Managing for Ecosystem Resilience in Fathom Five National Marine Park, Lake Huron, Canada

by

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A thesis
presented to the University of Waterloo
in fulfilment of the
thesis requirement for the degree of
Doctor of Philosophy
in
Social and Ecological Sustainability

Waterloo, Ontario, Canada, 2013

Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Declaration of Co-Authorship

This thesis consists of five chapters, including a general introduction and a general discussion which bookend three publishable manuscripts (Chapters 2, 3, and 4). For each manuscript, supplementary information and data is provided within the appendices. As of the thesis acceptance date, each manuscript has been submitted for publication.

The following are the proper citations for the manuscripts, including co-authorship. In addition to my supervisor, Dr. Stephen Murphy, Chapter 3 was co-authored by Jeff Truscott (Parks Canada) and Cavan Harpur (Parks Canada), and Chapter 4 was also co-authored by Cavan Harpur (Parks Canada). To be explicit, I researched and implemented the study designs, led the field work, coordinated data management, and wrote the manuscripts. However, I wanted to acknowledge the contributions that Stephen Murphy made through general guidance, Jeff Truscott made through GIS support, and Cavan Harpur made through field and statistical design assistance.

S.R. Parker and S.D. Murphy. Resilience in a protected area: Prospects for Fathom Five National Marine Park, Lake Huron, Canada

S.R. Parker, J. Truscott, C. Harpur, and S.D. Murphy. Exploring a resilience-based approach to zoning in Fathom Five National Marine Park, Lake Huron, Canada

S.R. Parker, C. Harpur, and S.D. Murphy. Development and use of control charts to monitor resilience in the coastal wetlands of Fathom Five National Marine Park, Lake Huron, Canada

Concurrent to this Ph.D. study, I was employed as an ecologist at Fathom Five National Marine Park and Bruce Peninsula National Park. The research was completed and supported through an employee educational agreement between myself and Parks Canada.

Abstract

Protected areas are considered to be the cornerstone of biodiversity conservation strategies and are valued sources of human well-being and ecosystem services. Yet they are not immune to the unprecedented impacts being felt worldwide. As an example, increased human activity, including development, transport of invasive species, and contributions to climate change, are transforming protected areas within the Laurentian Great Lakes into new and novel ecosystems. It is in this context of uncertainty that I explored the practice of managing for resilience. Canada's first national marine conservation area, Fathom Five National Marine Park in Lake Huron, functioned as the study area. Besides profound and complex ecosystem change, Fathom Five is also experiencing governance challenges in the form of tangled responsibilities and issues of legitimacy. The resilience-based approach recommended elements that strengthened the capacity of the park to cope with and recover from disturbance and maintain its defining structures, functions, and feedbacks. This included a reduction of vulnerabilities (e.g., limit exposure to coastal fragmentation, manage disturbance regimes, and maintain functional and response diversity), an increase in adaptability (e.g., need to foster social learning, innovation, and improved governance structures), and an ability to navigate change (e.g., better express desired state, identify thresholds, and influence transformations), within established management practices. More specifically, methods to make spatial planning and monitoring more operational and resilience-based, were developed. For spatial planning, the decision-support tool Marxan with Zones was utilized and demonstrated how themes of representivity, replication, and connectivity could be applied in a resilience-based zoning context. For monitoring, a multivariate distance-based control chart method was developed to detect a decrease in resilience of the parks coastal wetland fish communities. Although an increase in variability was observed, a regime shift was not reported during the years investigated (2005-2012). In summary, the thesis provided an original contribution to science by examining the uncertainties and complexities facing a freshwater protected area and reframing practical conservation solutions through a resilience lens.

Acknowledgements

I am thankful to my supervisor, Dr. Stephen Murphy, for his untiring efforts. He opened the door to this whole venture and guided me through with great encouragement. I certainly appreciated his generosity of time and continuous support.

I would also like to thank the other three members of my advisory committee. In this regard, I am deeply grateful to Dr. Gordon Nelson for planting the seed and nurturing my growth in ways beyond the scope of this thesis. He is a remarkable scholar and gentleman. Dr. George Francis, as an experienced veteran of the Great Lakes, provided valued insight and perspective and guided my appreciation of resilience thinking. Thank you to Dr. Roland Hall for his well received encouragement and thoughtful advice. In addition, I would like to acknowledge the thought provoking questions and feedback I received from Dr. Daniel McCarthy and Dr. Ryan Danby as part of the thesis defence.

I am truly grateful for the friendship and support of Cavan Harpur and Jeff Truscott at Fathom Five. Jeff's GIS technical ability and Cavan's statistical capacity, coupled with their unmatched patience, provided an incredibly positive and creative environment in which to explore the uncertainties and complexities of resilience.

This study would not have been possible without support from the Parks Canada Agency, under the terms of an employee education agreement. To this end, I acknowledge Carol Sheedy, Mike Briggs, Frank Burrows, and Ivan Smith for their assistance in making this opportunity possible. I am particularly grateful to John Haselmayer for his encouragement and trusted management support.

The field work benefitted for the kindness and contributions of many. Paula Travaglini (Canadian Hydrographic Service), Bob Covil (TEKmap Consulting Ltd.), Steve Blasco (Geological Survey of Canada), and Lisa Tutty (University of Toronto) were invaluable in their efforts to support the lakebed mapping project. I am also grateful to Kirk Gibbons (Parks Canada) and Stephen Gile (Ontario Ministry of Natural Resources) for making the task of gillnetting in unfavourable conditions as safe and as fun as possible. The coastal wetland monitoring effort in 2005 would not have been possible without the guidance and support provided by Dr. Patricia Chow-Fraser, McMaster University and her crew (at that time) of graduate students, Kristina Kostuk, Anhua Wei, Melanie Croft, Maja Cvetkovic and Roxanne Razavi. Other Parks Canada colleagues who routinely helped with coastal wetland field sampling included Robin Korn, Alexandra Eaves, and Scott Currie. I am also grateful to those additional Parks Canada colleagues who reviewed earlier versions of the manuscripts, including Dr. Norman Sloan, Michael Patrikeev, Philip Greyson, and Krista Royale.

Most of all I want to thank my family. Jennifer, my wife and best friend, is my enduring source of love and support. Moira, our daughter, is my sunshine and her smile radiates all that is good. Ethan, our son, has a joyful and inquisitive spirit that always makes me laugh. I am a fortunate person to be surrounded by such kindness, encouragement, and life.

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Chapter 1. General Introduction

“*If we cannot control the volatile tides of change, we can learn to build better boats*.”

Andrew Zolli and Marie Ann Healy (2012)

In an age of increased human activity, impacts are being felt even within the areas established to safeguard biodiversity and act as sources for our well-being (MEA 2005). Worldwide, protected areas are increasingly being cast in a challenging context, one in which management goals based on preserving historical conditions are no longer tenable or where traditional management practices are simply pushed beyond their adaptive capacity (Hobbs et al. 2010). The Convention on Biological Diversity (United Nations 1992), The World Summit on Sustainable Development (United Nations 2002), The World Parks Congress (IUCN 2005), and others (e.g., Saunders et al. 2002; Fitzsimons and Robertson 2005; Abell et al. 2007; Nel et al. 2009; Strayer and Dudgeon 2010) have all identified the need to establish and more effectively manage freshwater protected areas.

In such dynamic and often uncertain contexts, managing for resilience is increasingly cited as a possible solution for protected areas (e.g., Mumby et al. 2006; Cole et al. 2008; Pittock et al. 2008; Baron et al. 2009; Lemieux et al. 2011; NPS Advisory Board 2012). Resilience is understood to be the capacity of a system to absorb disturbance and remain within the same regime, essentially retaining defining structures, functions, and feedbacks, i.e., to maintain the same identity (Walker and Salt 2012). Thus, resilience offers continuity and recovery in the face of stress and disturbance. However, before resilience may come to supplant or augment ecological integrity, sustainability, or similar traditional goals, considerable study and effort is required to make the concepts applicable and operational. While there are a few select examples of regions testing the practicality of resilience (e.g., Wardekker et al. 2010; Barmuta et al. 2011; Upton and Ibrahim 2012), I found no examples that described it in a protected area context.

Purpose Statement

I investigated the philosophical and technical underpinnings of resilience as it related to a freshwater protected area context. Fathom Five National Marine Park on Lake Huron, Ontario, Canada, provided the study area. With growing interest in managing freshwater protected areas, the knowledge base and experience at this site provided a unique opportunity to address the following questions:

1) How can we understand and apply the concept of resilience in the context of a freshwater protected area?

2) Zoning is a spatial planning process often undertaken to support conservation goals and reduce user conflicts within a protected area. Therefore, how can zoning be strengthened through the application of resilience concepts?

3) How can we monitor resilience, thus developing timely feedbacks necessary to guide management actions?

Study Area

Fathom Five National Marine Park is a 114 km^2 freshwater protected area located on Lake Huron near Tobermory, Ontario, Canada (45^{o}19’17”N, 81^{o}37’34”W; Figure 1.1). It was established in 1987 in conjunction with the Bruce Peninsula National Park negotiations and represents an amalgamation of the former Fathom Five Provincial Park (ca. 1971) and the local islands of Georgian Bay Islands National Park (ca. 1930) (Wilkes 2001; Yurick 2010). Although designated to represent the Georgian Bay Marine Region (Mercier and Mondor 1995), Fathom Five’s boundaries capture only 49% of the features considered to be representative of this region (Beak Consultants Ltd. 1994). The enterprise initiated Parks Canada’s national marine conservation area (NMCA) program (Canada 2002), yet 25 years later, the site is not scheduled under the NMCA Act. The need to resolve complex governance issues, including First Nations-initiated litigation (Ontario Superior Court of Justice 1994), have slowed the scheduling process.

In the interim, the site is managed through the application of a diversity of provincial and federal legislation to meet the intent of the NMCA Act. Figure 1.2 illustrates the tangled nature of governance and the need for a cooperative approach on the part on both federal and provincial agencies. Unfortunately, administrative silos persist and full cooperation and coordination between these agencies does not always exist (e.g., currently, Parks Canada's has little influence on fisheries management).

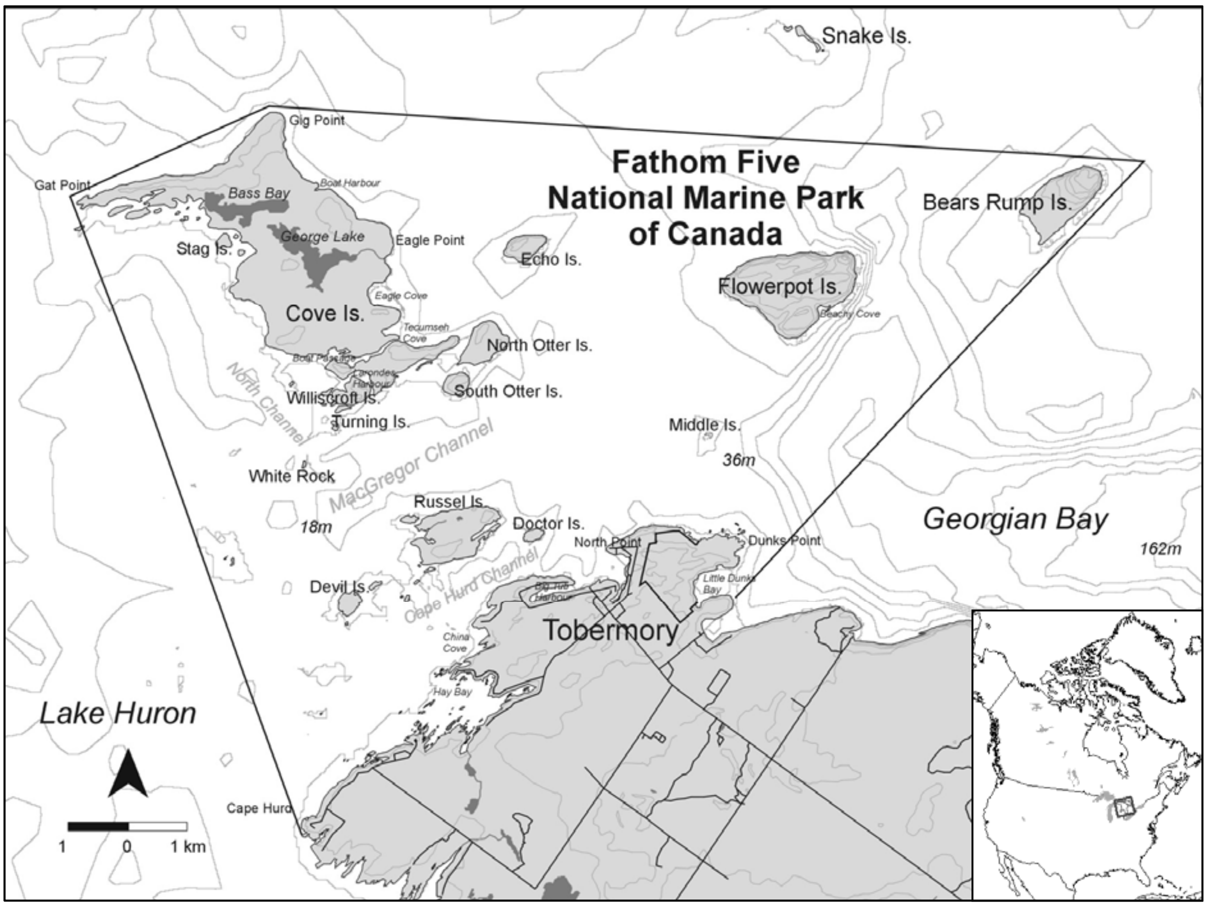

Figure 1.1 Map of Fathom Five.

Tobermory is the central community with approximately 500 residents. The economy of the past included logging and fishing, but today it is tourism and service based. The park receives 40,000 visitors to Flowerpot Island and 50,000 to its visitor centre in Tobermory each year (Canada 2012b). SCUBA diving is popular with approximately 3,500 divers registering each year (*ibid*).

Tobermory is the homeport for the M.S. Chi-Cheemaun car ferry, which carries approximately 200,000 passengers a year through the park as it transits between Tobermory and Manitoulin Island (OSTC 2011). While the Lake Huron watershed is home to over 2.5 million residents (EPA and EC 2008), 2.5 times that number live just outside the watershed and within three hours drive of the park in the Greater Toronto Area (Ontario 2011). The park is within the traditional territory of the Saugeen Ojibway Nations and forms a core protected area of the Niagara Escarpment World Biosphere Reserve.

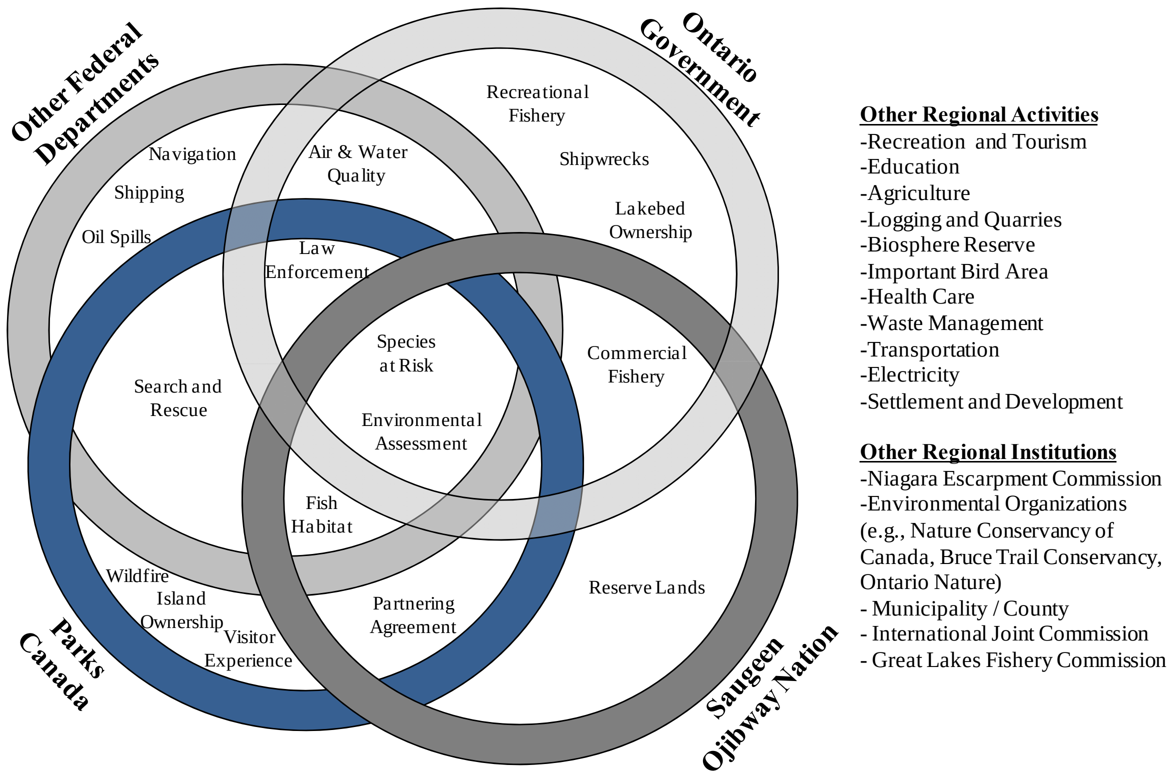

Figure 1.2 Fathom Five's governance context and regional influences.

