM principles discussed at the Lake Huron Committee meeting.

During 1970-1975, fishery management in Lake Superior was primarily focused on lake trout rehabilitation and control of sea lamprey. Lake Superior was not significantly impacted by anthropogenic pollution, contamination, or agriculture and was less disturbed compared to the other Great Lakes because regions around the lake were less developed (Lawrie and Rahrer 1973). Furthermore, effective sea lamprey control combined with stocking of hatchery lake trout had led to increased lake trout abundances (Swanson and Swedberg 1980). In the 1980s, catch of wild lake trout surpassed the catch of stocked trout demonstrating successful natural recruitment in Lake Superior (Muir et al. 2013). Additionally, lake trout rehabilitation in Lake Superior has also been attributed to the knowledge gained from the GLFC-sponsored Salmonid Community of Oligotrophic (SCOL) workshop published in 1972 (Bronte et al. 2003). The goal of the SCOL workshop was to compare salmonid fish communities across different oligotrophic lakes in different regions of the world to improve understanding of the structure and dynamics of fish communities in oligotrophic lakes, like Lake Superior (Swanson and Swedberg 1980).

Framework implications

Using content analysis to assess ecosystem-based management principles in reports (e.g., policy or management documents) or discussions was a useful framework to evaluate the development and progress of ecosystem-based management. Use of the framework and comparing the extent of principles discussed can describe the progression of, or lack thereof, ecosystem-based management principles through time within the Lake Committees. The ecosystem-based management content analysis framework captured that an EBM principle, ecological integrity, was discussed with an environmental emphasis during Lake Erie Committees. The EBM framework also confirmed that the Lake Committee meetings were an effective forum for data sharing and management evaluation.

Overall, my analysis indicated most ecosystem-based management principles were discussed (often with a fishery emphasis) in the Great Lakes basin during 1970-1975. Ecosystem-based management principles were discussed in the basin at all Lake Committee meetings, but EBM principles were not typically viewed within a social-ecological or environmental context during this time period. As there was not a social-ecological perspective for fishery management discussions, ecosystem-based management was not occurring in the basin in 1970-1975. Yet, the principles were being developed and understood through a fishery perspective (e.g., ecosystem boundaries based on fish migrations). A fishery perspective of ecosystem-based management principles later expanded to include environmental concerns when the fishery perspective was ineffective in developing sustainable fisheries. Expansion of management perspectives due to environmental concerns was demonstrated when Lake Erie managers adopted an environmental perspective for ecological integrity during high levels of mercury contamination in walleye.

The use of this framework to assess historical fishery management discussions showed ecosystem-based management principles gradually developed over time across different lakes prior to formal fishery and water management ecosystem-based management policies. The development of ecosystem-based management principles in the Great Lakes basin occurred during management meetings facilitated by the Great Lakes Fishery Commission. The meetings supported discussions across jurisdictions which led to lake-wide awareness and understanding of management implications. The Great Lakes were at different levels of environmental degradation and therefore had different focuses and emphasis to address management concerns specific to each lake. The differences between lakes was evident in the different discussions at each of the Lake Committee meetings. The significant environmental changes (e.g., mercury contamination) in Lake Erie caused the fishery managers to adopt a more holistic perspective of the lake through a human-fish-water linkage and laid the foundation for ecosystem-based management in the Great Lakes basin. Since the 1970s, natural resource and fishery management has expanded its perspective to include larger scales, global outlooks, ecological interactions and processes, yet these principles are based on the fundamental roots of the "human-fish-water" linkage (Taylor et al. 2013) that was developing in the basin in the later part of the 1960's and early 1970s.

CHAPTER 2: THE ROLE OF INTERNATIONAL INSTITUTIONS IN DEVELOPING ECOSYSTEM-BASED MANAGEMENT PRINCIPLES IN THE GREAT LAKES

INTRODUCTION

Ecosystem-based management (EBM) incorporates abiotic (e.g., physical, chemical), biotic (e.g., species, communities), and social (e.g., economy, values) components in decision making, aiming to increase natural resource sustainability (Grumbine 1994; Slocombe 1998; Curtin and Prellezo 2010). Ecosystem-based management diverges from traditional, sector-based fisheries management techniques (e.g., single species stock assessment) as it incorporates other ecological dynamics (e.g., habitat characteristics, food web interactions) that are directly or indirectly related to fisheries productivity. Because ecosystem-based management differs from past natural resource management paradigms, the development of EBM principles provides a beneficial case study to evaluate how new ideas are developed and then incorporated through natural resource policy and management networks. I used 12 established ecosystem-based management principles; (1) adaptive management, (2) data collection, (3) dynamic ecosystems, (4) ecological boundaries, (5) ecological integrity, (6) hierarchical context, (7) human values, (8) humans embedded in nature, (9) interagency cooperation, (10) management evaluation, (11) organizational change, (12) sustainability, (Grumbine 1994; Christensen et al. 1996) to track the flow of knowledge with respect to the development of EBM in the Great Lakes basin (refer to Chapter 1, Table 1 for EBM principle explanations).

Tracking knowledge flow among natural resource management agencies allows us to understand how novel management principles (e.g., ecosystem-based management principles) were communicated and transferred across jurisdictions throughout the Great Lakes basin. Managers and decision makers in the Great Lakes basin were leaders in the development of ecosystem-based management principles as Canada and the United States mutually agreed on an EBM approach in 1978 through the Great Lakes Water Quality Agreement (*Great Lakes Water Quality Agreement* 1978). Understanding how information is conveyed among agencies enhances our command of decision making as it demonstrates how interactions among groups affect management perspectives within agencies. Individuals or groups of people are connected to each other through communication networks among those individuals or groups (e.g., meetings, emails) (Frank 1996). The structure of networks can be assessed to evaluate characteristics of relationships among individuals or groups and how these relationships facilitate knowledge flow in the network (Burt 1976; Frank 1996). Interagency cooperation, which can be driven by communication and knowledge flow between organizations, is one of the 12 principles of EBM as it is necessary to work along ecosystem-boundaries rather than jurisdictional boundaries as changes or management decisions in one jurisdiction may have effects in surrounding jurisdictions (Grumbine 1994; Post et al. 2007).