Fathom Five is bisected by the Niagara Escarpment as it submerges off the northern tip of the Bruce Peninsula, emerging periodically to form a series of small islands. The western-half of the park is located atop the escarpment and has a diverse lakebed ranging from sand to boulder to bedrock with water depths less than 40 m. The eastern-half is located below the escarpment and is mostly glacio-lacustrine sediment with water depths greater than 90 m. This location is at the transition zone between Georgian Bay (area 15 000 km^2) and the main basin of Lake Huron (area 44 000 km2; Bennett 1988). As measured by area, Lake Huron is the third largest freshwater lake in the world, and the fifth in terms of volume (EPA and EC 2008).

Since the last glacial retreat, ~13,000 year before present (BP) in the Fathom Five area (Kor et al. 2012), the region's aquatic ecosystems have undergone many changes. Lake levels have fluctuated from 80 m above the present level, as part of Lake Algonquin (~11,000-10,000 BP), to ~30 m below present level, as waters drained northeastwardly from Lake Stanley, spilling over the escarpment into Lake Hough (~9,000-8,000 BP) (Blasco 2001; Kor et al. 2012). Today, the lake drains southward through the St. Clair River, and levels are ~176 m above sea level, fluctuating ~30 cm seasonally and ~1.5 m on a decadal cycle (Wilcox et al. 2007; IJC 2011). However, there is growing concern with the fact that since 1999, the lake has experienced a prolonged period of low levels, as compared with a maximum period of five years during the past century (e.g., Sellinger et al. 2008; IJC 2009; Millerd 2011; Midwood and Chow-Fraser 2012).

As glacial meltwater spilled into the Missouri, Mississippi, and Atlantic drainage basins, fish colonization was facilitated (Mandrak and Crossman 1992). The origins and evolution of the deepwater cisco complex is particularly interesting within Fathom Five. Early taxonomic studies confirmed seven Coregonus species (i.e., *Coregonus johannae, C. nigripinnis, C. reighardi, C. zenithicus, C. kiyi, C. hoyi, and C. artedi*) in Lake Huron, and it is believed that they speciated from a common ancestor(s) within the Great Lakes during this post-glacial period (Smith and Todd 1984; Turgeon and Bernatchez 2003). They were the dominant food for lake trout (*Salvelinus namaycush*) and served an important function in energy and nutrient transfer to the pelagic environment (Eshenroder and Burnham-Curtis 1999). Tragically, over-fishing and invasive species resulted in the extinction or extirpation of four of the cisco species in the last 60 years (Roseman et al. 2009).

Another significant change to the fish community relates to the invasion by rainbow smelt (*Osmerus mordax*) in the 1920s, followed by alewife (*Alosa pseudoharengus*) and sea lamprey (*Petromyzon marinus*) in the 1950s. Combined, over-fishing, sea lamprey predation, and a high alewife diet (which causes a thiamine deficiency), led to the collapse of lake trout populations in

Lake Huron (only two remnant stocks survived) (Eshenroder 1992). In the absence of a dominant predator, smelt and alewife populations exploded. A turnaround came in the 1960s through sea lamprey control and the stocking of Pacific salmon (*Oncorhynchus* spp.) which effectively controlled alewife and smelt and created conditions more favourable for lake trout (OMNR 2010). While still recovering from this first round of invasive species, the 1990s marked another significant wave of invasion when zebra mussels (*Dreissena polymorpha*), quagga mussels (*D. bugensis*), and round goby (*Apollonia melanostomus*) arrived from the Caspian region in the ballast of ships (Mills et al. 1993).

Dreissenid mussels have tremendous filtering capacity and in a few short decades have established themselves as the dominant benthic macroinvertebrate in the lake (Nalepa et al. 2007). Profound impacts to the foodweb and nutrient cycling has coincided with their colonization, including: increased water clarity; phosphorous decline; dramatic decline in zooplankton (e.g., cyclopoid copepods and cladocerns nearly extirpated) and *Diporeia* sp.; increased periphyton growth; and, near disappearance of alewife (in 2003) and a general decline in forage fish (e.g., Hecky et al. 2004; SOLEC 2009; Riley et al. 2010; Barbiero et al. 2011, 2012). Round goby have also continued to spread, and through competition for food and predation on eggs and young fish, have also impacted the ecosystem (Kornis et al. 2012).

Without a doubt, Lake Huron, including Fathom Five, has transitioned into a novel state, engineered by invasive species and human exploit. It is a complex and uncertain context, one in which rethinking of conservation goals in terms of resilience is necessary, particularly, as the feasibility of returning to historical conditions has slipped away (Hobbs et al. 2010).

As a System

From a holistic view, Fathom Five is a “system” in that its independent components interact and function as a whole (e.g., Kay et al. 1999). In fact, the whole, so the expression goes, is greater than the sum of the parts. The whole also has emergent properties, including an ability to self-organize when faced with change or disturbances, thus providing a sense of system identity. Self-organizing systems (or the more commonly used, complex adaptive systems (Levin 1999)), are characterized by dynamic and sometimes unpredictable behaviour, as they experience selection processes and component changes (Walker and Salt 2012). This is in contrast to a complicated system, such as a clock, where the parts are dependent on each other and do not change.

Around the world, sociologists, economists, ecologists, politicians, and others are asking similar questions of the systems they respectively study: *"why was one situation more resilient than another?"*; *"how much change can be absorbed and still maintain system identity?"*; and, *"how can resiliency be improved and according to whom?*". Therefore, resilience studies have often been defined in terms of their origins as social, ecological, or social-ecological systems (Brand and Jax 2007). Throughout this thesis, I explored resilience in Fathom Five as a linked social-ecological system. Humans are viewed as part of the system. In fact, protected areas are essentially a social contract in conservation and are very much dependent upon good governance to be effective. Although, I emphasized specific ecological elements, such as fish communities of coastal wetlands, this does not imply an exclusion of social dimensions when considering the whole study area.

Freshwater Protected Area Context

Freshwater protected areas, also referred to as aquatic protected areas (Suski and Cooke 2007; Hedges et al. 2010), satisfy the International Union for Conservation of Nature's (IUCN) general definition of protected area, "*as a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values*" (Dudley 2008). Depending on the management goals, freshwater protected areas can span the spectrum of IUCN categories from highly protected no-take reserve (Category I), where resource extraction is prohibited, to multiple-use areas (Category VI) that allow a higher diversity of activity (Dudley 2008).

The Laurentian Great Lakes form the largest surface freshwater system in the world and have been described as "freshwater seas" (Canada and EPA 1995). The basin is home more than 30 million Canadians and Americans (*ibid*), and the state of these lakes in terms of social, ecological, and economic well-being is indeed a matter of national significance. So although the Great Lakes are not truly marine, being large important aquatic ecosystems, they are often included in the marine protected area designs for both nations (Canada 2011).

In 2002, the Government of Canada enacted the *Canada National Marine Conservation Areas Act* (Canada 2002). This legislation enables Parks Canada to establish a system of NMCAs that are representative of the 29 marine regions identified in its system plan for Canada's three oceans and Great Lakes (Mercier and Mondor 1995). Parks Canada is the only federal agency mandated to protect representative areas. Several provinces, including Ontario, Quebec, and British Columbia, also have a legislated mandate to protect representative examples of their diverse ecosystems (Canada 2011). The NMCA Act also directs Parks Canada to demonstrate how marine protection and conservation practices can be harmonized with resource use and visitor experience at these sites.

From the NMCA Act:*"Marine conservation areas are established in accordance with this Act for the purpose of protecting and conserving* <u>*representative*</u> *marine areas for the benefit, education and enjoyment of the people of Canada and the world"* (Canada 2002: Section 4. (1))

"Marine conservation areas shall be managed and used in a sustainable manner that meets the needs of present and future generations without compromising the structure and function of the ecosystems, including the submerged lands and water column, with which they are associated" (Canada 2002: Section 4. (3)).

NMCAs are generally classified as IUCN category VI protected areas, managed resource areas with sustainable use: "*Areas which conserve ecosystems, together with associated cultural values and traditional natural resource management systems. Generally large, mainly in a natural condition, with a proportion under sustainable natural resource management and where low-level non-industrial natural resource use compatible with nature conservation is seen as one of the main aims*" (Day et al. 2012).

Although the NMCA Act does not introduce terms such "ecological integrity" (e.g., as in national parks, Canada 2000) or "ecological health" (e.g., as in the Great Lakes, SOLEC 2009), or explicitly define the management concepts of ecosystem management, precautionary principle, or ecologically sustainable use, the priority nonetheless for NMCAs is to protect ecosystem structure and function and ensure that use, where permitted, is sustainable (Parks Canada 1994, 1998; Canada 2002).

Zoning in Protected Areas

The NMCA Act requires that at least two spatially delineated management zones, one for “protection” and another for “ecological sustainable use”, be identified in each NMCA (Canada 2002). However, the current zoning policy (Parks Canada 1994) is out of date with this legislation because it was developed first. Fathom Five’s zoning plan was developed in 1998 and fails to include a “protection” zone for the aquatic ecosystems (Parks Canada 1998). Given the dated policy and protection limitations in Fathom Five, there is an opportunity for advances and innovation in zoning, particularly when it comes to addressing the contemporary challenges of new and novel ecosystems.

In marine protected areas, zoning forms the cornerstone of management (Day 2002). The process of developing a zoning plan is an inherently complex task and according to Villa et al. (2002), beyond the capabilities of common-sense decision-making. Zoning, nevertheless, requires the systematic integration of abiotic, biotic, and cultural themes and should provide design (e.g., representation, connectivity, replication, resilience, size and shape) and conservation priority (e.g., sensitive habitats, species at risk, spawning shoals and nursery areas) considerations for the site. In spite of the analytical challenges, data availability is often the primary limitation, since ecosystems such as lakebeds are difficult to inventory.

Fortunately, the advent of multibeam sonar in the last few decades has revolutionized seabed and lakebed mapping (Courtney and Shaw 2000; Pandian et al. 2009). Data and derived images reveal previously unrecognizable morphological and textural attributes (Kostylev et al. 2001). Theoretically, this new generation of bathymetric and geological maps, when integrated with biological data, could provide a framework for ecosystem and habitat mapping. There are very few examples of where such habitat mapping has been completed (e.g., Diaz et al. 2004;

Kostylev et al. 2005; Orpin and Kostylev 2006) and none where it is applied within a protected area zoning context.

Monitoring

Monitoring for resilience is primarily focused on questions related to the state of the system in reference to a potential regime shift to a new state. Investigations have revealed that there is a change in system dynamics as resilience decreases (e.g., Carpenter and Brock 2006; Scheffer et al. 2009). However, differentiating natural variability of the various components of a protected area relative to a critical threshold that may force a regime shift, is a major challenge, especially for timely and effective management decisions (Biggs et al. 2009; Contamin and Ellison 2009; Dakos et al. 2012). With sufficient lead time and knowledge, managers could prevent a shift to an undesirable state, help navigate the system to another desirable state, or transform the system to a fundamentally new state. However, bridging the theory to what is practical, including empirical testing of real world datasets, still remains as a key challenge (Thrush et al. 2009).

Resilience Explained

The concept of resilience, as applied within sustainability science, was first introduced by C.S. “Buzz” Holling (1973), and has since been redefined and extended in multiple dimensions (Brand and Jax 2007; Folke et al. 2010). Holling’s original concept was a descriptive term to understand persistence and the ability of a system to absorb change and disturbance and still maintain its basic structure and function. In some studies, engineering resilience was applied to describe how fast a system regained stability after a disturbance (Pimm 1984; Holling 1996). Whereas engineering resilience focused on the return to a stable equilibrium, Holling’s (1996) definition, now called ecosystem or ecological resilience, focused on thresholds to alternate states. This realization of alternate states had profound implications for resource management and overturned the long-standing assumption that ecosystems were characterized by a single stable state which they would return to following a disturbance (Holling and Meffe 1996; Nadasdy 2007).

For this thesis, resilience is understood as the capacity of a system to absorb disturbance and remain within the same regime, essentially retaining the same structure, function, and feedbacks (Walker and Salt 2012). In addition, the capacity for learning and adaptation are viewed as being central to managing for resilience in protected areas (Berkes et al. 2003; Brand and Jax 2007; Francis 2008). To be explicit, resilience is not about staying exactly the same; rather, it is about embracing dynamism and change within limits. For instance, a coral reef may be damaged by a hurricane, but if resilient it will recover and maintain its identity as defined by key structures, functions, and feedbacks.

To elaborate, the theory of resilience is built on three embedded concepts. The first relates to regime shifts - the understanding of thresholds to alternate states. The second relates to adaptive cycles - a heuristic explaining the changing properties and internal dynamics of resilience. The third relates to linked scales - the notion of interconnected systems within systems. While all these elements may appear to serve different purposes, they mutually reinforce one another, and resilience concepts.

Regime Shifts

Most of the time a system can absorb a disturbance (e.g., storm, drought, etc...), reorganize and maintain its identity. Thus the system exhibits resilience and remains in the same regime (also called “basin of attraction”). However, when a system cannot cope with the disturbance, its capacity for resilience is exceeded, and the system transitions across a threshold to a new regime.

Walker and Salt (2006) and others, use a heuristic of a “ball and basin” to describe resilience and thresholds to new regimes (Figure 1.3). The ball represents the current state of the system and the basin the system regime. Within the basin the ball tends to roll towards the bottom, to the attractor equilibrium state. Resilience is a measure of the topology of the basin and system regimes are separated by thresholds. Since the shape of the basin is dynamic and always changing due to external factors (e.g., climate), the ball never reaches the bottom. If the ball remains within the same basin, the system has resilience. However, when there is a change in the systems feedbacks, often due to slow ecological drivers, the ball may cross a threshold into a new basin. This represents a loss of resilience and the system shifts to a new regime with different structures, functions, feedbacks, and attractor equilibrium state.

Managing for resilience is often focused on regime shift thresholds. Understanding where thresholds exist, the system's distance from them, and how to best navigate to avoid or cross are key needs in order to manage for resilience. Within the literature there are numerous examples of thresholds (e.g., Scheffer et al. 2001; Folke et al. 2004; deYoung et al. 2008), and the Resilience Alliance maintains an on-line database of thresholds (www.resalliance.org). With that said, thresholds are still difficult to identify, and most variables in a system don't show a threshold effect (Walker and Salt 2012). That is, they show a linear response to a controlling variable (Figure 1.4(a)). The variables with threshold effects are the ones that cause a regime shift. Figure 1.4 illustrates different forms of thresholds.

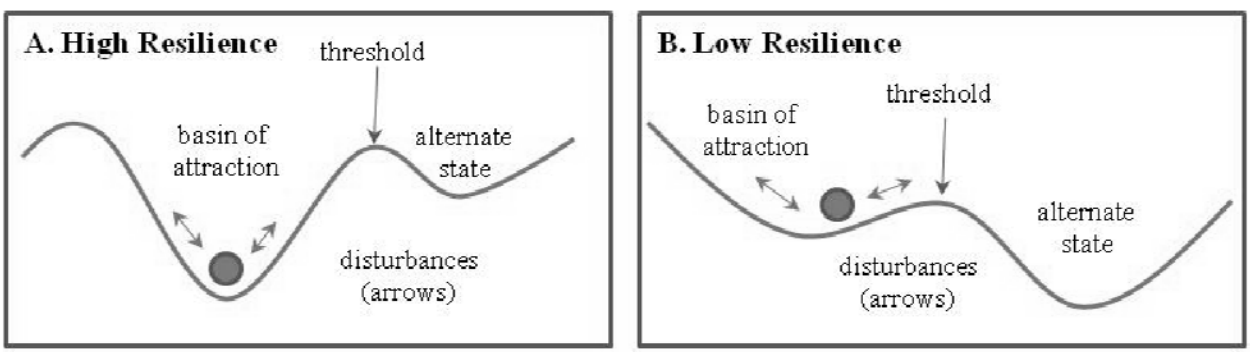

Figure 1.3 "Ball and Basin" model. The ball is the current state of the system. The basin is the system regime defined by similar structure, functions and feedbacks. In A, resilience is high because of the large basin of attraction. In B, resilience is lower because a disturbance could more easily force the ball across a threshold to an alternate state given the basin topology. Metaphorically, managing for resilience involves influencing both the shape of the basin and the position of the ball (adapted from: Folke et al. 2004).

For clarity, external drivers (e.g., lake-level fluctuations and exotic species invasions), can cause a change in a "slow" or controlling variable (e.g., macrophyte structure and water chemistry). As these variables approach a threshold, "fast" variables (e.g., fish assemblage) fluctuate more in response to disturbances (Carpenter and Brock 2006; Scheffer et al. 2009). With loss of resilience, external drivers (disturbances) can push a system to an alternate regime.

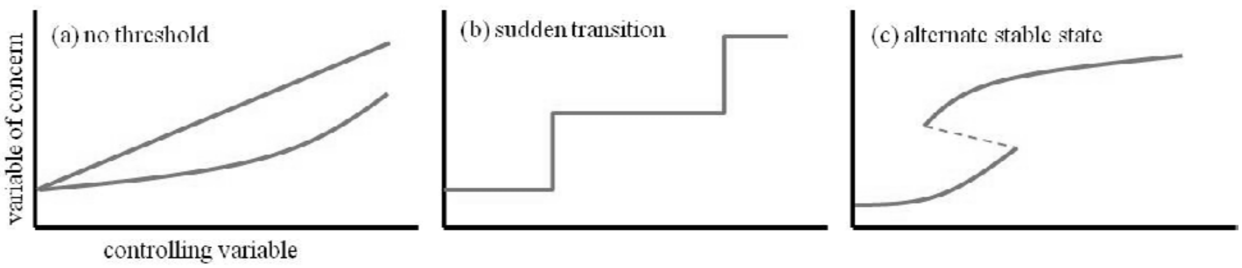

Figure 1.4 Threshold effects. Changes in controlling variable (e.g., nutrients, grazing) leads to different response in variable of concern (e.g., algae productivity, shrub dominance). The response can be steady (a), lead to large step changes (b), or flips a system into an alternate stable state (c) (adapted from: Walker and Salt 2012).

Adaptive Cycles

The notion of succession towards a climax community, which represents an evolved and final equilibrium state, provides a static and incomplete picture of ecosystem development. In fact, systems are dynamic. Observing emergent patterns from ecosystems has led to deductive lines of studies, such as, cellular automata and self-organized criticality (Scheffer 2009). A more holistic and inductive approach is the adaptive cycle (Gunderson and Holling 2002), which provides opportunity to explore the internal behaviour of self-organization within a system over time.

Generated from observations of system dynamics, the adaptive cycle (Figure 1.5) presents a recurring pattern of four phases in which energy and resources go into developing structures and connectivity (Gunderson and Holling 2002; Walker and Salt 2006). There is a general sequence of change from a rapid growth phase, where resources are readily available (e.g., early succession), through to a conservation phase, where things change slowly and energy and resources are locked up (e.g., climax community). In this phase the system is considered to have low resilience and is vulnerable to disturbance. This phase is followed by a release phase where resources and structures are suddenly released (e.g., by fire, disease, drought). This is then followed by a reorganization phase (e.g., colonization), with opportunity for novelty. This cycles around to the rapid growth phase again. Ecosystem resilience is expressed in the release and reorganization phases. Regime shifts can occur in the reorganization and renewal phases. This is also a period when other variables, including slow ones, can exercise greater influence. It is important to emphasize that the adaptive cycle is not a fixed sequence. For instance, a disturbance in the growth phase could result in a system reset to a reorganization or release phase.

The adaptive cycle may not be the best fit for all systems (Cumming and Collier 2005). For instance, some ecosystems may be better characterized by shorter pulsing patterns (Odum et al. 1995). Gunderson and Holling (2002) identified physical systems (e.g., plate tectonics), ecosystems strongly influenced by external variables (e.g., pelagic, open water), and human systems with foresight and adaptability that may not fit the cycle. The adaptive cycle does, however, have wide appeal and is worth understanding in the context of Fathom Five.

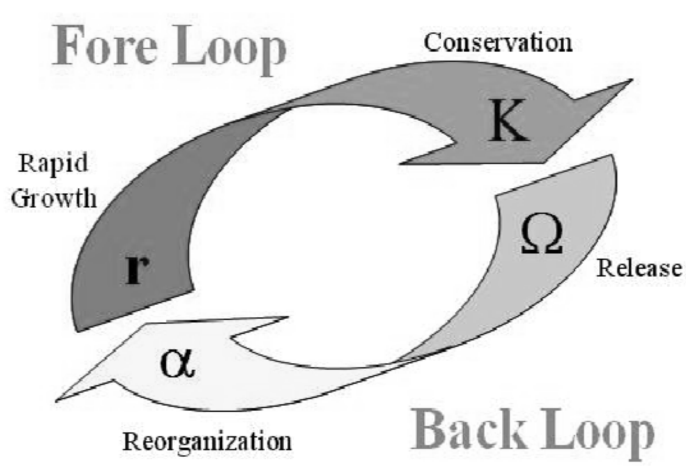

Figure 1.5 The adaptive cycle. In the fore loop the system slowly accumulates capital and grows. Following a disturbance it undergoes a period of release and renewal in the back loop before re-entering a period of growth. The fore loop is characterized by stability, the back loop novelty and uncertainty (adapted from: Walker and Salt 2006).

Linked Scales

In addition to the focal scale (e.g., park), it is necessary to understand that the system is, in fact, part of a hierarchy of linked adaptive cycles operating at different scales in time and space. The term used to describe this concept is “panarchy” (Figure 1.6), and it explains how cross-scale interplay can influence the dynamics and trajectories of system change (Gunderson and Holling 2002). Panarchy explores the interactions of both top-down (“remember”) with bottom-up (“revolt”) controls and slow, broad variables with small, fast variables. For example, if a level of the panarchy enters a release phase (e.g., wildfire), that effect can cascade up to the next larger and slower level, possibly triggering a similar release if that level is vulnerable (e.g., catastrophic wildfire due to low resilience conservation phase). Likewise, once the release phase is triggered at a level, the opportunities for renewal (e.g., seed source) are strongly organized by resources available from the larger scale. Ecosystem resilience is largely determined by the interaction across this panarchy (Peterson et al. 1998).

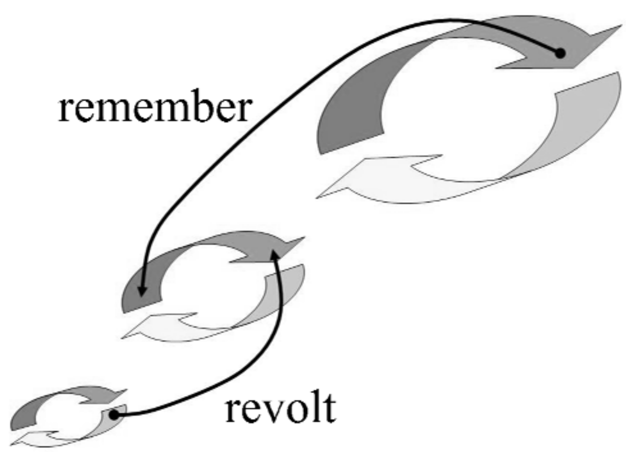

Figure 1.6 Panarchy. A heuristic model of linked and nested hierarchical adaptive cycles. “Revolt” (e.g., disturbance) and “remember” (e.g., seed source) are examples of cross-scale interplay (adapted from: Walker and Salt 2006).

Matching the scale of a problem with the scale of a solution seems intuitive. However, with respect to natural resource management, mismatch in scale, as described by Cumming et al. (2006), does occur and leads to mismanagement and loss of resilience. For instance, the global fisheries crisis (e.g., Pauly et al. 1998; Myers and Worm 2003) demonstrates that the scale of exploitation and effectiveness of harvesting technologies is far greater than the scale of the institutions charged with species conservation (Cumming et al. 2006). Mismatch in scales, can take other forms. Many resilience models represent generalization, and, although the data are less variable at lower scales, models are invariably more predictive at higher scales. Minns et al. (1996) remarked that the reference context for assessing ecological impacts, in terms of habitat restoration, is often set at too fine a scale and then scientific uncertainty is replaced with political confidence to justify decisions. It is recognized that the range of scales at which resilience functions is one of the challenges behind establishing its general application (Holling 1992; Levin 1992; Peterson et al. 1998; Kerkhoff and Enquist 2007), and achieving resilience at one time or place may compromise resilience at other scales.

Understanding within-scale resilience, degree of connectivity across-scales, and available capital are three properties that can help to unravel the complexity of ecosystem management, and diagnose system traps (Allison and Hobbs 2004; Gunderson et al. 2010). Existing in a narrow management regime, trapped systems are stubbornly resilient or maladapted are in, or are heading towards, an undesirable state. Gunderson et al. (2010) characterize four examples of trapped systems, termed rigidity, poverty, lock-in, and isolation. The Florida Everglades are in a rigidity trap due to high resilience and connectivity, but low management capital. Open-water pelagic systems with low resilience, connectivity, and capital are in a poverty trap. Allison and Hobbs (2004) describe a lock-in trap in the agricultural regions of western Australia where capital (e.g., social and natural) has eroded, yet the system has high resilience and connectivity. The isolation trap describes a situation where there is high capital, but low resilience and connectivity, as may be the situation with a species at risk. Awareness of a trap is essential for escaping from it.

To advance the understanding of spatial and temporal scales, Holling (1992) put forward a relatively concise model of the boreal forest which scaled from tree needle to landscape and from days to millennia. A similar model was developed by Minns et al. (1996) to explain the ecological scales affecting Great Lakes fishes. Given the value of such models as conceptual tools for describing ecosystems and their drivers, Figure 1.7 was developed to support resilience thinking within Fathom Five. As Carpenter et al. (2001) suggest, answering the question, "Resilience *of* what *to* what?" can lead to a better understanding of the time and spatial scales necessary to effectively manage a project or strategy.

As a final comment on linkages, acknowledging the interplay across social, economic, and biophysical domains or systems is important (Walker and Salt 2012). For instance, change in one system (e.g., economic debt in fishers) may result in change in another (e.g., over-fishing biophysical domain or social stress) due to connectivity and feedbacks between them.

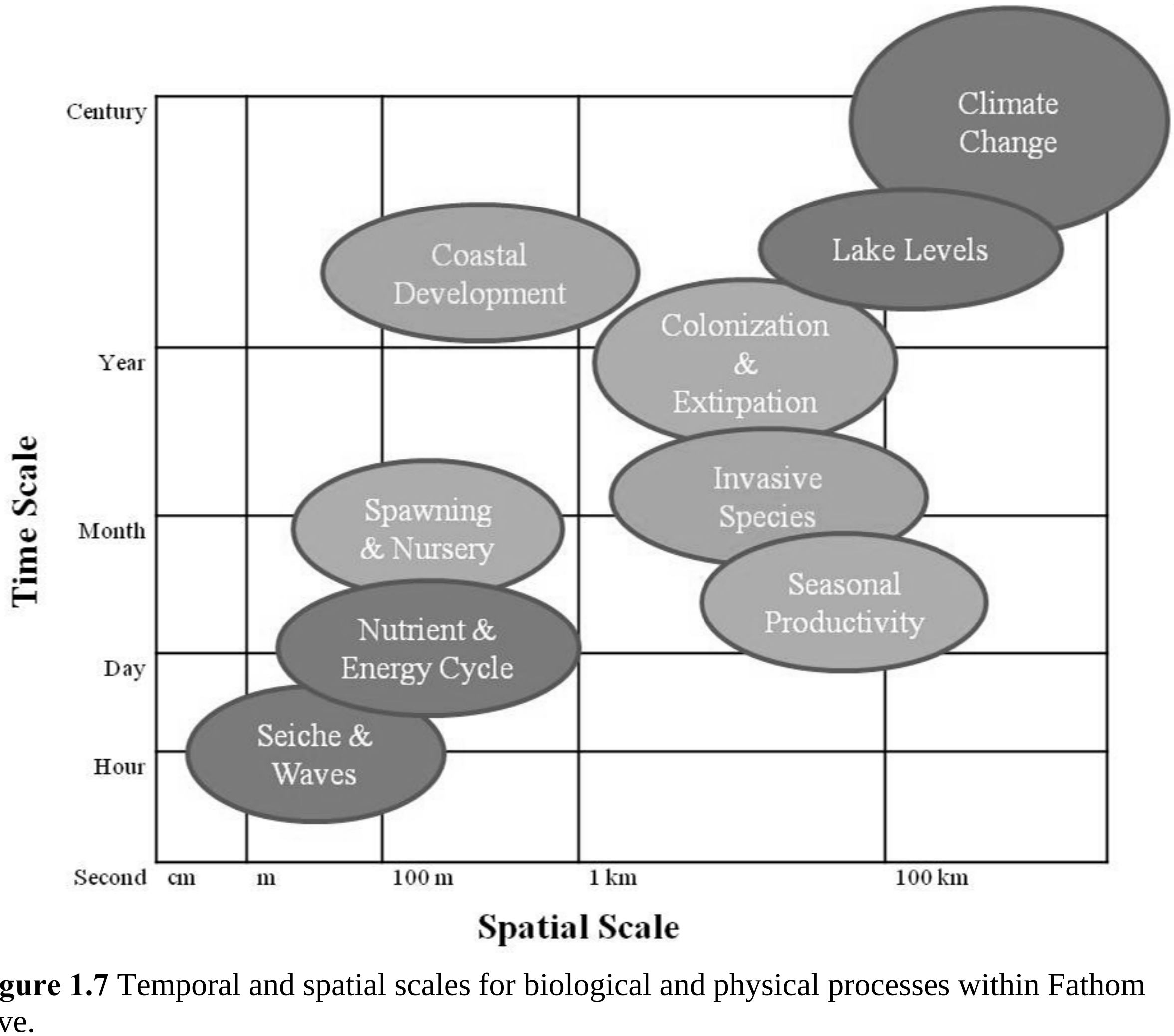

Figure 1.7 Temporal and spatial scales for biological and physical processes within Fathom Five.

Additional Elements

Adaptability, transformability, and vulnerability are central to management efforts based on resilience. Adaptability refers to the capacity of actors within a system to learn and influence resilience (Walker et al. 2004; Folke et al. 2010). Thus, adaptability is the system's ability to maintain certain processes by adjusting responses to changing internal demands and external drivers (Carpenter and Brock 2008). Transformability, on the other hand, is the ability to create new systems when the existing one becomes untenable (Walker et al. 2004). Vulnerability relates to the degree a system is likely to suffer harm when exposed to a specific stress or shock (Chapin et al. 2009), hence a function of the disturbance and system sensitivity.

In consideration of resilience there are both general and specified aspects. General resilience refers to the capacity to cope with all kinds of disturbances, including unpredictable ones. In practice, to build or maintain high general resilience requires system diversity, openness, tightness of feedbacks, redundancy, and modularity (Folke et al. 2010). Specified resilience refers to the capacity to cope with a specific disturbance.

Thesis Objectives

This study provides an original contribution to science by applying a resilience lens to the challenge of managing a freshwater protected area in a new and novel context. The practice of managing for resilience is in its relative infancy, and the thesis advances its applicability by bridging theory and management practice.

Chapter 2 provides an overview of managing for resilience at Fathom Five National Marine Park and describes the uncertainties and complexities facing the offshore, coastal, and governance systems (see Appendix 1 for supplementary information). The approach challenges conventional management practices, which in many regards are underdeveloped or inadequate, and presents a new approach to build and maintain resilient desired systems. Explicit recommendations for how resilience can be incorporated into the assessment, planning, and implementation stages of a management cycle are formulated. Although specific to Fathom Five, this work generates general guidance and lessons which can be applied at others sites.

Chapter 3 explores a resilience-based approach to zoning the park. Additive models have been used in the past to identify conservation priorities (e.g., Beak Consultants Ltd. 1994; Parks Canada 1998), but there is a recognition that “the whole is more than the sum of all parts”. Within this chapter, a complementarity-based algorithm to achieve conservation targets for resilience is tested. This approach considered the interactions between the planning units in the evaluation of the entire solution. For this, geospatial layers of ecosystem structures and functions, as well as the social structure important for maintaining resilience, needed to be identify and developed (see Appendix 2 for supplementary information). How this can be integrated within a process that is iterative and supports learning and adaptation is discussed.

Chapter 4 tests a method for monitoring variability in Fathom Five’s coastal wetland fish community. There are few real-world examples of how monitoring for resilience can be made operational. I examined the use of a control chart method (Anderson and Thompson 2004) to distinguish natural variability in fish assemblage from increased variability due to a weakening of stabilizing feedbacks. Eight years of data were analyzed (2005-2012; see Appendix 3 for supplementary information) and it is recognized that this was a relatively short-time span for studying system resilience. Managing in the face of such limitations is discussed.

Chapter 2. Resilience in a protected area: Prospects for Fathom Five National Marine Park, Lake Huron, Canada

Note: This chapter provides a general synthesis of concepts developed as part of this overall study and there are redundancies with other chapters. The intended audience of the manuscript is conservation practitioners active in other protected areas. It has been accepted for publication in the April 2013 edition of "The George Wright Forum".

Introduction

Building or maintaining resilience within a protected area is increasingly cited as a means to achieve long-term conservation goals in the face of climate change and other human impacts (e.g., Mumby et al. 2006; Cole et al. 2008; Pittock et al. 2008; Baron et al. 2009; Lemieux et al. 2011; NPS Advisory Board 2012). Although there is an established body of ecological and social-ecological knowledge related to resilience concepts, in application it is still conceptually and methodologically early in its development. Within this paper, the applicability of a resilience-based approach to planning and management was explored by using Fathom Five National Marine Park as a study area.

Resilience is a system property that describes the capacity to cope with disturbance and remain within the same regime, essentially retaining defining structures, functions, and feedbacks (Walker and Salt 2012). To support resilience in a protected area context, learning, cross-scale linkages, and adaptability are needed (Berkes et al. 2003; Fazey et al. 2007; Francis 2008). Resilient systems are more diverse, flexible and prepared for change and uncertainty (Hughes et al. 2005). Resilience is founded on non-equilibrium dynamics, where systems can transition to alternate states and where system behaviour and progression is described within an adaptive cycle involving phases of collapse, renewal, growth, and conservation (Holling and Gunderson 2002). Whereas a traditional management approach may focus on maintaining historic conditions (e.g., composition and abundance of native species) or promoting system efficiency (e.g., maximum sustainable yield, single stable state), a resilience-based approach focuses more on the desired system regime and maintaining functional and response diversity (Table 2.1 and Text Box 2.1) (Folke et al. 2004; Chapin et al. 2010). Resilience itself is neither inherently good nor bad. As noted by those studying degraded systems, being locked-in an undesirable state due to high resilience would be perceived as bad (Carpenter et al. 2001). Thus, in managing for resilience there rests a caveat that the intent is to maintain a resilient desired state and, where necessary, leverage out of a less desired one.