Institutional support (e.g., management endorsement from institutions) is fundamental for the establishment of ecosystem-based management. EBM is a comprehensive and interdisciplinary natural resource use and conservation strategy that incudes various sectors, regions, and viewpoints for natural resource regulations (e.g., water quality and fisheries productivity) (Imperial et al. 1993; Imperial 1999). For ecosystem-based management goals to be sustained, institutions need to develop relationships characterized as an "institutional ecosystem" to effectively and collectively address the causes of environmental disturbances at ecosystem–scales and –perspectives (Imperial 1999). Binational institutions (e.g., International Joint Commission, Great Lakes Fishery Commission) in the Great Lakes basin have supported ecosystem-based management across management jurisdictions as the overarching institutions facilitated communication between jurisdictions. Coordination of Great Lakes fishery management is facilitated by the Great Lakes Fishery Commission (GLFC), a Canada-US organization that was established by the Convention of Great Lakes Fisheries (1954). The GLFC was formed as there was increasing awareness of the need to cross-jurisdictionally manage the impacts of the invasive Sea Lamprey (*Petromyzon marinus*) on valuable Great Lakes fisheries (*Convention on Great Lakes Fisheries* 1954).

The GLFC promotes collaborative fisheries management by hosting meetings that are attended by provincial, state, and federal fisheries management agencies in the Great Lakes basin. At annual GLFC Lake Committee meetings (i.e., annual lake-specific fishery management meetings) management agencies meet to discuss previous, current and future fishery management decisions (Gaden 2007). Attendees at the meetings include GLFC Commissioners (i.e., four federally selected representatives from each country), GLFC Scientific Advisory Committee (i.e., researchers that counsel fishery managers; the Committee is currently named the GLFC Board of Technical Experts), and natural resource management representatives (e.g., federal, state and provincial management agencies). The Great Lakes Fishery Commission is unique as it supports discussions through a non-binding, binational agreement and does not jeopardize individual jurisdictional management powers (Gaden et al. 2013). Management agency cooperation with the GLFC is voluntary (Gaden et al. 2008, 2013), although the GLFC is supported by Canada and the United States and derives influence through federal support.

In addition to Lake Committee meetings, the GLFC has sponsored workshops for researchers across North America and Europe to develop generalizable theories about fish communities to improve fisheries management and ecosystem understanding. Proceedings from the first workshop Salmonid Community of Oligotrophic Lakes (SCOL) was published in 1972 as a special issue in Canadian Journal of Fisheries and Aquatic Sciences (Loftus and Regier 1972). SCOL bolstered the development of ecosystem-based management in the Great Lakes basin as it sought to understand human stressors on oligotrophic fish populations across lakes, particularly the impact of fishing practices, eutrophication, and non-native species (Loftus and Regier 1972; Regier 2013). The Salmonid Community of Oligotrophic Lakes workshop was innovative as attendees viewed oligotrophic (low nutrient, high oxygen) lakes across North America and Europe as replicate case studies to assess different stressors affecting fish communities and therefore was able to assess anthropogenic influences on the lakes (Loftus and Regier 1972).

The goal of this study was to investigate the role of the GLFC in the facilitation and development of ecosystem-based management principles in the Great Lakes basin to better understand the role of institutional structure for collaborative natural resource management. The two primary research objectives were to i) identify key proponents (e.g., management agencies) that influenced the development of ecosystem-based management principles in the Great Lakes basin and ii) evaluate the relationships and flow of knowledge about ecosystem-based management principles among the proponents through GLFC Lake Committee meetings and SCOL. I hypothesized that SCOL and Lake Committee influenced the development of ecosystem-based management principles because these were meetings were forums for discussions among management agency jurisdictions.

METHODS

Data

To identify natural resource management agencies (e.g., Michigan Department of Natural Resources) and GLFC representatives (e.g., Commissioners, Scientific Advisory Committee, Secretariat) participating in the Great Lakes Fishery Commission network (i.e., Lake Committee meetings and SCOL) during 1970-1975, Lake Committee meeting minutes and the publication abstracts from the SCOL workshop were used to collect attendance data at respective meetings. Attendance data were collected from the attendance list included in meeting minutes for Lake Committees and through the authors of the publications in the SCOL special journal issue in the Canadian Journal of Fisheries and Aquatic Sciences (1972).

The GLFC network data were comprised of two modes (i.e., types of data) (Borgatti and Everett 1997). One mode was comprised of the agency/GLFC representatives, henceforth referred to as an actor; the other mode was comprised of meetings that an actor attended (i.e., Lake Committee meeting, SCOL workshop), henceforth referenced to as a meeting. Each mode was separated into sub-units, or nodes (Borgatti and Everett 1997), to reflect either an individual actor or meeting (e.g., one node represents the Lake Erie Committee meeting in 1971 and another node represents the Lake Erie Committee meeting in 1972). In the network, actor nodes were linked to a meeting node if the actor attended that meeting. The network was comprised of 30 Lake Committee meetings and each Lake Committee meeting was represented by a separate node. There were 36 publications in the Canadian Journal of Fisheries and Aquatic Sciences special journal issue for SCOL; these data were combined under one node to represent the SCOL workshop as a single meeting. In total, the GLFC fishery management network from 1970-1975 was comprised of 46 actors and 31 meetings. I assumed if an actor attended a meeting they had exposure to the other actors at the meeting and to the discussions as recorded in the meeting minutes or content in the publications.

Members of the GLFC Scientific Advisory Committee and Commissioners attended SCOL, as evident by individual attendance data. Links among individuals that were GLFC representatives in Lake Committee meetings that also attended SCOL were not captured in this analysis due to data limitations. These individuals were categorized as GLFC representatives for Lake Committee meetings and were categorized by their employment organization for SCOL and therefore the network doesn't encompass all connections between institutions. For example, one participant attended SCOL and was recorded as an attendee under University of Toronto but he was recorded under Scientific Advisory Committee at Lake Committee meetings. The participant had different roles in the two positons and therefore the institutional connection (i.e., University of Toronto to Lake Committee meetings) was not recorded in the GLFC network. Finding employment affiliations for GLFC Commissioners and Scientific Advisors was not practicable as employment data from the 1970s was not readily available. In this analysis, management agency and GLFC representative attendance data characterized the roles of these actors during 1970-1975, rather than the role of individuals, and provided valuable insight to institutional roles in developing ecosystem-based management.

Cluster analysis

Kliquefinder (Frank 1995) was used to determine if there were clusters (i.e., cohesive subgroups) evident in the GLFC network, defined as the 1970-1975 Lake Committee meetings, and SCOL. Clusters are comprised of actors that more often interact with other actors in their cluster and have minimal or less interaction with actors outside their clusters demonstrating either integration or segregation among actors. In the GLFC network, network ties are among actors and meetings, therefore clusters represent groups of actors connected to a group of meetings (i.e., the clusters are comprised of agencies that attended similar meetings). Primary groups (i.e., the cluster an actor or meeting is in), as assessed through cluster analysis, informally influence beliefs and behaviors of members within clusters (Kadushin 1966).

Kliquefinder (Frank 1995) assessed the number of clusters in the GLFC network by iteratively rearranging the nodes (actors and meetings) till the ties among actors and meetings are optimized into clusters. Actors in clusters had strong connections to meetings within that cluster and had fewer connections to meetings in other clusters. Cluster optimization was determined by the log odds ratio (θ_1), which compared the number of ties within and between cluster (Frank 1995)

$$\theta_1 = \frac{\text{(presence of ties inside subgroups)(absence of ties outside subgroups)}}{\text{(presence of ties outside subgroups)(absence of ties inside subgroups)}}$$

Statistical significance of θ_1 was assessed by comparing the calculated θ_1 value to a distribution of simulated θ_1 values. Monte Carlo simulations (i.e., random rearrangements of the network data) were created and analyzed for clusters producing a distribution of simulated θ_1 values. This allows for a statistical analysis of θ_1 values to determine if the original data were comprised of statistically significant clusters or a factor of the optimization method.

To assess the GLFC network structure among actors and their connection to meetings, cluster analysis was conducted using actor attendance at Lake Committee meetings and SCOL. Understanding the network connections highlights the collaborative nature of the meetings, and collaboration is a necessary component of ecosystem-based management. For each meeting, the actor was weighted by the number of representatives that were in attendance for that meeting to emphasize actors with more individuals attending and therefore potentially had greater prominence or influence in meetings. Additionally, high attendance at meetings could indicate the actor viewed the meeting favorably. Cluster analysis was performed based on meeting attendance in individual years (1970, 1971, 1972, 1973, 1974, and 1975) and based on meeting attendance pooled across the study period (1970-1975) to assess the institutional relationships through this time period as institutions needed to collaborate across jurisdictional boundaries to enact ecosystem-based management. For all cluster analyses, Monte Carlo data simulations were performed to create a sampling distribution of θ_1 to assess the significance of clusters found in the GLFC network (Frank 1995).

Core-periphery analysis

To assess the actors and meetings that were structurally central (core) in the network, two-mode categorical core-periphery analysis was conducted using Ucinet6 (Borgatti et al. 2002). Attendance data were not weighted for this analysis as core-periphery analysis was used to measure the overlap between actors and meetings, irrespective of number of actor representatives. The core consists of central actors and meetings; actors are closely connected to other actors through mutual attendance at meetings that were highly attended. The periphery consisted of actors and meetings that were loosely connected through meetings that were not well attended. Core-periphery analysis was conducted for actors and meetings within each year (1970, 1971, 1972, 1973, 1974, and 1975) and across the entire study period (1970-1975) to determine if there were changes or trends across years or a trend over multiple years. The strength of core-periphery relationships was assessed by comparing the density of connections of core actors and core meetings to 1: the highest density possible as it indicates all connections are saturated. The density of the periphery actors and periphery meetings was compared to 0: the lowest density possible resulting in no connections between the periphery actors and meetings.

Document Content Analysis

The focus of the discussions at the Lake Committee meetings from 1970-1975 and SCOL (1972) were determined using content analysis though explicit code rules to assess the content of the discussions (Stemler 2001; Elo and Kyngäs 2008). The use of content analysis to understand themes in text is applicable to "verbal material" (e.g., conversations, documents), including written documentation and thus an applicable method to capture EBM principles in Lake Committee meeting minutes and SCOL publications (McTavish and Pirro 1990). Lake Committee meeting minutes and SCOL publication abstracts were coded using 12 *a priori* literature-based principles of ecosystem-based management: (1) adaptive management, (2) data collection, (3) dynamic ecosystems, (4) ecological boundaries, (5) ecological integrity, (6) hierarchical context, (7) human values, (8) humans embedded in nature, (9) interagency cooperation, (10) management evaluation, (11) organizational change, (12) sustainability, (refer to Chapter 1, Table 1 for explanations; Grumbine 1994; Christensen et al. 1996).

The code unit for the Lake Committee meetings was determined based on the messages (e.g., principles stated) and the document syntax (e.g., paragraphs, bullets) (Rourke et al. 2001). A section was split into smaller units if 1) the principle that was discussed changed, 2) the speaker changed, or 3) there were bullets or listed sections as these were independent components. Coded units were linked to the speaker. The code unit for the SCOL abstracts was a sentence (Rourke et al. 2001). All SCOL coded units were attributed to the authors of the respective manuscripts. Statements that were not relevant for assessing ecosystem-based management (e.g., the start time of the meeting) or did not have sufficient context to understand the statement, were excluded. In total, 4,051 segments were coded based on the 12 ecosystem-based management principles determined from the literature to represent EBM. Two researchers independently coded subsections (n=113) of Lake Committee meetings minutes and SCOL abstracts to assess reproducibility of the code rules, termed intercoder agreement. Intercoder agreement was calculated using Cohen's Kappa:

$$k = \frac{p_o - p_c}{1 - p_c},$$

Where p_o is the proportion agreed upon between the coders while p_c is the proportion agreed upon due to chance (Cohen 1960). Kappa was 0.652, above the value set for "substantial" agreement (Landis and Koch 1977); therefore coding bias is not likely to influence results.