C.S. Holling's (1973) seminal work on resilience characterized several events of ecosystem change (i.e., lake eutrophication, fishery collapse) in the Laurentian Great Lakes. As described, when ecological resilience decreased, the lakes became more vulnerable to disturbance and a sudden regime shift. Today, the lakes continue to be affected in complex and novel ways, and the drivers of change include: invasive species – as extreme as the introduction of a new species every 28 weeks (Ricciardi 2006); climate change (Cruce and Yurkovich 2011); governance effectiveness (McLaughlin and Krantzberg 2011); and, contaminants (SOLEC 2009). It is a context that is particularly problematic for a protected area whose goals may be based on preserving historical conditions or where management practices are simply pushed beyond their adaptive capacity (Hobbs et al. 2010).

Table 2.1 Attributes of both a traditional and a resilience-based approach to protected area management (adapted from: Chapin et al. 2009). Many of the "Traditional" attributes are currently evident in Fathom Five (see Appendix 1).

Characteristic	Traditional	Resilience-based
Reference	Historic condition	Trajectory of change
Role of manager	Decision maker who establishes sustainable course; fixed targets/performance measures; disseminates information; maintains institutional structure; and, may respond to changing human values	Facilitator who engages stakeholders and shapes social-ecological resilience; adaptive/flexible targets; integrates across institutions and scales with some devolved/shared decision-making; and, responds to and shapes human values
Research	Reduces uncertainty before taking action	Increases flexibility for an uncertain future
Role of science	Species inventory, model predictable change, and maintain ecosystem composition	Complex social-ecological systems, adaptive cycle and panarchy, and maintains functional and response diversity
Community perspective	Waivers, dependent on individual disposition; and, people use and are part of protected area context	Improves through social learning and acceptance of complexity; and, people have responsibility to sustain protected area
Disturbance	May prevent or accept natural disturbances within historical range	Fosters disturbances that sustain function and structure
Establishment	For scenic value, representative features, scientific, economic or cultural reasons	To support ecosystem services, adaptation or mitigation to change, or build regional resilience

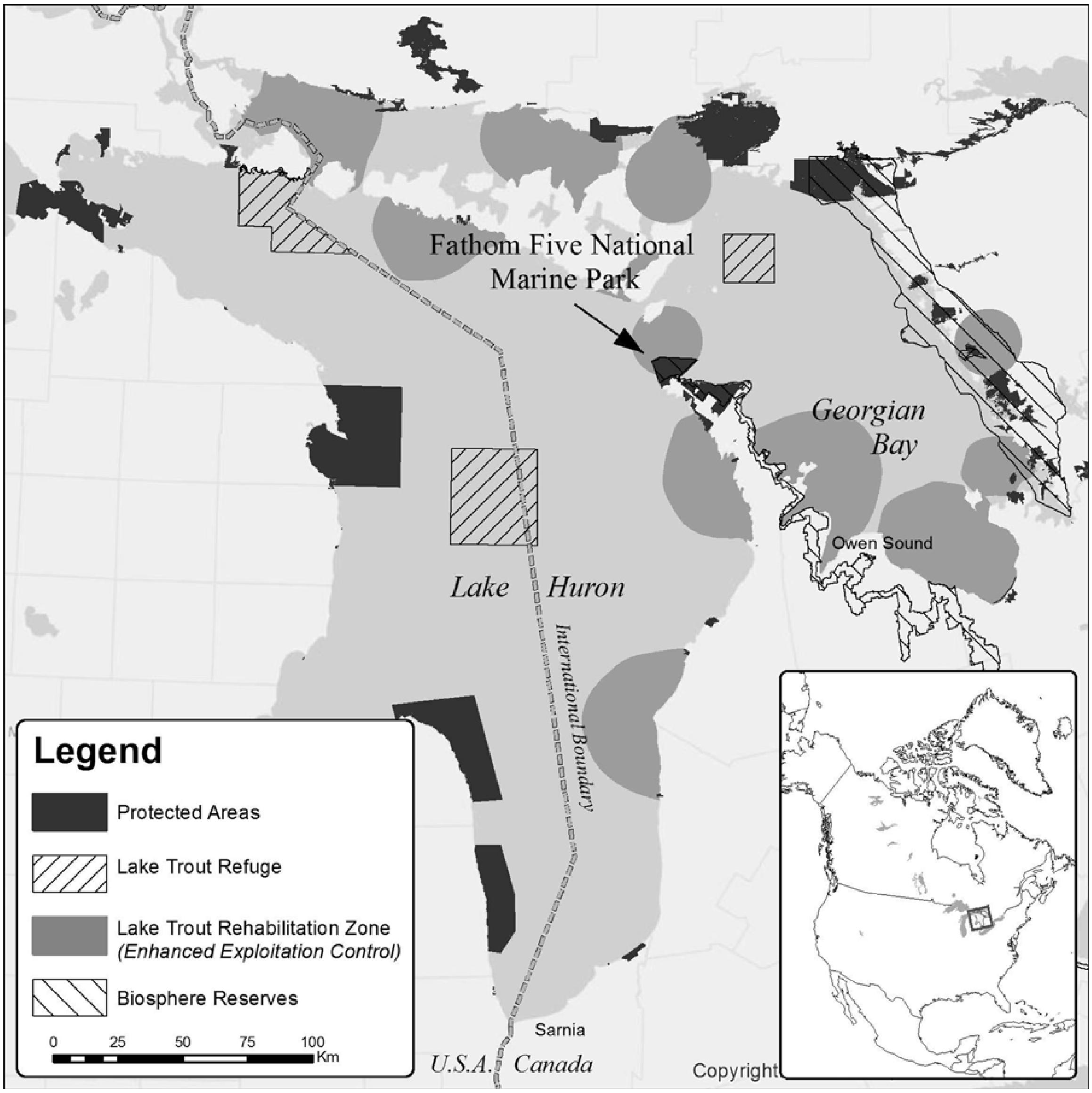

Figure 2.1 Lake Huron's protected area and enhanced fisheries management context. For details on lake trout zones see OMNR (2010), refuge areas are generally no-take or gear restricted areas (e.g., no gill net), whereas rehabilitation areas are the focus of enhanced management efforts (e.g., increased stocking, monitoring).

Fathom Five National Marine Park is a 114 km^2 freshwater protected area located on the Great Lakes (Lake Huron, Canada, Figure 2.1). It was first established as a provincial park in 1972 and in 1987 became the first site to be managed under the stewardship of Parks Canada's national marine conservation area (NMCA) program (Wilkes 2001). It provided a good study area to explore resilience because the site faces considerable management challenges at both the local (e.g., limited capacity and influence on fisheries, not yet scheduled under NMCA Act) (Parks Canada 2011) and Lake Huron (e.g., changing food web and nutrient dynamics) (SOLEC 2009) scales. To advance conservation efforts, the possibility of incorporating resilience-based concepts within a management cycle of assess, plan, and implement, were explored.

Assessing Resilience

A protected area is comprised of diverse and interacting biophysical elements and associated actors and institutions. To assess resilience, there is an initial need to scope, describe, and bind these into relevant issues, components, and scales. For the description and assessment of Fathom Five, the Resilience Alliance practitioners workbook, “Assessing Resilience in Social-Ecological Systems” (Resilience Alliance 2010) was utilized. It acted as a guide to determine resilience *of* what, *to* what, and *for* whom (Carpenter et al. 2001; Lebel et al. 2006). A review of relevant literature and discussions with park staff and other experts was required. Supplementary information on this review, including a more detailed description of Fathom Five is provided in Appendix 1. The process highlighted important aspects of resilience, including:

- Identification of the key structures, functions, and feedbacks that define the desired state;
- An understanding of the current state and trajectory of the park’s ecosystems;
- Recognition of elements that guide system recovery, including representative and replicate sources of functional and structural diversities, and connectivity between them;
- Disturbances, disturbance regimes, and cross-scale influences;
- Governance structures, ownership, and potential constraints; and,
- Patterns of visitor use.

Here follows a brief description of the current state and drivers for the interconnected offshore, coastal, and governance systems as discovered through the assessment (see Table 2.2 for summary of alternate and desired states). This provided the context for resilience thinking.

Offshore Assessment

Much of the recent change in the offshore ecosystem is coincident with invasive dreissenid mussel (*Dreissena rostriformis* and *D. polymorpha*) colonization (Nalepa et al. 2009; Barbiero et al. 2011). Although recent declines in the invasive sea lamprey (*Petromyzon marinus*) and alewife (*Alosa pseudoharengus*) fish population have created favorable conditions for native lake trout (*Salvelinus namaycush*) and cisco (*Coregonus* spp.) recovery, abundance across all trophic levels is generally low or declining (Dobiesz et al. 2005; OMNR 2010). For instance, four of the six deepwater cisco species are considered extinct or extirpated in the past century (Roseman et al. 2009), and, by feeding on benthic invertebrates, these fishes played an important function in energy and nutrient transfer to the pelagic environment (Eshenroder and Burnham-Curtis 1999). The dramatic decline of the benthic crustacean *Diporeia* spp. has also contributed to this break in traditional energy and nutrient cycles (Nalepa et al. 2009; Barbiero et al. 2011). It appears the offshore ecosystem of Fathom Five is transitioning to a resilient and less desired state.

Coastal Assessment

There is growing concern with sustained low lake levels, which is now approaching twelve years as compared with a maximum period of five years during the past century (e.g., Sellinger et al. 2008; IJC 2009; Millerd 2011; Midwood and Chow-Fraser 2012). Non-native species, including round goby (*Neogobius melanostomus*), common carp (*Cyprinus carpio*), and Eurasian watermilfoil (*Myriophyllum spicatum*) are present and may impact some coastal areas (e.g., GLANSIS 2012). The cumulative or direct impact of adjacent coastal development and domestic nutrient inputs remains unknown. In spite of this, the coastal ecosystem of Fathom Five appears to be in a resilient and desired state (Parks Canada 2011).

Text Box 2.1 Resilience, ecological integrity, and the NMCA Act

From the guiding legislation for Fathom Five, "*Marine conservation areas shall be managed and used in a sustainable manner that meets the needs of present and future generations without compromising the structure and function of the ecosystems…*" (Canada 2002: Section 4 (3)). This is a shift from the more familiar "ecological integrity" endpoint, as is found in national and provincial parks in the region (see, Canada 2000; Ontario 2006). As defined in the Canada National Parks Act, ecological integrity is " *…a condition that is determined to be characteristic of its natural region and likely to persist, including abiotic components and the composition and abundance of native species and biological communities, rates of change and supporting processes*" (Canada 2000: Section 2 (1)).

Resilience, especially its concept of persistence, may sound complementary to achieving ecological integrity, and it can with some qualification. Since many ecosystems face escalating uncertainty and novelty, efforts defined by maintaining the "composition and abundance of native species" may confront significant challenges, both socially and ecologically (Fluker 2010). In contrast, resilience is less focused on the persistence of a single species, and more reflective of an insurance metaphor by maintaining functional diversity, response diversity, and natural processes (Folke et al. 2004). Therefore, resilience appears to reinforce the expectations of the NMCA Act, including sustainability and the maintenance of structure and function (not specifically composition), and with qualification can also augment ecological integrity goals.

Structure, function, and composition can be characterized at all scales, from genetic to landscape. Structure is the physical organization or configuration of an ecosystem including density, spatial patterns (connectivity, fragmentation, slope and aspect), and population structure (Noss 1990; Minns et al. 1996). Function involves ecological and evolutionary processes, including demographic processes (recruitment, survivorship), productivity, energy flow, nutrient cycling, and disturbance processes (Noss 1990; Minns et al. 1996). Composition refers to the presence of particular species, including their relative abundance and distribution (Noss 1990).

Governance Assessment

Issues of legitimacy and effectiveness are the foremost challenges to governance in Fathom Five. Fisheries and water quality are managed without park involvement (e.g., see Table 10 in Parks Canada 2011). The transfer of ownership of the water column and lakebed to Parks Canada as per the establishment agreement (Canada and Ontario 1987) has yet to occur, and as a result the site is not scheduled under the NMCA Act. A park advisory committee representing a cross-section of public interest groups exists, however this committee has no decision-making authority or role in goal setting, implementation, or evaluation (Werhum 1994). Fathom Five is within the traditional territory of the Saugeen Ojibway Nations, and consultation and management processes are currently being negotiated. Although the archipelago is recognized as a lake trout rehabilitation zone (Figure 2.1), enhanced conservation measures such as fish sanctuaries or gear restrictions have not been implemented (OMNR 2010). The park boundary is considered inadequate in terms of representing either the Georgian Bay or Lake Huron marine regions (Beak Consultants Ltd. 1994). There is little demonstrated engagement in lake-wide initiatives, such as those stemming from the Great Lakes Water Quality Agreement (IJC 2012a). In practice, there is a clear focus on the scale of the park for management concerns and actions (Parks Canada 2011). Governance in Fathom Five appears to be in a resilient and less desired state.

Table 2.2 Alternate states and system drivers in Fathom Five. A decrease in resilience can make a system more vulnerable to disturbances. This can result in a regime shift when a threshold to a new basin is crossed. For example thresholds, see the Resilience Alliance threshold database (www.resalliance.org) and the Stockholm Resilience Centre regime shift database (www.regimeshifts.org). Currently, within Fathom Five the offshore is transitioning to a less desired state, coastal is in a desired state, and governance is in a less desired state.

Desired State	← Drivers →	Less Desired State
	Offshore	
native benthic diversity and lake trout-cisco community	nutrient and energy pathways colonization / extinction phase cycle of ecosystem temperature	dreissenid dominance and alewife-salmonie community
	Coastal	
low turbidity and sub/emergent vegetation	nutrient and energy pathways coastal development phase cycle of ecosystem colonization / extinction lake level fluctuations	high turbidity and algal biomass
	Governance	
legitimate, accountable, adaptive, and regionally integrated	politics and policy cultural beliefs and values population and demographics socio-economics problem-solving ability	lacks authority, limited mandate support, and little regional integration

Planning for Resilience

Planning involves identifying a desired state and developing strategies to reduce vulnerabilities, increase adaptive capacity, and monitor system feedbacks. Table 2.2 summarizes the perspective of the desired state for the three systems and Table 2.3 provides the recommended planning strategies and actions for each that emerged from this study.

Desired State

A degree of uncertainty and a plurality of perspectives on the desired state are to be expected. It is an open and on-going discussion, influenced by changing social values, system novelty, management institutions, and other factors (Olsson et al. 2006; Hobbs et al. 2009). To illustrate the challenge, Sloan (2004) presents an interesting dilemma involving a choice between the recovery of sea otter (*Enhydra lutris*) or northern abalone (*Haliotis kamtschatkana*) in Gwaii Haanas NMCA and Haida Heritage Site. These species represent potentially mutually exclusive desired states with different social and ecological values. It is a choice between otters and kelp forests or abalone and "urchin barrens", with the former better representing historic conditions and the latter specific fishery values. Similar debates exist within Fathom Five. For example, stocking non-native pacific salmon versus a full focus on native species recovery (Crawford 2001), or debating the need to regulate lake levels or not (IJC 2011, 2012b).

To move forward, planners need to be aware of biases and assumptions and be open and prepared for such questions as: "who decides"; "why is one state better than all the others"; and, "what if there is disagreement" (Nadasdy 2007). Much is hindered by uncertainty, but this can be reduced by incorporating active learning and adaptability within a resilience framework (Fazey et al. 2007).

Opportunities to explore diverse perspectives and alternative desired states could be facilitated through visioning (Olsson 2007) or future scenario exercises (Peterson et al. 2003). An active research and learning program that incorporates social and ecological sciences and adequately educates and informs decision-making is essential. However, this may be challenging to implement, as is evident at Fathom Five. For instance, most social indicators in the recent state of the park report (SOPR) are not reported due to a lack of knowledge (Parks Canada 2011) and the ecological indicators provide limited insight when compared to other government initiatives, such as the State of the Lake report (SOLEC 2009) or the Binational Partnership (EPA and EC 2008). Since the SOPR is developed as the key document for informing the planning process, its content matters (for management planning process details see, Parks Canada 2008). Knowledge of emerging issues or trends is also central to the identification of desired state. For instance, at Fathom Five knowledge of visitor carrying capacity (sensu Manning 2007) or valuation of ecosystem services (sensu MEA 2005) would be informative and guiding.

Based on the assessment of the offshore (e.g., Appendix 1; Cuhel and Aguilar 2013), the dominance of invasive dreissenid mussels has virtually eliminated any prospect of restoring this ecosystem to a historical composition. Although a degree of reconciliation and acceptance of system novelty is required, there still exists an opportunity to actively navigate the transition and maintain structural and functional elements for energy and nutrient transfer from the benthic to pelagic realm. To this end, the desired state focuses on maintaining lake trout-cisco communities. Of note, other areas on Lake Huron which have established fish sanctuaries have witnessed native fish recovery and progress towards a more desired and resilient state (Reid et al. 2001; Madenjian et al. 2004).