Influence model

Coded discussions reflected an actor's views about the 12 principles of ecosystem-based management during the year the discussions were stated. Actors were linked to the coded units they stated during the meeting or if they were authors of the coded units from SCOL publication abstracts. An actor was defined as the management agency or the GLFC affiliation of the individual attendees. Individuals were assumed to be speaking as a representative for their agency and discussions were most often attributed to the agency. For example, the following segment from the Lake Erie Committee minutes in 1970 demonstrated the attribution of a statement to an agency (Pennsylvania Fish Commission), not an individual:

> *"Pennsylvania reported natural spawning in Elk Creek Park Run (a tributary to Elk Creek) and New York spawning in three tributaries of Cattaraugus Creek (Clear, Big Indian, and Little Indian). Many eggs were noted on the gravel bottom in Elk Creek with one eyed egg being found and others appearing viable. Some natural spawning was observed in Young's Creek in Ontario. Natural spawning in*

other Pennsylvania tributaries might have occurred had it not been for weirs constructed near the mouths."

To understand the flow of knowledge among actors as facilitated by the Lake Committee meetings and SCOL workshop, an influence model was developed based on the actors' statements. The statements for each of the 12 principles was a proxy for their views about the importance of ecosystem-based management principles. An influence model was developed to calculate the extent that interactions between actors (e.g., actor A talked with actor B three times) influenced the actors' belief across time (e.g., actor A's views after three interactions with actor B). As the discussions were proxies for the beliefs of an actor, an influence model was used and accounted for an actor's initial views and assessed the extent an actor's belief was changed relative to the actor's network connections. The network included in this analysis was two mode (i.e., actors linked to meetings) and thus the actors were assumed to be influenced by their attendance at Lake Committee meetings and SCOL.

An agency's views towards each ecosystem-based management principle was determined by the proportion that the agency stated concepts that correspond to an ecosystem-based management principle during the Lake Committee meetings or SCOL. Proportions were standardized to meeting length to account for the variation in meeting duration. To assess the impact of the Lake Committee meetings and SCOL on an actor's view of ecosystem-based management principle, an influence model was developed using the content analysis from Lake Committee meetings (1970-1975) and SCOL publication abstracts (1972). Ecosystem-based management principles were modeled independently.

$$EBM_{a,E,m_{1975}} =$$

$$EBM\ Belief_{a,E,m_{1970-75}}$$

$$+\left[\rho_1 \sum_{m=1}^{m} Attendance_{a,m_{1972-74}} \times EBM_{\ E,m_{1972-74}}\right]$$

$$+\left[\ \rho_2 (Attendance_{a,scol} \times EBM_{E,scol}\ )\right]$$

$$+Canadian + \ American,$$

Where $EBM_{a,E,m1975}$ is the mean proportion that agency, *a*, stated ecosystem-based management principle, *E*, during Lake Committee meetings in 1975.

$EBM\ Belief_{\ a,E,m1970\text{-}71}$ is the proportion that agency, *a*, stated ecosystem-based management principle, *E*, during Lake Committee meetings between 1970 and 1971.

$Attendance_{a,m1972\text{-}74}$ is the mean weighted attendance of actor, *a*, attendance at Lake Committee meetings. Committee meetings attendances were averaged separately for each lake (e.g., Lake Erie Committee meeting attendance from 1972-1974 were averaged separately from Lake Ontario Committee meeting attendance from 1972-1974.)

$EBM_{m,E,1972\text{-}74}$ is the mean proportion that ecosystem-based management principle, *E*, was spoken at Lake Committee meetings between 1972-74. Mean averages for EBM proportions were averaged separately for each lake, similar to $Attendance_{a,m1972\text{-}74}$.

$Attendance_{a,SCOL}$ is the mean weighted attendance of actor, *a*, attendance at the Salmonid Communities of Oligotrophic Lakes workshop.

$EBM_{E,SCOL}$ is the mean proportion that ecosystem-based management principle, *E*, was spoken at the Salmonid Communities of Oligotrophic Lakes workshop.

Canadian and *American* were binary variables denoting actor nationality

I assumed if an actor attended a meeting the actor was exposed to discussions about ecosystem-based management principles at the meeting ($EBM_{a,E,m1972\text{-}74}$). Weighted attendance data were averaged ($Attendance_{a,m1972\text{-}74}$) and standardized proportion of ecosystem-based management principles was averaged ($EBM_{m,E,1972\text{-}74}$), as longitudinal data (1972, 1973, 1974) were collinear (highly correlated) if they were separate model terms.

RESULTS

No significant clusters were found in individual years (1970, 1971, 1972, 1973, 1974, 1975) or across the study period (1970-1975). The lack of clusters means actors in the Great Lakes basin were not grouped based on lakes, regions, institution type (e.g., federal, state) or nationality. Clusters or subgroups within the network can be barriers to collaboration as clusters represent limited connections among groups, allowing the clusters to work independently (Bodin and Crona 2009).

A core-periphery structure suggested some actors and meetings were more central in GLFC network than other actors or meetings. Core-periphery structure was detected in 1972, with the core density value 0.704 and periphery value 0.047, compared to an idealized core-periphery structure with core density values of 1 and periphery density values of 0 (Hanneman and Riddle 2005). A core-periphery structure was also detected in combined years 1970-1975 (Figure 7), with the core density value 0.669 and periphery value 0.049. All the core actors that were established prior to 1972 (Ontario Ministry of Natural Resources was named in 1972) were also core actors across 1970-1975 as shown in Table 3. Core meetings in 1972 were Lake Erie, Lake Superior, and SCOL. No core meetings (e.g., uniquely highly attended) occurred in 1970 or 1973, thus no meeting was more dominantly attended (refer to Table 4).

Figure 7. The Great Lakes Fishery Commission (GLFC) network of actors and meetings from 1970-1975 and the Salmonid Community of Oligotrophic Lakes (SCOL) in 1972 did not have any clusters although it had a core-periphery structure. Core actors and core meetings were denoted by colored circles and squares, respectively. SCOL was denoted by a dark blue square and was determined to be a core meeting. Periphery actors and periphery meetings were denoted by white circles and squares, respectively.

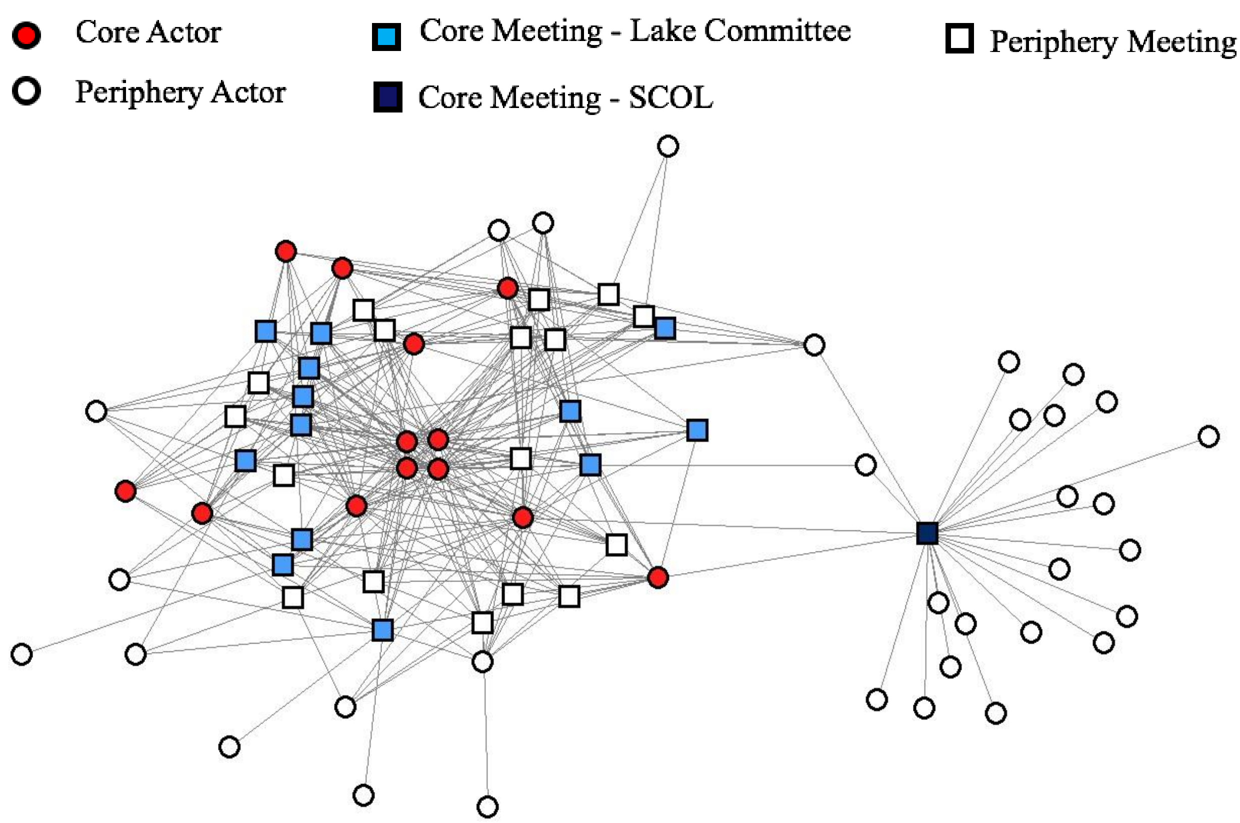


Table 3. Core actors (e.g., management agencies, and GLFC representatives) in the Great Lakes Fishery Commission network in 1972 and 1970-1975 as determined by 2-mode categorical core-periphery analysis. An X indicated a core actor. If an organization changed names after the study began in 1970 the name change was denoted in italics under the name, noting the name the current name of the organization or the prior name of the organization in 1970.

Actors	**1972**	**1970-1975**
Bureau of Sport Fisheries and Wildlife *became US Fish and Wildlife Service*	X	X
Canada Department of Environment *became Environment and Climate Change Canada*	X	X
Center for Great Lakes Studies, Wisconsin	X	
Commissioner *	X	X
Cornell University	X	
European Institutions (5 organizations)	X	
Fisheries Research Board of Canada	X	
Fisheries Research Institute, Washington	X	
Illinois Department of Conservation *became Illinois Department of Natural Resources*	X	X
Meeting Observer *	X	X
Michigan Department of Natural Resources	X	X
National Marine Fisheries Service	X	X
New York State Department of Environmental Conservation	X	X
Ontario Department of Lands and Forests *became Ontario Ministry of Natural Resources*	X	X
Ontario Ministry of Natural Resources *was Ontario Department of Lands and Forests*		X
Scientific Advisory Committee *	X	X
Secretariat	X	X
Wisconsin Department of Natural Resources	X	X
U.S. Fish and Wildlife Service *was Bureau of Sport Fisheries and Wildlife*	X	

* No organization affiliation listed

Table 4. Core meetings in the Great Lakes Fishery Commission network in 1972 and 1970-1975 as determined by 2-mode categorical core-periphery analysis. Core meetings during 1970-1975 were marked by X while the core periphery found in 1972 were marked by a dot •.