For the coast, planning efforts are directed towards monitoring and maintaining structure and function, reinforcing the need to identify sources of biodiversity and maintaining connectivity to different lake-level scenarios. Much of the coast is already in a desired state, as characterized by low turbidity, submergent and emergent vegetation, and little development.

The focus for governance is on leveraging out of a less desired state, mostly through partnership and networking initiatives (e.g., IUCN WCPA 2008). Desired state for governance was based on the expressed elements of leadership and regional cooperation in the Fathom Five management plan (Parks Canada 1998) and on general attributes of good governance (Gunderson et al. 1995; Francis 2008).

Park Zoning

Zoning is a spatial planning process often undertaken to support conservation goals and reduce user conflicts within a protected area. The current zoning plan for Fathom Five (Parks Canada 1998) does not have any zones that fully protect aquatic ecosystems in the park. To explore and advance a zoning concept that explicitly attempts to strengthen resilience by spatially prioritizing protection needs, the decision support tool Marxan with Zones (Watts et al. 2009) was utilized. It provided a platform by which to define and service zoning in a complementarity-based approach. Resilience-based features were selected for the analysis, including ecosystem structure (e.g., benthic complexity and composition, deepwater, ice coverage, currents, coastal wetlands, shoreline complexity and exposure), ecosystem function (e.g., spawning and breeding areas, areas of high nutrient and energy flow), and social structure (e.g., visitor use nodes) (Figure 2.2; see Chapter 3). Conservation target values were assigned in terms of resilience-based needs for representativeness, replication, and connectivity. Cost layers included coastal development, commercial shipping, and fishing areas. The Marxan approach provides a potential link to an adaptive management design (sensu Holling 1978). The conservation targets form a prediction of change and benefit, thus providing a quantitative measure of management effectiveness, to be monitored, evaluated, and adjusted in an iterative manner.

As a “proof of concept”, the method was successful. However, to receive a high degree of legitimacy and acceptance in its implementation, future iterations will need to be reinforced through a public and partner planning process. The Great Barrier Reef Marine Park Authority credits their communication strategy and level of public engagement as key to their success in increasing the area of no-take protection zones from 4.5% to 33% of the park (Kenchington and Day 2011).

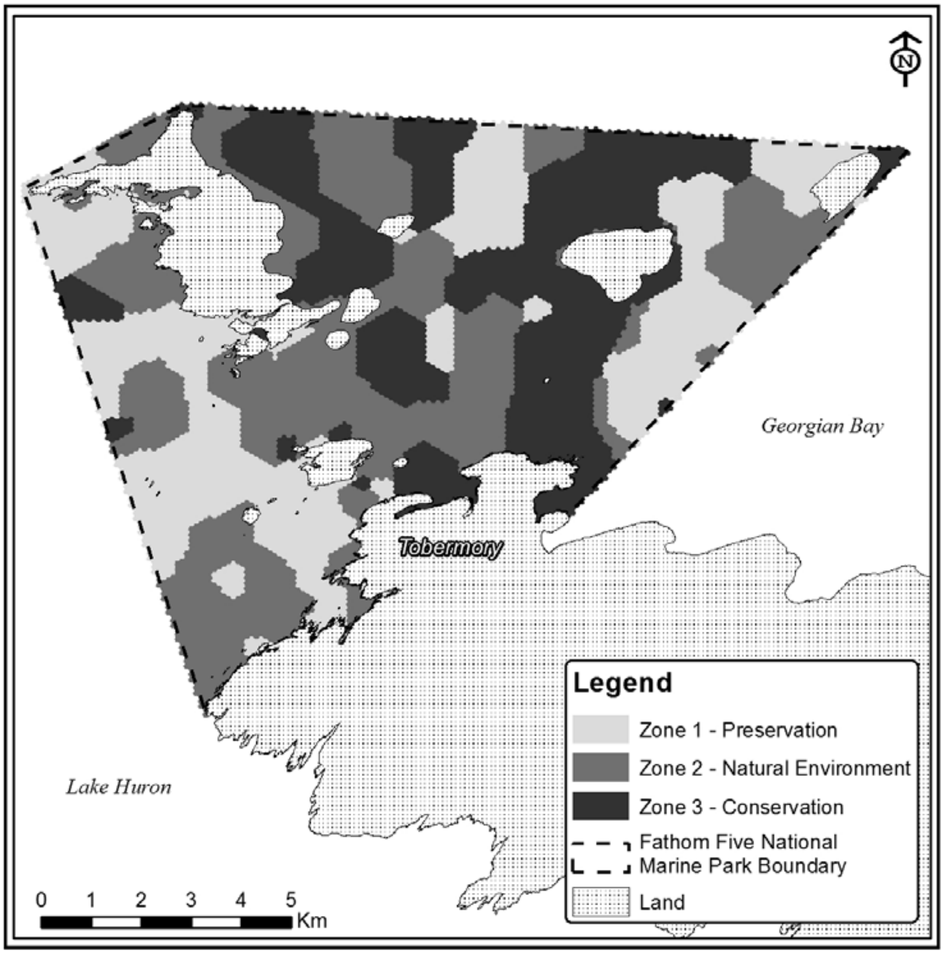

Figure 2.2 An example of a “best solution” based on generated by Marxan with Zones. Using resilience-based representativeness, replication, and connectivity targets for key structures and functions. This is only a proof of concept and does not represent a final or approved plan. The results highlight the importance of protecting lake trout-cisco habitat and coastal wetlands within a Zone 1 Preservation area. The Zone 2 Natural Environment and Zone 3 Conservation provide for ecological sustainable uses, recognizing the social benefits and values of facilitating meaningful experiences (for zone descriptions see Parks Canada 1994)

Regional Scale

Resilience, in part, is predicated on an understanding of cross-scale linkages (Resilience Alliance 2010), and therefore, planning efforts need to consider larger (regional) scale influences. Although Fathom Five remains somewhat isolated from regional initiatives (e.g., EPA and EC 2010), Figure 2.1 illustrates the existence of other protected areas and the potential for a more systematic approach to networking and partnership. The Georgian Bay Littoral Biosphere

Reserve (http://www.gbbr.ca), 80 km to the east, presents an example of an integrated regional vision which maintains an aquatic ecosystem focus. An alternate concept to biosphere reserves is a network of protected areas that function collectively with corridors or stepping-stones to facilitate species or process movement (e.g., Wildlands Network (http://www.twp.org), IUCN WCPA 2008). This could be particularly relevant for coastal wetland or spawning shoal connectivity. Future Marxan zoning exercises could be undertaken at a larger scale, such as the Bruce Peninsula and archipelago or Lake Huron, to help promote a resilient network concept (e.g., IUCN WCPA 2008; Green et al. 2009), as well as address boundary adequacy and representativeness issues (Beak Consultants Ltd. 1994). Networks also have the benefit of facilitating informed contributions to planning, building knowledge bases for research and monitoring, and engaging curiosity or stewardship interests in a learned fashion. UNESCO's knowledge society concept, which promotes knowledge valuation, participatory approaches to access, and integration of knowledge in policies, may be particularly illuminating in this regard (UNESCO 2005).

Monitoring

Recent research has revealed that there are leading indicators within ecological time-series data of abrupt and surprising system changes due to a loss of resilience, including an increase in variance, change in skewness, rise in autocorrelation, and decrease in return rates (e.g., Carpenter and Brock 2006; Guttal and Jayaprakash 2009; Scheffer et al. 2009; Dakos et al. 2011). While many studies have been able to show retrospectively that such a transition occurred, methods to predict change, allowing for actions to either prevent or actively navigate a transition, have been more difficult to develop (Andersen et al. 2009; Biggs et al. 2009).

The current monitoring program for Fathom Five (Parks Canada 2011) does not explicitly address resiliency or leading indicators of regime shifts. However, the possibility for monitoring increasing variability was tested through multivariate control chart analysis (Anderson and Thompson 2004; Morrison 2008) of the park's coastal fish community (see Chapter 4 for details). The data were limited to the past eight years (2005-2012) and was only beginning to generate tighter confidence limits for expected stability in variability. An exceedance in variability would be viewed as a potential leading indicator of a regime shift. The changes may be due to increased lake levels, colonization/loss of macrophyte dependent species, or invasive species. Further monitoring and analysis is required, but the method shows promise for interpreting multivariate environmental data and informing managers of potential concerns. In reality, it may take decades of research and monitoring, as it did with lake (Scheffer and Carpenter 2003) and coral reef systems (Hughes et al. 2010), before sufficient understanding of system indicators and thresholds is available to help manage for resilient desired states.

Expanding the monitoring measures and discourse beyond visitor metrics, to those that link social-ecological values and benefits, such as “healthy parks, healthy people” (Maller et al. 2008) and “quality of life” (Costanza et al. 2007) is recommended. As with ecosystem services (MEA 2005), this may help to deepen the appreciation and importance of Fathom Five and identify grounds for networking and additional support and understanding for resilience.

Implementing a Resilience-Based Approach

Implementation includes organizing and managing for resilience (Table 2.3). Institutional rigidity, struggles translating plans into actions, and weak or insular management structures are general concerns with any organization (Gunderson et al. 1995) that may represent particular challenges at Fathom Five. Given the complexity, uncertainty, and origin of some of the park issues, an adaptive management approach to promote learning and experimentation with new policies, partnerships, and institutions may be beneficial (e.g., fisheries management) (sensu Holling 1978). As a model, the Great Barrier Reef embraced the need for transformation and overcame similar barriers. Through leadership and innovation, they were able to coordinate the scientific community, increase public awareness, broaden stakeholder engagement, and navigate the political system for support at critical times (Olsson et al. 2008). They essentially developed a resilience-based approach to cope with uncertainty, risk, and change. The IUCN has also addressed some of these issues by developing best practices for management planning (Thomas and Middleton 2003), guidelines for legislation (Lausche 2011), methods for establishing networks (IUCN WCPA 2008), and approaches to assess management effectiveness (Pomeroy et al. 2004; Hockings et al. 2006).

Conclusion

A resilience-based approach provides perspective on system disturbances, drivers, alternate regimes, and cross-scale interactions (Resilience Alliance 2010). With this understanding, there is an opportunity to better manage towards a more resilient and desired state. The desired state is variable and adaptive, and defined by key structures, functions, and feedbacks. Management efforts aim to prevent undesired regime shifts and support post-disturbance recovery with functional and response diversity (Folke et al. 2004; Chapin et al. 2010). To fully embrace resilience requires a management structure that supports social learning, experimentation, trust building, and a mandate to take action (Prato 2006). Managers of protected areas should feel confident that those willing to look through its lens can make the concepts and methods of a resilience-based approach operational.

It is an opportune time for Fathom Five to consider incorporating resilience within its planning and management processes. The NMCA program is in a period of growth, there is growing interest in Great Lakes protected areas (e.g., Hedges et al. 2011; IJC 2012a), and the Fathom Five management plan is about to be opened for review. The concepts and methods explored here appear to be promising and there is a sense that even though the Great Lakes continue to face escalating uncertainties and change, Fathom Five can effectively achieve its long-term conservation goals by maintaining and building resilience.

Table 2.3 Recommendations to strengthen resilience by reducing vulnerability, increasing adaptability, and navigating change in Fathom Five.

System	Scale Below (specific sites)	Focal Scale (Park)	Scale Above (Lake Huron)
Offshore	• Establish lake trout and whitefish spawning refuges. • Restore and protect lake trout and cisco populations (e.g., stocking, sustainable fishery).	• Research and monitor disturbances, functional, and response diversity. • Restore and protect the lake trout-cisco community. • Develop a sustainable fishery in collaboration with First Nations and other government departments. • Re-assess boundary adequacy.	• Meaningfully engage on lake-wide coordinating policies and programs. • Conduct a regional representativeness and network analysis of offshore ecosystems. • Express conservation and resilience concerns. • Integrate with "State of the Lake" reporting and monitoring.
Coastal	• Engage landowners in learning, monitoring, and area planning opportunities for place-based conservation. • Restore sites degraded by development. • Protect coastal wetlands from development.	• Research and monitor disturbances, functional, and response diversity. • Manage coastal connectivity (e.g., reduce stranding barriers, prevent phragmites colonization). • Assess boundary adequacy. • Assess cumulative impacts from coastal development.	• Meaningfully engage on lake-wide coordinating policies and programs. • Conduct a regional representativeness and network analysis of coastal ecosystems. • Support stewardship activities, including restoration and conservation incentives. • Integrate with "State of the Lake" reporting and monitoring.
Governance	• Conduct scenario and desired state exercises, with resilience as a goal, for areas of local interest. • Develop mechanisms for ecosystem stewardship at specific sites, including social learning and involvement of adjacent landowners and commercial operators. • Promote sense of place.	• Evaluate governance, including vulnerabilities related to legitimacy, adaptability, capacity, and participation. • Develop a communication and learning strategy related to NMCAs and resilience. • Demonstrate place-based conservation. • Assign adaptive management targets. • Recalibrate management objectives in terms of resiliency and ecosystem change. • Report on ecological services and promote the site as a source of knowledge and well-being.	• Establish regional partnerships with initiatives focussed on broader social-ecological stewardship issues. • Examine regional social networks, strategic policies, and opportunities for involvement. • Improve and coordinate access to information and knowledge. • Participate in regional land-use and lake-wide planning. • Support NMCA policy development and include resiliency concepts.

Chapter 3. Exploring a resilience-based approach to zoning in Fathom Five National Marine Park, Lake Huron, Canada[1]

[1] See Preface (page ii) for manuscript details and description.

Overview

Zoning is a spatial planning process that reinforces conservation goals and reduces user conflicts within a protected area. Here, a resilience-based approach to zoning in Fathom Five National Marine Park, Lake Huron, Canada was explored using the decision support tool Marxan with Zones. Conservation feature identification was based on a resilience assessment and organized into the general themes of ecosystem structure, ecosystem function, and social structure. Target values were set to achieve representativeness, replication, and connectivity targets while minimizing social and economic costs. The resilience-based approach also included consideration for adaptive management and good governance practices. The Marxan solutions provided a proof of concept and guidance for Fathom Five in achieving its management goals within its complex and novel ecosystem context.

Introduction

Worldwide, freshwater ecosystems and their protected areas are experiencing a period of profound change (MEA 2005; Suski and Cooke 2007; Strayer and Dudgeon 2010). For instance, the Laurentian Great Lakes continue to face new and novel ecosystem changes due to: invasive species – as extreme as the introduction of a new species every 28 weeks (Ricciardi 2006); climate change (Cruce and Yurkovich 2011); emerging contaminants (SOLEC 2009); and, other human-induced stresses. It is a context of increasing uncertainty and complexity which challenges the effectiveness of traditional protected area planning and management approaches.

Within protected areas, resilience is increasingly cited as a means to address such a challenge (e.g., Pittock et al. 2008; Baron et al. 2009; Lemieux et al. 2011). Resilience is a system property that describes the capacity to cope with disturbance and remain within the same regime, essentially retaining defining structures, functions, and feedbacks (Walker and Salt 2012). A resilience-based approach focuses on maintaining functional and response diversity, capacity to cope with and recover from disturbance, cross-scale linkages, and, innovation and adaptability

(Chapin et al. 2010). While managing for resilience, the intent is to identify and maintain a resilient desired state and, where necessary, leverage out of a less desired state.

To explore further the applicability of a resilience-based approach, Fathom Five National Marine Park was utilized as a study area. Fathom Five is a 114 km^2 freshwater protected area located centrally in the Laurentian Great Lakes on Lake Huron, Ontario, Canada (Figure 3.1). It was established in 1972 as a provincial park and later in 1987 became the first site to be under the stewardship of Parks Canada's national marine conservation area (NMCA) program (Yurick 2010). Consistent with global conservation objectives, the aim of the NMCA program is to establish a comprehensive and representative system of marine protected areas that includes the Great Lakes (Canada 2002). Naturally, success depends not only on location and configuration of sites, but also on the effectiveness of management practices such as zoning. Zoning is a spatial planning process that attempts to ameliorate and communicate protection and human-use objectives. The NMCA Act states that "*each marine conservation area shall be divided into zones, which must include at least one zone that fosters and encourages ecologically sustainable use of marine resources and at least one zone that fully protects special features or sensitive elements of ecosystems, and may include other types of zones*" (Subsection 4(4), Canada 2002).

Key to zoning for resilience are concepts of representativeness, replication, and connectivity by protecting variant portfolios of ecosystem structure and function, reducing human-induced disturbances, and establishing refuge areas for exploited species (CCSP 2008; IUCN WCPA 2008). Within the current zoning plan for Fathom Five there are no zones that fully protect aquatic ecosystems (Parks Canada 1998). Therefore, this review is not only an opportunity to improve the current zoning plan in terms of the NMCA Act, but also offers a means to strengthen resilience of a desired state within a changing and novel ecosystem context.