Lake Committee	**1970**	**1971**	**1972**	**1973**	**1974**	**1975**
Lake Erie		X	•		X	
Lake Huron		X				X
Lake Michigan			X		X	X
Lake Ontario			X		X	
Lake Superior		X	X•			X
SCOL			X•			

Influence models were individually run for each ecosystem-based management principle. Beliefs about an EBM principle prior to 1972 were often strong indicators of the actor's view of that principle in 1975. Lake Committee meetings were shown to influence two principles (data collection, interagency cooperation), SCOL influenced four principles (hierarchical context, ecosystem boundaries, ecological integrity, organizational change), and Canadian actors influenced three principles (data collection, humans embedded in nature, sustainability). There were no significant relationships noted in management evaluation, adaptive management, and dynamic ecosystems or US actors (Table 5), demonstrating these principles were not influenced during this period.

Table 5. Results from 12 separate influence models that assessed an agency's statements of ρ estimates (first value) and standard deviations (in parenthesis) for each EBM principle model. P-values less than 0.05 are denoted by *, less than 0.01 are denoted by **, less than 0.001 are denoted by ***.

EBM Principle	LC meetings (1970-1971)	LC meetings (1972-74)	SCOL	USA	Canada
Adaptive Management	0.76980 (0.5916)	-0.0003 (0.0081)	-0.0017 (0.0041)	0.0141 (0.0152)	0.0223 (0.0236)
Data Collection	-0.0168 (0.0357)	0.0032 *** (0.0008)	0.0002 (0.0002)	0.0151 (0.0304)	0.1686 ** (0.0476)
Dynamic Ecosystems	0.2538 (0.2105)	0.0036 (0.0030)	0.000006 (0.0001)	0.0072 (0.0067)	-0.0083 (0.0112)
Ecological Integrity	0.3979** (0.1208)	0.0027 (0.0019)	0.0001* (0.00006)	0.0049 (0.0445)	0.0374 (0.0683)
Ecosystem Boundaries	0.16378 (0.1681)	0.0029 (0.0033)	0.0033 ** (0.0009)	0.0735 (0.0520)	0.1533 (0.0820)
Hierarchical Context	0.3875** (0.0264)	0.0207 (0.0123)	0.0002** (0.00007)	0.0663 (0.0363)	0.0114 (0.0647)
Human Values	0.2113 * (0.0991)	0.0031 (0.0024)	0.0089 (0.0337)	-0.0048 (0.0348)	0.0103 (0.0541)
Humans Embedded in Nature	0.5507 ** (0.1670)	0.0028 (0.0031)	-0.00003 (0.0002)	-0.0372 (0.0871)	0.2897* (0.1384)
Interagency Cooperation	0.8443 *** (0.3061)	0.0043 * (0.0018)	0.0026 (0.0032)	0.0228 (0.0359)	0.0325 (0.0572)
Management Evaluation	0.2981 (0.1571)	0.0011 (0.0022)	0.0022 (0.0012)	0.0716 (0.0761)	0.2115 (0.1223)
Organizational Change	0.0829 (0.3291)	0.0042 (0.0034)	0.0110 * (0.0042)	0.00248 (0.0155)	-0.0131 (0.0243)
Sustainability	1.507 * (0.6347)	0.0005 (0.0129)	-0.0010 (0.0043)	-0.0119 (0.0324)	0.1369** (0.0503)

DISCUSSION

From my analysis, it appears that the Great Lakes Fishery Commission facilitated management agencies across the basin to work as one unit as no clusters were detected within or across all years (1970-1975). Three types of misfits can occur between natural resource management institutions and ecosystems: jurisdictional divisions, limited single-sector perspectives, and lack of adaptability to technology (Young 2003). As evident through the absence of clustering, the Great Lakes Fishery Commission bridged a jurisdictional fragmentation in large part through annual Lake Committee meetings which provided a forum for collaboration for the whole network in all jurisdictions. Collaboration across jurisdictions is an EBM principle as it is necessary to work along ecological boundaries rather than jurisdictional boundaries (Grumbine 1994).

Throughout 1970-1975, core actors and meetings were present in 1972 (primarily driven by the inclusion of SCOL in the network) and in 1970-1975. Core meetings in 1972 included SCOL, Lakes Erie and Superior Committee meetings. SCOL introduced actors to the GLFC network by including European and North American researchers and fishery managers. SCOL was determined to be a core meeting (i.e., highly attended) as it had a high diversity of actors attending the meeting and attendees had exposure to many institutional views at that meeting.

The employment location (e.g., Toronto, Canada) of the SCOL organizers potentially attributed to Lake Erie being a core meeting in 1972 as SCOL organizers, Henry Regier and Ken Loftus, were based in the Toronto area, near the Lower Lakes (Lake Erie, Lake Ontario) potentially influencing which actors were invited or attended SCOL. As SCOL attendees were invited, there may have been a bias for the organizers to invite other actors from the Lower Lakes (Lakes Erie and Ontario) irrespective of the oligotrophic lake focus for SCOL that more directly related to the Upper Lakes (Lakes Superior, Michigan, and Huron). The determination of Lake Superior as a core meeting, in conjunction to SCOL, was anticipated as Lake Superior is a dominant oligotrophic lake that was heavily focused on its salmonid communities and was the last lake to retain some diversity of Lake Trout (*Salvelinus namaycush*) forms and their natural C*oregonid* prey (Muir et al. 2013).

The GLFC acted as a bridging institution that facilitated links between the science and policy interface cross jurisdictionally, promoting data sharing, conflict resolution, and knowledge transfer across the various actors through these meetings (Berkes 2009; Kowalski and Jenkins 2015). The importance of the role of the GLFC in the fishery network is further highlighted as the GLFC Secretariat, Commissioners, and Science Advisory Board were core actors during the study period and thus were important actors. The role and position of the Great Lakes Fishery Commission provided them the opportunity to have a unique perspective of the management decisions and their impact on the ecological status among all the lakes.

Other core actors (i.e., actors that attended many meetings) in the network went through organizational changes throughout the study period, potentially demonstrating organizational restructuring to adapt to developing natural resource management values. Organizational change is an EBM principle as it is necessary for organizations to adapt to emerging values, and the complexity of implementing ecosystem-based management (Grumbine 1994). As examples of such organizational change noted in the Great Lakes basin during this time period, the Bureau of Sport Fish and Wildlife become a component of US Fish and Wildlife Service in 1974 ("Fish and Wildlife Service" n.d.). The Ontario Department of Lands and Forests became the Ontario Ministry of Natural Resources in 1972 ("Archives of Ontario" n.d.). Both the Ontario Ministry of Natural Resources and Ontario Department of Lands and Forests were in the core, showing their continued prominence in the Great Lakes basin and GLFC Lake Committee meetings before and after the organizational change. These reorganizations demonstrate that there was an awareness by the management agencies that organizations needed to change to reflect that values and goals at that time.

Across all years evaluated (1970-1975), there were core meetings that occurred in 1970 or 1973. However, each lake had a core meeting at least twice; Lake Michigan has a core meeting three times. The relative equal proportions of all lakes having core meetings showed unity of all the Great Lakes as there was no lake dominating the fishery management network in the Great Lakes basin. The lack of a bias towards one lake coincides with the lack of clusters in the network which supported data sharing and knowledge flow across the network (Bodin and Crona 2009).

The impact of SCOL on the GLFC network structure depended on the temporal scale of the analysis. In 1972, the core meetings included Lakes Erie and Superior, and SCOL. Across all years (1970-1975), the core meetings in 1972 were Lakes Michigan, Ontario, Superior and SCOL. Analysis using six years of network data compared to the annual snapshots demonstrated the influence of the Salmonid Community of Oligotrophic Lakes workshop was dependent on the temporal scale used. Additionally, Lake Erie was considered a core meeting in 1972 using annual network data but the Lake Erie Committee meeting in 1972 was not considered a core meeting over the full study period. Additionally, the study period included three years after findings from SCOL were published, and the influence of SCOL has extended beyond the study period and Great Lakes region as findings are still referenced in current literature.

Actor views about hierarchical context, ecological integrity, interagency cooperation, human values, and sustainability were associated with their actor's prior views that were expressed in 1970 and 1971. The influence of SCOL on ecologically-driven EBM principles showed that ecological perspectives for management were already present in the region, as evident in this study. The increase in environmental concerns corresponded to the burgeoning environmental movement during the late 1960s and early 1970s in North America that translated into the development of ecosystem-based management approaches for fisheries in the 1980s (Minns 2014).

Many Lake Committee members did not recall using the Lake Committee meetings to develop cross-jurisdictional regulations or management objectives, although the meetings were used for agencies to share information and standardized stocking protocols (Gaden 2007). The only two significant EBM principles for Lake Committees from 1972-1974 were data collection and interagency cooperation, as Lake Committee meeting discussions during this time period often pertained to fishery stocking decisions. Collective discussions at Lake Committee meetings however is a precursor for higher level agreements that were necessary for ecosystem-based management to occur. Collaborations and data sharing potentially developed trust among actors and therefore potentially expanded collaboration in future years and common agreement as to regulation design and implementation.

SCOL significantly influenced discussions about hierarchical context, ecosystem boundaries, ecological integrity, and organizational change. Hierarchical context, ecosystem boundaries, ecological integrity were ecologically focused and the motivation of SCOL was to assess anthropogenic stressors on fish communities (Loftus and Regier 1972; Regier 2013). The impact of SCOL on organizational change was unexpected as this was not a stated focus of SCOL and it likely occurred due to the influx of new researchers and their ideas into the Great Lakes Basin management network. It was expected that there would be a time lag in organizations restructuring or re-organizing after new EBM principles were implemented. Increased discussions of the EBM principle organizational change after attendance at SCOL may be attributed to the influence of other actors that were introduced to the network from outside the basin.

The spread of knowledge due to Lake Committee meetings and SCOL demonstrated that the GLFC facilitated the development of ecosystem-based management through hosting meetings for fishery management agencies across Great Lakes basin jurisdictions. During 1970-1975, ecosystem-based management principles were developing in the basin and knowledge was spread among attendees at the Lake Committee meetings and SCOL. Lake Committees meeting from 1970-1975 and SCOL were shown to collectively influence change in the GLFC network through their different roles and influenced the development of different EBM principles.

Collectively, the Lake Committees and SCOL were important for the development of different EBM strategies in the Great Lakes basin. Lake Committees were composed of management agency representatives, whereas SCOL included academics and researchers from North America and Europe and thus the influence of SCOL was different from the influence of the Lake Committee meetings. Across all influence models, if a principle was significantly discussed in Lake Committees 1972-1974 it was not significantly related to discussions at SCOL; the reverse is also true – any principle that was significantly related to SCOL discussions was not significantly related to Lake Committee meetings from 1972-1974, showing there were different impacts among Lake Committee meetings and SCOL.

The study period captured a quick snapshot after the SCOL workshop yet further integration of SCOL findings into Great Lakes fisheries management programs was presumed to have had a time lag. Discussions held during SCOL influenced the actors that attended the workshop and the impact of those changes to other actors that did not attend SCOL was delayed. The different influences of SCOL and Lake Committees demonstrated the different roles each meeting type has in the network, related to the different actors that were in attendance, and presumably demonstrated a time lag in knowledge diffusion.