Methods

There are numerous geospatial decision-support tools available for systematic conservation planning and zoning (e.g., see Ecosystem-Based Management Tools Network, www.ebmtools.org) and one of the most widely used is Marxan (Ball et al. 2009) and its

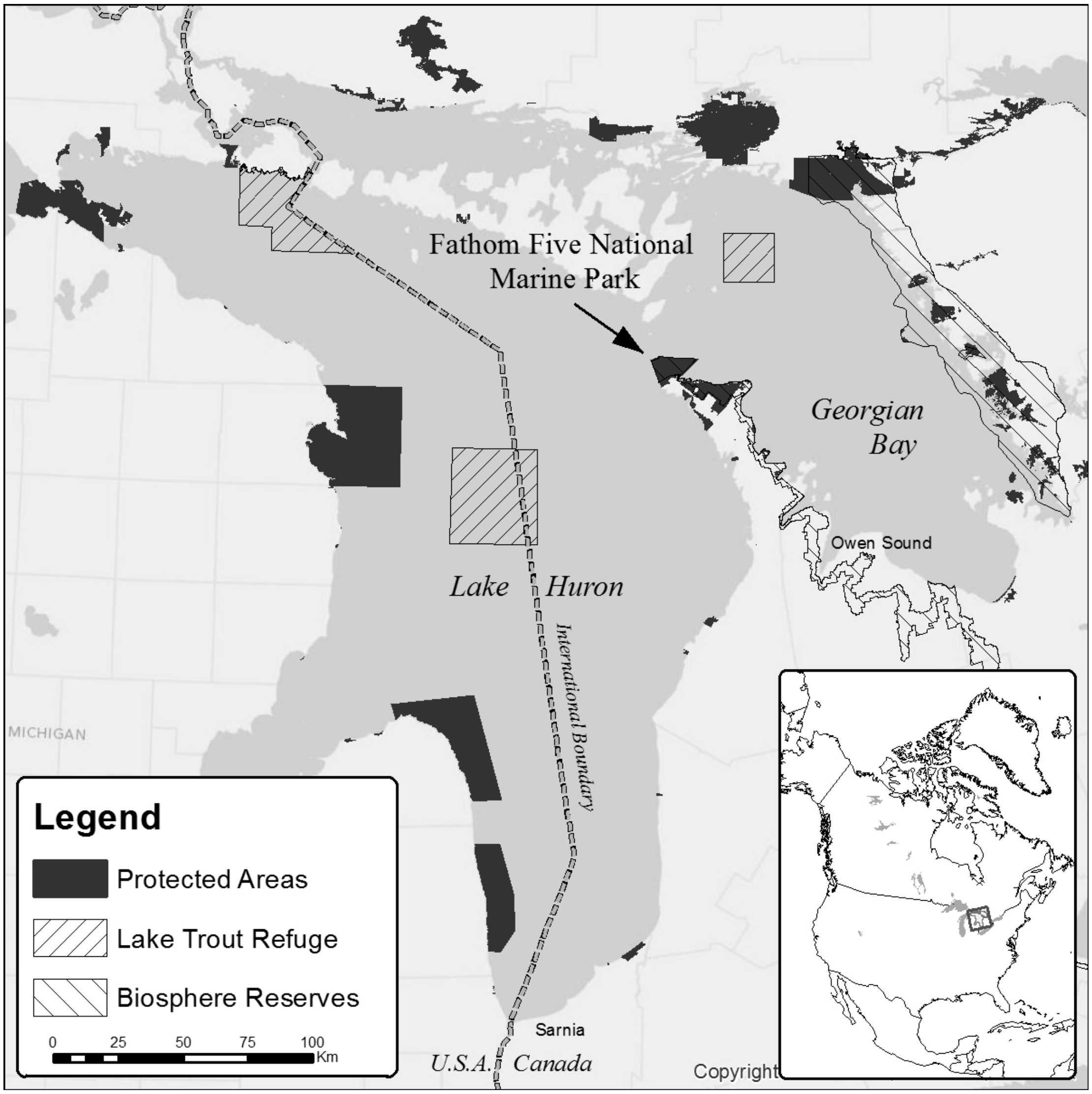

Figure 3.1 Fathom Five's location and regional protected area context

extension Marxan with Zones (Watts et al. 2009). This software has guided numerous high profile projects, including the rezoning of Australia's Great Barrier Reef (Fernandes et al. 2005) and California's central coast (Klein et al. 2009). Marxan employs a complementarity-based algorithm to solve the minimum-set problem using simulated annealing (Kirkpatrick 1983). Essentially, the algorithm systematically selects different combinations of planning units to achieve the target objectives while minimizing associated costs. Each run of Marxan produces a different solution and typically the "best solution" across multiple runs and a "selection frequency" for each planning unit is used to communicate results (Ball et al. 2009).

To produce efficient, compact, and logical results Marxan parameters require calibration (Watts et al. 2008a; Watts et al. 2008b). To influence connectivity, clustering, and "nesting" of zones, the zone boundary cost and feature penalty factor were tested and manipulated. For the final analysis: 1 hectare hexagonal planning units were utilized; 100 runs with 1 million iterations were completed; zone boundary cost was set to 1.0; and, feature penalty factor was set to 1.25.

To aid in the selection of resilience-based conservation features, targets, and costs, a description and assessment of Fathom Five was completed guided by the Resilience Alliance practitioners workbook (Resilience Alliance 2010). This conceptualization and analysis brought forward important aspects of resilience, including:

- Identification of the essential structures, functions, and feedbacks that define the desired state;
- Recognition of elements that guide system recovery, including connectivity, sources of replicates, and functional diversities;
- Disturbance regimes and cross-scale influences;
- Governance structures, ownership, and other potential constraints; and,
- Patterns of visitor use.

As organized in Table 3.1, conservation features were grouped into the three general themes of ecosystem structure, ecosystem function, and social structure. The Table also identifies the data layers used and their source; several of which are original to this study (for details see the supplementary information in Appendix 2). The three zone scheme was based on NMCA policy (Parks Canada 1994)(Table 3.2). Target values represent the amount of each conservation feature to be found within the respective zones in the final solution and were assigned subjectively[2]. General guidance was provided by other studies and best practices which recommend 20-30% Zone 1 type protection (Roberts et al. 2003; Fernandes et al. 2005; Ardron et al. 2010).

[2] The original intent of the study was to complete the conservation feature identification and valuation as part of the official park management plan review. Unfortunately the planning process stopped and was deferred until a future year. As a result, features and values were assigned by consulting a small group of park staff instead, and the process was treated as a "proof of concept".

Table 3.1 Marxan inputs, including conservation features, cost layers, and zoning target values.

Conservation Feature		Area (km^2)	Zone (%)			Data Source
			1	2	3	
Ecosystem Structure						
Benthic Structure	Boulder/Rock; High Complexity; 0-30m	1.70	20	30		Multibeam sonar collected between 2002 and 2007 using a Kongsberg-Simrad EM 3002 system. Backscatter layer separated into 3 composition classes using principal component analysis and Kruskal-Wallis rank sum test and validated by lakebed video and sediment samples. Complexity modelled within ArcGIS (www.esri.com) utilizing the bathymetric layers. Where multibeam sonar coverage was absent (e.g., < 2m depth), lower resolution bottom type and bathymetric data found on Canadian Hydrographic Service Chart 2274 and 2235 was used.
	Boulder/Rock; High Complexity; 30-182m	0.90	10	30		
	Boulder/Rock; Low Complexity; 0-30m	12.20		30		
	Boulder/Rock; Low Complexity; 30-182m	3.00		30		
	Boulder/Rock; Moderate Complexity; 0-30m	20.40		30		
	Boulder/Rock; Moderate Complexity; 30-182m	5.20		30		
	Gravel/Clay; High Complexity; 0-30m	1.60	10	30		
	Gravel/Clay; High Complexity; 30-182m	0.35	20	30		
	Gravel/Clay; Low Complexity; 0-30m	6.70		30		
	Gravel/Clay; Low Complexity; 30-182m	3.30		30		
	Gravel/Clay; Moderate Complexity; 0-30m	12.40		30		
	Gravel/Clay; Moderate Complexity; 30-182m	5.70		30		
	Sand/Silt; High Complexity; 0-30m	0.64	10	30		
	Sand/Silt; High Complexity; 30-182m	0.07	20	30		
	Sand/Silt; Low Complexity; 0-30m	3.30		30		
	Sand/Silt; Low Complexity; 30-182m	5.20		30		
	Sand/Silt; Moderate Complexity; 0-30m	8.20		30		
	Sand/Silt; Moderate Complexity; 30-182m	7.30		30		
Pelagic Structure	Deepwater Ecosystem >50m	10.50	30			Mainly classified using bathymetry and Bennett (1988). Ice coverage determined using maximum mean ice coverage between 1973-2002 from Assel (2003).
	Major Upwelling Areas	0.90	10	30		
	Main Currents	29.8		10		
	30 - 45 days > 90% Ice Cover	34.80		30		
	45 - 60 days > 90% Ice Cover	63.50				
Coastal Structure	Lake Fluctuation Zone (175.6-177.4m ASL)	3.30	30	10		Shoreline classification by Environment Canada (1994). Lake level fluctuations based on historic monthly mean minimum and maximum water level values from 1918-2010 (CHS 2011). Shoreline complexity and exposure modelled using fractal dimension and fetch models (USGS 2008) respectively within ArcGIS.
	Low Shoreline Complexity	0.20				
	Medium Shoreline Complexity	7.00		10		
	High Shoreline Complexity	0.80		30		
	Protected Shoreline Exposure	3.30	30	20		
	Semi-Protected Shoreline Exposure	2.00		20		
	Semi-Exposed Shoreline Exposure	2.20		20		
	Exposed Shoreline Exposure	2.00				
	Boulder Beach	0.96		30		
	Broad Wetland	0.26	10	30		
	Cobble Beach	0.69		30		
	Exposed Bedrock Bluff 1-5m elevation	1.10		30		
	Exposed Bedrock Bluff > 5m elevation	0.90		30		
	Exposed Bedrock Bluff < 1m elevation	1.00		30		
	Fringing Wetland	0.80	20	30		
	Low Vegetated Bank	0.60		30		
	Pebble/Cobble Beach	0.04		30		
	Retaining Wall/Harbour Structure	0.05				
	Rip Rap	0.01				
	Shelving Bedrock	2.30		30		
Ecosystem Function						
Nutrient and Energy Flow	Littoral with Macrophytes (Coastal Wetlands)	0.74	30	70		Habitat maps modelled with DOMAIN (Carpenter et al. 1993) using species occurrence data, water depth, rugosity, and slope. Smallmouth bass and *Diporeia* spp. habitat classified using benthic structure and occurrence data. Chlorophyll derived from SeaWiFS (NASA 2011) using mean of 5 samples for April-June from 1999-2009.
	Diporeia spp. Habitat	22.00	30			
	Lake Herring (*Coregonus artedi*) Habitat	38.00	20	10		
	Lake Whitefish (*Coregonus clupeaformis*) Habitat	36.00	20	10		
	Deepwater Cisco (*Coregonus* spp.) Habitat	8.60	50	10		
	Smallmouth Bass (*Micropterus dolomite*) Habitat	14.80	30	10		
	Burbot (*Lota lota*) Habitat	41.50	20	10		
	Lake Trout (*Salvelinus namaycush*) Habitat	59.30	20	10		
	High Concentrations Lake Surface Chlorophyll	10.97		30		
Spawning/ Breeding Areas	Lake Trout and Lake Whitefish Spawning	15.20	50	50		Spawning shoals from Goodyear et al. (1992). Littoral areas physically surveyed. Colonies confirmed active (2005-2011).
	Littoral Protected Waters	1.29		30		
	Waterbird Colonies	0.17	100			
Social Structure						
Visitor Use	Visitor Nodes (popular day use and anchorage)	1.37			100	Park staff confirmed.
Cost Layers						
Developed	Density of Coastal Human Infrastructure	0.99				Digitized from 2006 airphoto series.
Shipping	Established Vessel Traffic Lanes	16.30				Park staff confirmed.
Fisheries	Established Fishing Areas	23.60				Beak Consultants (1990) and local knowledge.
Governance	Legislative Landscape	1.8				Park staff confirmed.

Table 3.2 An adaption of the 3 zone system described by NMCA policy (Parks Canada 1994).

Zone	Objective
Zone 1 Preservation	Recognizes the importance of protecting key representative features or areas, and of the vulnerability of some features and areas. • Protect: ecosystem structure and function; best or unique examples of representative species, ecosystems and features; areas deemed critical for species at risk; and, significant cultural resources. • Facilitate visitor experience and learning opportunities with recognition of the area or features sensitivities. • Resource harvesting not permitted.
Zone 2 Natural Environment	Recognizes that some species, areas and features are more sensitive than others. • Support protection of Zone 1 areas and representative species, ecosystems and features. • Provide limited ecologically sustainable uses that maintain ecosystem structure and function. • Support meaningful visitor experience and learning opportunities through access, service, and facilities. • Provide economic, social, and cultural benefits.
Zone 3 Conservation	Recognizes the social, cultural, and economic contribution and benefits of a protected area. • Provides a broad spectrum of ecologically sustainable uses. • Supports meaningful visitor experience and learning opportunities. • Provide economic, social, and cultural benefits. • Resource harvesting permitted in a manner consistent with maintaining ecosystem structure and function.

As a guideline, structures and functions which would contribute to a more desirable offshore ecosystem with improved benthic to pelagic energy pathways (Table 3.3) were focussed on. With respect to coastal areas, the focus was on resilience of coastal wetlands by maintaining biodiversity and connectivity to assist in post-disturbance recovery (e.g., low lake levels, hazardous spills) and by increasing resistance to invasive species.

Results

After 100 runs, the "best solution" was evaluated and found to be sufficiently close to achieving the conservation targets (Figure 3.2). Eighteen of the 22 layers with Zone 1 targets, 26 of the 47 layers with Zone 2 targets, and all Zone 3 targets were met. "Littoral with Macrophytes" fell short by 27% for Zone 1 and 16% for Zone 2. "Protected Shoreline Exposure" fell short by 68% for Zone 1 and 42% for Zone 2. "Broad Wetland" was not captured by Zone 1 and "Lake

Table 3.3 Zoning considerations to maintain or build a resilient desired state in Fathom Five.

Subsystem	Current State	Resilience to	Zoning Considerations
Offshore	• Dramatic reductions in phosphorus, plankton, and benthos (e.g., *Diporeia* spp.) coincident with invasive dreissenid mussel colonization (Barbiero et al. 2012) . Fish community change, notable reductions in prey fish (including non-native alewife), lake trout, and deepwater cisco populations (Warner et al. 2009). • **Transitioning to a resilient and less desired state.**	• Changing food web structures and energy and nutrient pathways. • Invasive species. • Unsustainable fisheries practices.	• Mitigate risk by protecting replicates of representative species, habitats, and structures. • Protect critical areas that serve as sources for ecological function (e.g., spawning and nursery refuges). • Protect and restore keystone predators (e.g., lake trout). • Use zones to communicate conservation priorities.
Coastal	• Natural cover along shoreline is high (i.e., minimal development on islands, mainland >80% natural within 100 m of shore). • Coastal wetland fish and water quality rate as good for years 2005-2011, although evidence of greater disturbance along mainland observed (Parks Canada 2011). Overall downward trend in lake levels since mid-1990s • **Resilient and desired state.**	• Climate change driven alterations in lake level fluctuations and water temperature. • Anthropogenic nutrient and silt inputs. • Invasive species. • Cumulative impacts from coastal development.	• Protect replicates of representative species, habitat, and structures. • Protect critical areas that serve as sources for ecological function (e.g., wetlands). • Maintain connectivity between wetlands under various lake level scenarios. • Support sympathetic land-use. • Identify and protect structures/functions that limit invasive species colonization.
Governance	• Transfer of ownership to Parks Canada has not occurred. • Site lacks authority and inclusion in key decision-making processes, including fisheries management. • Minimal engagement in regional governance and networks. • **Resilient and less desired state.**	• A lack of legitimacy, accountability, flexibility, and connectivity.	• Treat zoning as an adaptive management project with social learning elements. • Integrate with regional plans and partners including First Nations, other government departments and civil societies.

Fluctuation Zone" fell short by 30% for Zone 1. The remaining Zone 2 target short falls were marginal and related mostly to classes of lakebed and coastal structure. Some of the short falls in Zone 1 and 2 areas appear to be related to locked-in planning units containing visitor nodes designated to Zone 3 exclusively. A "Summed Solution" was also generated (Figure 3.3). This represents planning units which were allocated to a specific zone >50% of the time during the 100 runs.

Discussion

Marxan Inputs

The integration of multibeam sonar backscatter, bathymetry, sediment samples, and lakebed video was effective at classifying the lakebed. Multibeam sonar coverage significantly improved the resolution of lakebed bathymetry by approximately 10 times, resulting in 0.5 to 2 m^2 pixel resolution, depending on water depth. Coastal waters proved more difficult to classify since multibeam sonar data collection was restricted by vessel draught (i.e., no data <2m) and the shallows are generally served by two independent mapping traditions, hydrographic charts and topographic maps. These unfortunately did not provide a seamless or consistent interface between aquatic and terrestrial features and layers. With respect to coastal structure the Environmental Sensitivity Atlas (Environment Canada 1994) provided sufficient detail on morphology. Similarly, NOAA's ice data (Assel 2003) provided sufficient detail on ice coverage patterns. More detailed spatial knowledge of water movements and its influence on colonization, productivity, and thermal stress would have been beneficial.

The cost layer was perhaps a bit simplistic and more meaningful results could be generated if quantitative and spatial data was available on cultural and socioeconomic values. For instance, it was recognized that the commercial fishing data may not reflect the efforts and values of the Saugeen Ojibway Nations fishery and that a more informed process would be beneficial. As an example, extensive interviews were completed with commercial operators to collect georeferenced information about the extent and relative importance of fisheries as part of California's central coast Marxan-based zoning initiative (Scholz et al. 2006; Klein et al. 2009).

The target values reflected an understanding of resilience goals for the site and were subjectively assigned. It is recognized that future iterations will benefit from a broader discussion of these target values and alternative layers (e.g., species/area relationships, population viability analysis).

Connectivity was adjusted to minimize fragmentation by calibrating the zone boundary cost following Watts et al.(2008b) and by and using a hexagon rather than a square planning unit (Lötter et al. 2010). As an option, a habitat feature (e.g., coastal wetland complex, spawning shoals) could potentially be classified as a single planning unit and not split by zoning (Fernandes et al. 2005). This level of differentiation of a given habitat feature or the use of species-specific connectivity requirements (e.g., Bouvier et al. 2009; Olds et al. 2012) was considered to have merit, but not utilized in the analysis because of data limitations.

Marxan Outputs

Currently, there are no fish refuges (e.g., Zone 1) in Fathom Five and lake trout rehabilitation efforts have met with limited success (OMNR 2010). The benefits of a highly protected area that excludes fishing (Zone 1) is widely demonstrated (e.g., Lester et al. 2009) and includes examples from Lake Huron (Hedges et al. 2010). In the results, areas of Zone 1 to the west coincide with historic spawning habitat for lake trout. Reid et al. (2001) suggest that with complementary stocking, regulations and other management actions, a smaller refuge can have a positive effect on lake trout recovery. The deepwater (50-90 m) ecosystem to the east was also classified as a Zone 1. The extinction of three deepwater cisco species, a decline in lake trout and *Diporeia* spp. and an increase in dreissenid mussels, all contribute to the transformation of the offshore ecosystem to a new and novel state (Roseman et al. 2009; Barbiero et al. 2012). In navigating this transition, the re-establishment of a lake trout-cisco community, however challenging (see: Zimmerman and Krueger 2009), would improve resilience by improving the energy and nutrient flow from the benthic to pelagic realm. Zoning efforts that reduce vulnerability (e.g., protect species and habitat) would be beneficial.

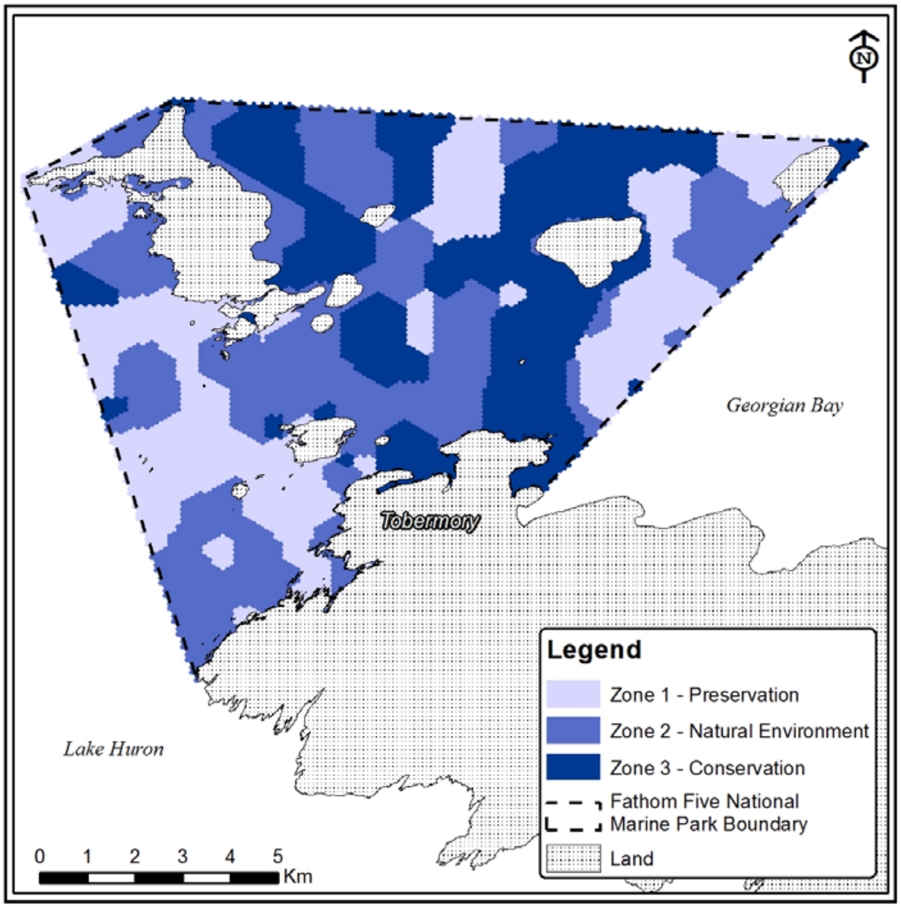

Figure 3.2 An example "best solution" output from Marxan with Zones for Fathom Five.

Coastal areas along the western mainland are generally classified as Zone 1 or 2. Connectivity between coastal wetlands within the large bays appears to be maintained. Coincidently, these areas are also vulnerable to adjacent residential land use practices including failing septic systems and shoreline (e.g., 2.2% annual increase of in-water development since 1966). In addition to zoning, other interventions (e.g., education, financial, and governance) for managing coastal development are necessary. Connectivity between island and mainland coastal wetlands also appears to be maintained through zoning, but in reality the large expanse of colder open water presents a hydrological barrier to many coastal fish species (Leslie and Timmins 2001).

The lake fluctuation zone and coastal wetlands, as examples, were classified uniformly, however the possibility to classify specific planning units according to probability of persistence (e.g., to extreme water level reductions) could be considered (Game et al. 2008).

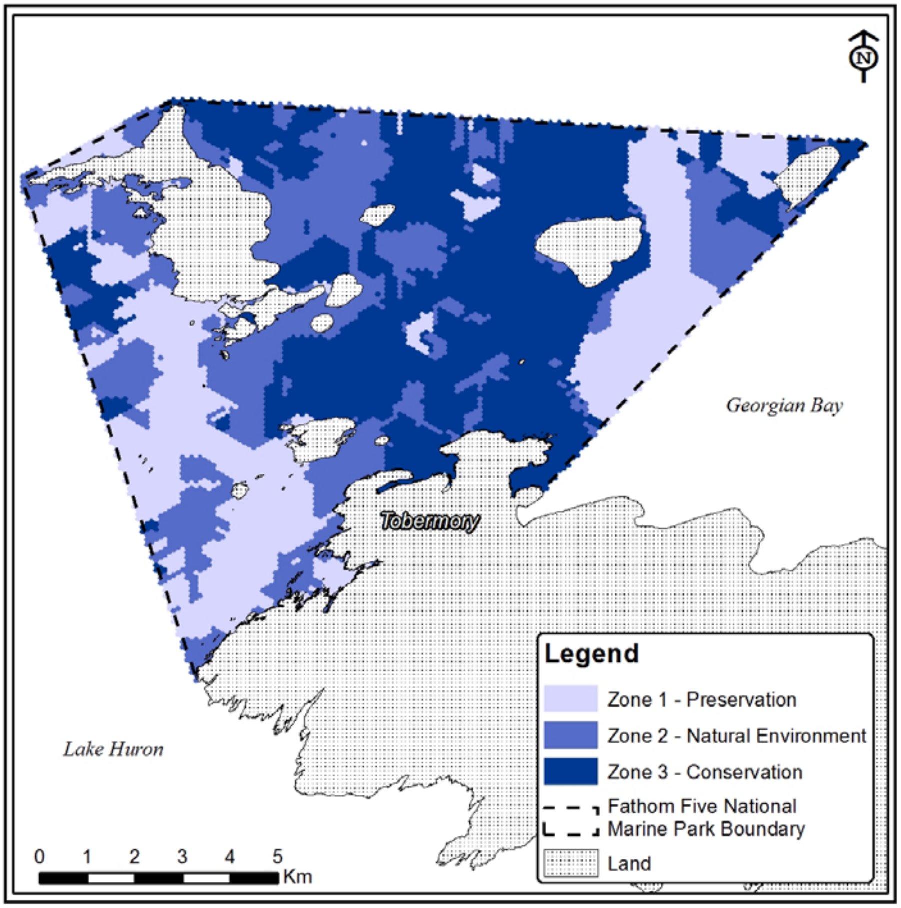

Figure 3.3 An example "50% summed solution" output from Marxan with Zones for Fathom Five. This represents the number of times a planning unit was selected at least 50% of the time in 100 runs.

While the outputs from Marxan provide decision-support, the best solution is not necessarily the most suitable. The other solutions can be drawn upon to make informed decisions or better understand zoning patterns. For instance, the "summed solution" (Figure 3.3) highlights areas frequently selected and because of this is often referred to as a summed irreplaceablity layer (Ball et al. 2009). More recently, Linke et al. (2011) demonstrated a method to create a "portfolio of very good solutions" for planning considerations based on similarity analysis. Regardless of the Marxan solution used, the final zoning map may require some tradeoffs and modifications to be made operational. General guidelines include: buffer Zone 1 with a Zone 2; keep the layout as simple as practical; and, utilize recognizable bathymetric contours, landmarks or lines of longitude and latitude, especially where legal descriptions are important (Day 2002) (see Figure 3.4).

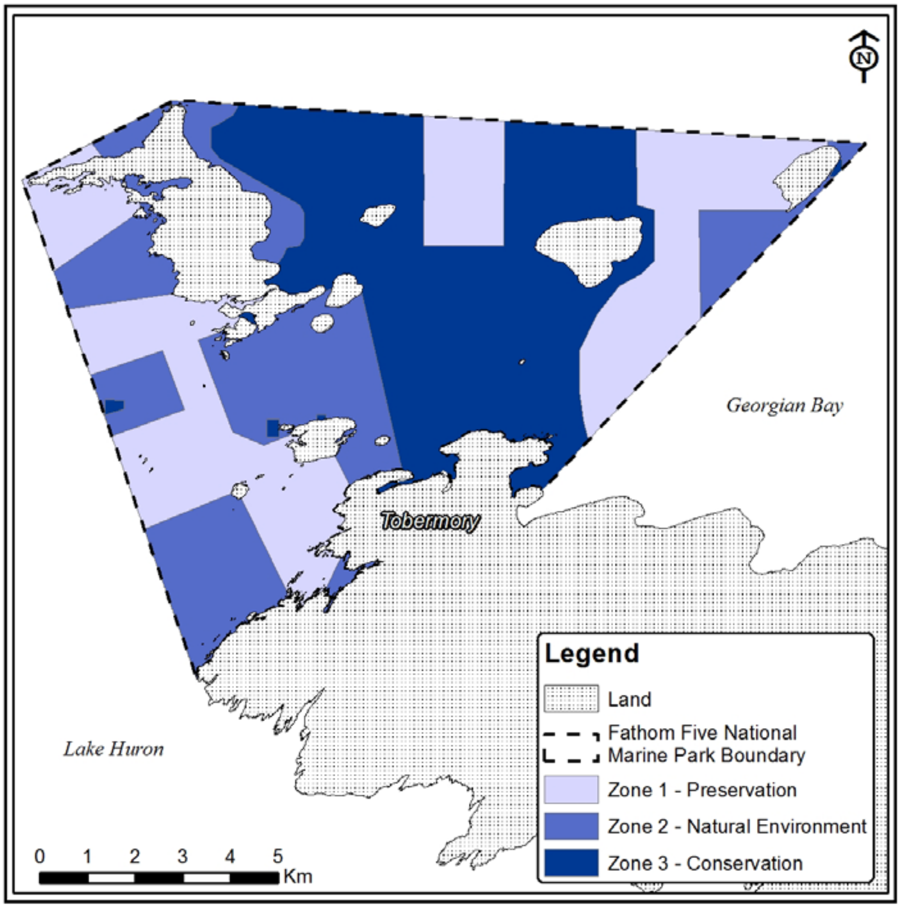

Figure 3.4 An example of an operational zoning strategy adapted from Marxan outputs. Simplified for legal description and visitor needs, e.g., use headlands, lines of latitude/longitude, and bathymetry.

Resilience Considerations

Incorporating resilience attributes such as representativeness, replication, and connectivity within a zoning decision-support tool does not necessarily confer resilience. Uncertainty and capacity to manage can hinder the effectiveness of the planning decisions. Therefore, to be successful zoning needs to be part of an active learning and adaptation process (sensu Holling 1978). To this end, Kingsford et al. (2011) provide a potentially useful framework described as “strategic adaptive management”. Similarly their approach is concerned with freshwater protected areas and starts by describing the desired state. Management actions are then built into their framework as explicit predictions and are subsequently evaluated and adjusted in an iterative manner. In this example, the quantitative conservation zoning targets coupled with explicitly stated desired state objectives, could serve as a prediction to be tested. The results could support a social learning process which would be most effective for the actors involved and the governance context (Fazey et al. 2007; Grantham et al. 2010).

Given the social, economic, ecological and political consequences associated with zoning, public and partner inclusion is essential for successful implementation. It is considered good practice when using Marxan to engage diverse interests and perspectives, including independent scientists, local residents, Aboriginal people, regional governments and non-governmental organizations, in the planning and review process (Ardron et al. 2010). This can create conditions for social learning and building trust, and underpins good governance, which is essential to the successful implementation of a resilience-based approach (Folke et al. 2005; Lebel et al. 2006).

Feedback from larger scales can either reinforce or undermine resilience. It is recommended that a similar zoning exercise be completed for the greater park ecosystem (e.g., waters around Bruce Peninsula to Manitoulin Island) and Lake Huron scales. This could provide a framework for regional governance and network establishment. The 2009 World Ocean Conference declared the need to further the establishment of “representative resilient” marine protected area networks (World Ocean Conference 2009) and a similar need exists for freshwater ecosystems. A network is not simply a collection of protected areas. It implies some interconnection to facilitate the movement of species or other values to collectively achieve a conservation goal (IUCN WCPA

2008). The interconnection of coastal wetlands or spawning shoals or the establishment of networks to facilitate learning and governance would be particularly relevant in the region of Fathom Five. As well the larger scale analysis could assist Parks Canada in its efforts to establish a NMCA in Lake Huron and make Fathom Five more representative of the Georgian Bay marine region (Mercier and Mondor 1995). Working on larger scales will require harmonization of policies and practices (e.g., data standards).

Conclusion

C.S. Holling's (1973) seminal work on resilience characterized several events of ecosystem change in the Great Lakes. When ecological resilience decreased the lakes became more vulnerable to disturbance and a sudden transition in state. Today the lakes continue to be affected in complex and novel ways because of invasive species, climate change, and other human-induced stresses (SOLEC 2009). It is a context that is particularly problematic for protected areas including Fathom Five National Marine Park.

A resilience-based approach to zoning, including the use of the Resilience Alliance (2010) workbook and Marxan with Zones (Watts et al. 2008a), provided an opportunity to better understand the complexities and uncertainties facing Fathom Five. Zoning was able to focus on the persistence of key structures and functions in terms of representativeness, replication, and connectivity (e.g., to spread the risk associated with disturbance, establish sources of "seed" to assist in system recovery, etc. (Chapin et al. 2010)). The approach also promotes the importance of learning and adaptation. Although many of the study elements are not restricted to the domain of resilience, the resilience lens provided new insight on the context and challenge ahead.

Chapter 4. Development of a control chart to monitor resilience in the coastal wetlands of Fathom Five National Marine Park, Lake Huron, Canada

Overview

A resilient coastal wetland recovers from disturbance by retaining its defining structures, functions, and feedbacks, in other words, identity. Methods to monitor a loss of resilience and eventual change in identity, termed a regime shift, have been difficult to develop, yet are essential to either prevent or actively navigate such a change. The management goals for Fathom Five National Marine Park, Lake Huron, include the protection and conservation of its coastal wetlands. To further management effectiveness, a resilience-based approach to monitor these ecosystems was developed. By means of a multivariate distance-based control chart, the variability of fish assemblages in eight coastal wetlands over an eight year period (2005-2012) was monitored and assessed. As others have reported, ecosystem behaviour becomes more variable when resilience begins to weaken and a regime shift is pending. A control chart is a statistical method that identifies when a site may be "out of control". Based on the distance to a mean centroid baseline, the control chart identified occasions when variance in three of the park's wetlands deviated more than expected, i.e., distance exceeded the 95% confidence limit. To explain the exceedances, an ordination of fish assemblages was completed using principal components analysis (PCA) and redundancy analysis (RDA). Colonization by the invasive round goby (*Neogobius melanostomus*) and the prolonged period of low lake levels and stranding was discussed as possibile explanations for the exceedances. As concluded, the monitoring method was able to provide valuable insight on wetland condition and ecological resilience.

Introduction

Within protected areas, managing for ecosystem resilience is increasingly being cited as a goal to address the contemporary challenges and uncertainties caused by human activity (e.g., Pittock et al. 2008; Baron et al. 2009; Lemieux et al. 2011). Resilience is an ecosystem property that describes the capacity to cope with disturbance yet remain within the same regime, essentially retaining defining structures, functions, and feedbacks, in other words, retain its identity (Walker and Salt 2012). Ecosystems are, however, complex, adaptive systems characterized by nonlinearity, multiple basins of attraction (regimes), and threshold-effects (Levin 1999). Differentiating natural variability within a regime relative to a critical level that may force a shift to another regime is a major challenge, especially in the context of making timely and effective management decisions (Biggs et al. 2009; Contamin and Ellison 2009; Dakos et al. 2012).