In 1981, the GLFC and Great Lakes management agencies adopted A Joint Strategic Plan for Management of Great Lakes Fisheries, henceforth referred to as “Joint Strategic Plan”. The Joint Strategic Plan was conceived by management agencies and the GLFC as there was an awareness of the need to more actively manage fishery restoration in the basin (Gaden et al. 2008). The Joint Strategic Plan further outlined the role of the Great Lakes Fishery Commission in coordinating fishery management to support ecosystem-based management. Fishery management agencies can be viewed within three “pillars” (overlapping jurisdictional entities) of Great Lakes fishery management agencies: (1) State, Provincial, Tribal Management; (2) the Great Lakes Fishery Commission; (3) Federal Legislated Mandates (Gaden et al. 2008). The GLFC structure has evolved to a hierarchical structure allowing for management agency and research to be incorporated at multiple levels. The evolution of the GLFC structure reflects the flexibility and coordination role of the Great Lakes Fishery Commission through time and its important role as a bridging institution in the basin that resulted in the spread of knowledge of EBM principles.

SYNTHESIS

My thesis demonstrated that development of ecosystem-based management occurred in the Great Lakes basin through meetings facilitated by the Great Lakes Fishery Commission. Largely, the principles of ecosystem-based management were developing in the basin in the early 1970s under a fisheries perspective, rather than an ecological perspective, before the formal implementation of ecosystem-based management in the 1978 Great Lakes Water Quality Agreement. At this time the International Joint Commission (IJC) and Great Lakes Fishery Commission (GLFC) agreed on a holistic approach to managing the Great Lakes basin. Since Joint Strategic Plan for Management of Great Lakes Fisheries was created in 1981, the Great Lakes Fishery Commission has been formally coordinating ecosystem-based management in the Great Lakes basin.

The Unites States of America and Canada agreed to jointly adopt an ecosystem approach to managing the Great Lakes beginning with the 1978 Great Lakes Water Quality Agreement, but principles and practices supporting ecosystem-based management existed before the formal implementation in the 1978 Great Lakes Water Quality Agreement. In the 1970s, fishery managers linked water and fish within the basin and urged the Great Lakes Fishery Commission to work with the International Joint Commission to include ecological linkages in natural resource and water policies (Francis et al. 1979). In 1977, the GLFC and IJC agreed to adopt an ecosystem approach for management, before the Great Lakes Water Quality Agreement of 1972 was amended to formally include ecosystem-based management principles in 1978 (Francis et al. 1979).

Development of ecosystem-based management in the Great Lakes basin can be attributed to numerous events, particularly fishery management discussions in Lake Erie in the early 1970s, and the Salmonid Community on Oligotrophic Lakes (SCOL) workshop which was held in 1972 to understand the influence of humans on salmonid communities in oligotrophic lakes. Lakes Erie fishery managers adopted an environmental approach, not solely a fisheries approach, in understanding the lake ecosystems for fishery management decisions. At the time, Lake Erie fisheries were contaminated and harmful to humans due to environmental exposure of mercury. The inclusion of environmental considerations led to the development of ecosystem-based management principles in fishery management discussions in Lake Erie and eventually environmental and ecosystem considerations spread to all Great Lakes. The majority of ecosystem-based management principles were discussed at the Lake Committee meetings, although under a fisheries emphasis and not an environmental emphasis which is necessary for ecosystem-based management. The SCOL workshop reaffirmed and introduced ecosystem-based management principles (hierarchical context, ecosystem boundaries, ecological integrity, and organizational change) in the basin by discussing these principles though management and research contexts.

SCOL workshop organizers added a diversity of fisheries and aquatic researchers (e.g., European researchers) to the GLFC fishery management network through their selection of the attendees to attend the Salmonid Community of Oligotrophic Lakes workshop. SCOL attendees discussed a new approach to understanding fisheries as the attendees viewed lakes as comparable units for study to assess anthropogenic stressors on fish communities (Loftus and Regier 1972; Regier 2013). Previously, it was common for researchers to view lakes as independent and incomparable systems (Loftus 1976) and thus there was a limited perspective about the lake ecosystems. SCOL attendees' discussions were novel as the attendees adopted community-based landscape-informed approaches to understand fisheries. Furthermore the SCOL workshop was the first workshop hosted by the Great Lakes Fishery Commission and laid the foundation for other seminal workshops that advanced the understanding and management of the Great Lakes Fishery community (e.g., PERCIS, Percid International Symposium [Stevenson 1977], SLIS, Sea Lamprey International Symposium [Fetterolf Jr. 1980], STOCS, Stock Concept International Symposium [Fetterolf Jr. 1981]).

The emergence of ecosystem-based management principles in the Great Lakes basin can be attributed to a large degree to the role of the Great Lakes Fishery Commission as a binational fishery organization designed to facilitate the restoration and coordinated management of species of common concern between the United States and Canada. The Lake Committee meetings facilitated the flow of data and management evaluations between fishery jurisdictions enabling the various jurisdiction to harmonize their management programs leading to greater success of this basin-wide approach. The Lake Committee meetings, although held in different locations and occurring on different dates, interacted as one unit. This integration was seen in my study results as there were no clusters found in the Lake Committee network. Additionally, the core agencies within the network (highly connected agencies) included the GLFC representatives (Commissioners, Scientific Advisory Committee) and secretariat; again emphasizing their importance as a facilitator of fisheries knowledge and practice.

In 1981 the Great Lakes Fishery Commission and Great Lakes basin fishery management agencies signed A Joint Strategic Plan for Management of Great Lakes Fisheries to create more extensive collaborative structure that was built on the Lake Committees relationships (Dochoda and Jones 2003). The new GLFC meeting structure was hierarchical through the creation of new committees and new committee roles. For example, Technical Committees reported to Lake Committees that reported to the newly developed Council of Lake Committees. This hierarchical meeting structure was created to enhance collaboration across jurisdictions through a bottom-up management process that was informed by fisheries professionals (Gaden et al. 2008), and has been the basis for the noted successful cooperative fishery management in the basin for decades. The structure of the GLFC thus has evolved to promote the implementation of ecosystem-based management as fishery management agencies work across jurisdictions to encompass the Great Lakes ecosystem for management decisions. Overall, the Great Lakes Fishery Commission facilitated the spread of knowledge through coordinating management across jurisdiction in the basin and supporting holistic, ecosystem-based management since the 1970s.

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