To help overcome this, investigations have revealed that as resilience decreases, stabilizing feedbacks in an ecosystem are weakened causing system dynamics to change and fluctuate more than expected (Walker and Salt 2012). Examples of such indicators include: an increase in variance; change in skewness; rise in autocorrelation; and, a decrease in return rates (e.g., Carpenter and Brock 2006; Biggs et al. 2009; Chisholm and Filotas 2009; Guttal and Jayaprakash 2009; Scheffer et al. 2009; Dakos et al. 2011). However, bridging the theory with what is practical, including empirical testing of real world datasets, still remains as an important need and challenge (Thrush et al. 2009).

Fathom Five National Marine Park is a 114 km^2 protected area located in Lake Huron-Georgian Bay at the tip of the Bruce Peninsula, Ontario, Canada. Established in 1987, it is the first site to be under the stewardship of Parks Canada's national marine conservation area (NMCA) program (Yurick 2010). According to the NMCA Act, it ... "*shall be managed and used in a sustainable manner that meets the needs of present and future generations without compromising the structure and function of the ecosystems*" (Sec. 4(3), Canada 2002). It is in this context that a resilience-based approach was selected for detecting change in variability and a possible regime shift in the parks coastal wetlands.

Coastal wetlands are dynamic ecosystems, adapted to seasonal and yearly variations in lake levels (e.g., approx. 30 cm seasonal and >1.5 m decadal) (Wilcox et al. 2007). Resilience is maintained through functional and response diversity of species and seed banks (Chapin et al. 2010). These wetlands provide valued ecosystem services (Sierszen et al. 2012), including resident habitat for many fish species, as well as spawning and nursery habitat for 80% of the Great Lake fishes (Jude and Pappas 1992; Chow-Fraser and Albert 1999). They are also under considerable stress. For instance, since European settlement it is estimated that less than 30% of the Great Lake wetland fish habitat remains (Smith et al. 1991; Jude and Pappas 1992).

The coastal wetlands of Fathom Five are generally considered to be in good condition, characterized by clear, oligotrophic water, with a rich assemblage of turbidity intolerant fish species (e.g., brook stickleback (*Culaea inconstans*), blackchin shiner (*Notropis heterodon*)) (Trebitz et al. 2007; Cvetkovic and Chow-Fraser 2011). Although they are recognized as naturally dynamic systems, there is a concern that new or novel stresses may further challenge their ability to be managed towards a resilient, desired state. For example, increased nutrient runoff from residential waste water systems and fertilizers, siltation from land alteration and drainage, and non-native carp feeding, contribute to an increase in turbidity. This may lead to a regime shift characterized by turbidity tolerant fishes (e.g., common carp (*Cyprinus carpio*), spottail shiner (*Notropis hudsonius*)) (Trebitz et al. 2007) and high algal biomass (Chow-Fraser 2006). As well, aquatic invasive species, such as common reed (*Phragmites australis*), Eurasian watermilfoil (*Myriophyllum spicatum*), and round goby (*Neogobius melanostomus*), have known and unknown impacts to system resilience, including a change in structure and function through exclusion of native species (Trebitz and Taylor 2007; Kornis et al. 2012). As a final example, the majority of climate change models suggest an overall decline in lake levels, increased water-surface temperature and decreased ice cover (Mortsch et al. 2006; Sellinger et al. 2008; Angel and Kunkel 2010; Hanrahan et al. 2010). This change in hydrology will affect the distribution, structure and function of coastal wetlands, including fish (Mortsch et al. 2006; Ficke et al. 2007) and plant communities (Wilcox and Jerrine Nichols 2008).

From 2005 to 2012, coastal wetlands in Fathom Five have been monitored[3] following methods developed by McMaster University's Coastal Wetland Research Group (CWRG), including the wetland fish index (Seilheimer and Chow-Fraser 2007), water quality index (Chow-Fraser 2006), and macrophyte index (Croft and Chow-Fraser 2007). The indicators are well correlated with each other and have provided the park with an effective method to evaluate the "state of" its wetlands relative to others in the Great Lakes (Parks Canada 2011). The Great Lakes Coastal Wetland Consortium has also developed a suite of indicators by which to monitor coastal wetlands (Burton et al. 2008). Methods from both groups have become widely established and are routinely used to assess the health or integrity of Great Lake coastal wetlands (e.g., SOLEC 2009; Cvetkovic and Chow-Fraser 2011). This study is not a critique of these assessment

[3] Project led by S. Parker.

methods; rather, it is simply a re-analysis of the monitoring results through a resilience lens. Instead of reporting that an index value had changed class, the intent of this study was to find a leading indicator of change. That is, to detect an increase in variability as an indicator of weakening feedbacks and a possible decrease in resilience.

Univariate control charts were originally developed for industrial applications and involved plotting a measure of a stochastic process to its expected value through time and within control limits of 2 or 3 standard deviations from the mean (Montgomery 2012). A measure exceeding its expected value indicated that something in the system was “out of control”. There are only a few examples of control charts used to monitor ecological change (e.g., Pettersson 1998; Anderson and Thompson 2004; McGinty et al. 2012) and, given the inherent complexity of ecosystems, they tend to rely on a multivariate analogue. As introduced by Anderson and Thompson (2004), a multivariate observation (e.g., species assemblage at a given site-time) can be described in multivariate space and these observations would be expected to remain “in control” while moving stochastically around a central value through time. Following this method, multivariate data are reduced by a similarity coefficient (e.g., Euclidean distance) or ordination technique, and the distance change in multivariate space to the central value is measured and monitored for exceedances (i.e., distance greater than expected from an established baseline).

To monitor resilience in Fathom Five, a distance-based multivariate control chart method (Anderson and Thompson 2004) and eight years of data (2005-2012) from eight coastal wetlands was utilized. Additional ordination techniques were employed to interpret the control chart outputs and explore environmental influences and patterns of ecological change.

Methods

Study Sites

Water quality, aquatic plant, and fish data were collected from eight coastal wetlands in Fathom Five. Four sites were located on islands and four on the mainland (Table 4.1, Figure 4.1). Sites were selected in 2005 in collaboration with McMaster University's CWRG (related projects include, Croft and Chow-Fraser 2007; Wei and Chow-Fraser 2007; Cvetkovic and Chow-Fraser 2011). With the exception of Bass Bay on Cove Island, which was excluded for logistical reasons (i.e., difficult to access), all the major wetland complexes in the park were represented by the study.

Field Sampling

Water and fish sampling were conducted once annually at each of the eight wetlands between the last week of June and mid-July from 2005 to 2012, with the exception of HBW in 2005, which was not sampled (therefore, n=63 samples). The same gear and locations were used each year. Water samples were collected within the wetland and at least 10 m from the edge of emergent aquatic vegetation and, where necessary, in the deepest area with the least amount of submergent aquatic vegetation. Water temperature, specific conductivity, pH, and dissolved oxygen concentrations were measured *in situ* using a calibrated YSI 600QS multi-parameter probe (YSI, Yellow Springs, OH) at a depth of 50 cm. Turbidity was measured *in situ* using a Hach 2100P portable turbidimeter (Hach, Loveland, CO) from a sample collected at a depth of 50 cm. A 1-L Van Dorn horizontal type beta sampler was deployed to 50 cm depth and dispensed into laboratory supplied and cleaned bottles for total nitrogen, total phosphorous, major ions, metals, and chlorophyll *a* analysis. Samples were shipped to and analyzed by the National Laboratory for Environmental Testing (Environment Canada, Burlington, ON). A water quality index (WQI) value (Chow-Fraser 2006) was calculated for 6 parameters (i.e., WQI 6 = turbidity, conductivity, temperature, pH, total phosphorus, and total nitrogen) and 7 parameters (WQI 7 = WQI 6 plus chlorophyll *a*) at each site.

To survey the fish community, three paired fyke nets (two large pairs with 13 mm and 4 mm mesh, 4.25 m in length, 1 m X 1.25 m front opening and one small pair with 4 mm mesh, 2.1 m length and 0.5 m X 1.0 m front opening) were set parallel to the shoreline or emergent zone in water approximately 1 to 0.5 m depth so that the opening was just above the water level. The paired nets were positioned to face each other and were connected with a 7 m (4 mm mesh) lead and 2.5 m (4 mm mesh) wings were set at a 45° angle to the opening. Nets were set in an area of submergent vegetation. After 24 hours, fish captured were identified to species (n=38 species of fish), enumerated, and minimum and maximum total lengths for each species were recorded. The fish were released at the site. Fish data were pooled from the three paired fyke nets at each site.

Table 4.1 Coastal wetland site descriptions.

Site Code	Site Name	Type	Potential Stranding	Vegetation Density			Human Impact
				Submergent	Emergent	Floating	
CN	Cove Island North	Island	Yes	High	Low	Low	None
BP	Boat Passage	Island	No	High	Moderate	Low	None
RUW	Russel Island West	Island	Yes	High	High	Low	None
RUE	Russel Island East	Island	Yes	Low	Low	None	None
HBE	Hay Bay East	Mainland	No	High	Moderate	High	High
HBW	Hay Bay West	Mainland	No	High	High	Moderate	Moderate
HBS	Hay Bay South	Mainland	Yes	High	Moderate	Moderate	Moderate
BT	Big Tub Harbour	Mainland	No	Low	Low	none	High

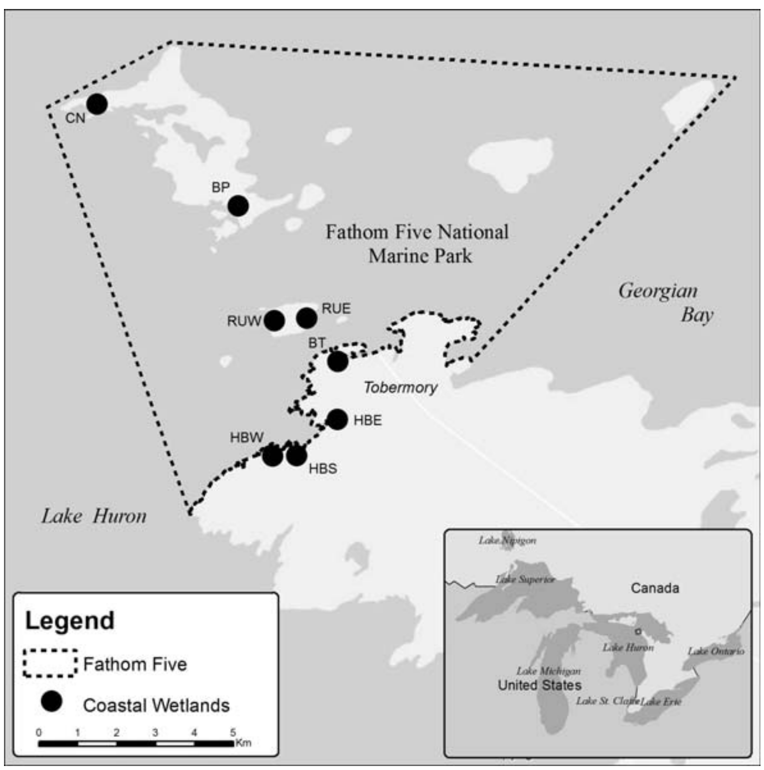

Figure 4.1 Location of Fathom Five National Marine Park and the coastal wetlands used in this study. Site codes on Table 4.1.

In August, an annual aquatic plant inventory was conducted at each of the water and fish sample sites. The inventory was completed by purposefully wandering throughout the study area below the water's edge (n=32 macrophyte species). Water clarity was such that submergent aquatic vegetation could be identified from the surface; however, an underwater viewing tube and weighted rake were used to aid in identification and collection when needed. A wetland macrophyte index (WMIadj) value (Croft and Chow-Fraser 2007) was calculated from presence-absence data at each sample site.

Shoreline development, represented as evidence of physical work or infrastructure (i.e., docks, water lines, and shoreline modification) found below the ordinary high water mark, was digitized from orthorecitified aerial photographs obtained in 2006. Polygon features were converted to 10 m grid cells and a point-density model was calculated. Lake levels were determined to be the mean value for the 24-hour period of fish sampling. The data was provided by the Canadian Hydrographic Survey's station in Tobermory (station no. 11690, 45.25°N, 81.67°W). Stranding (i.e., loss of hydrological connection to the lake due to low lake levels), for part or all of the wetland area, was evaluated during the time of fish sampling.

Statistical Analysis

For the analysis, the recommendation of Jackson and Harvey (1997) to utilize presence-absence fish data was followed. A sample (site-year) by species matrix was created. Very rare fish species (i.e., those found in <5% of the samples) were removed since they had little effect on the amount of variation explained and thereby prevented congestion in the ordination. A principal component analysis (PCA), an analysis technique that attempts to explain the variability in multivariate data through a series of orthogonal vectors (Legendre and Legendre 1998), was used to examine patterns in the fish assemblage data. A Hellinger transformation, expressing each presence as a square root fraction of the total number of species observed at the site, was performed to make the data more amenable to Euclidean-based ordination methods such as PCA and redundancy analysis (RDA) (Legendre and Gallagher 2001). Linear models were selected because of the short gradient in species assemblages, as determined by a detrended correspondence analysis.

Explanatory variables included: water temperature, water levels, pH, chlorophyll *a*, turbidity, total phosphorus, WQI 6, WQI 7, WMIadj, easting, northing, stranding, shoreline development, and year. Each was tested for normality using the Shapiro-Wilk test. If necessary, they were transformed to best approximate normality by taking the natural log (i.e., chlorophyll *a*, turbidity, and total phosphorus). All variables were transformed to be dimensional homologous, having a mean of 0 and standard deviation of +/- 1 (*z*-score), making them amenable to ordination techniques (Legendre and Legendre 1998). RDA, a direct gradient approach, was used to display the relationship between fish assemblages and explanatory variables. To this end, the RDA constrains the ordination of the fish assemblages on axes that are linear combinations of the explanatory variables (ter Braak 1994; Legendre and Legendre 1998). To determine those variables that explained a significant ($p<0.05$) amount of variance in the fish assemblage data, a forward selection process was performed. The remaining statistically significant variables were checked for redundancy by assessing their variance inflation factors (i.e., confirm VIF <5) (Hall and Smol 1996; DeSellas et al. 2008). The resulting RDA tri-plot displayed sample (site-year), fish species, and the influence of environmental and other variables, allowing for visual interpretation.

To monitor variability in fish assemblages, the control chart method was used (Anderson and Thompson 2004; Anderson 2008). A control chart displays stability in variability by showing consistency with the past. The measurement of deviation was based on the Hellinger distance measure of an observed sample to a centroid (mean) baseline using all previous year samples (t-1) for that site. The sample (site-year) by fish presence-absence matrix was input into the Control Chart program (Anderson 2008) and a 95% confidence limit was determined using 10,000 random bootstrap samples with replacement. Bootstrapping was performed within each site through time, and the 95th percentile was calculated from the mean of all sites. In this manner, temporal variability for a given site was considered “out of control” when it exceeded the 95% confidence limit for all sites.

The statistical software R version 2.14.1 (R Development Core Team 2011) with the "vegan" library was used for all the analysis, with the exception of the control chart, which used Anderson (2008).

Results

The following fish species were removed from the analysis due to their relative rarity, most were only captured in a single sample: lake trout (*Salvelinus namaycush*), freshwater drum (*Aplodinotus grunniens*), longnose sucker (*Catostomus catostomu*), mottled sculpin (*Cottus bairdi*), longnose gar (*Lepisoteus osseus*), largemouth bass (*Micropterus salmoides*), finescale dace (*Phoxinus neogaeus*), and longnose dace (*Rhinichthys cataractae*). A PCA bi-plot was generated with the remaining 30 fish species (see Table 4.2 for species and their traits). The first principal component axis explained 19% of the variation in fish assemblage (PC1; λ_1= 0.08) and was positively associated with phytophils including northern pike (*Esox lucius*), blackchin shiner, and golden shiner (*Notemigonus crysoleucas*) and warm water species including brown bullhead (*Ameiurus nebulosus*) and pumpkinseed (*Lepomis gibbosus*). The more densely vegetated sites, including those in Hay Bay (see Table 4.1), were also positively associated with this axis. This axis was negatively associated with lithophils, including white sucker (*Catostomus commersoni*) and round goby, as well as other cool water species, including threespine stickleback (*Gasterosteus aculeatus*) and ninespine stickleback (*Pungitius pungitius*). The least densely vegetated wetlands, including Big Tub and Russel Island East, were also negatively associated with this axis. The second principal component axis explained 10% of the variation in fish assemblage (PC2; λ_2= 0.04) and was positively associated with smallmouth bass (*Micropterus dolomieu*), a relatively large-bodied carnivore and equilibrium species (i.e., found in more stable environments). The second axis was negatively associated with johnny darter (*Etheostoma nigrum*), Iowa darter (*Etheostoma exile*), and emerald shiner (*Notropis atherinoides*), relatively small-bodied invertivores and opportunistic species (i.e., occupy disturbed and unstable environments). The mainland sites displayed less variability than the island sites.

From the forward-selection process, water temperature, northing, time, stranding, and easting (in that order) were all significant ($P<0.05$) explanatory variables and included in the final RDA model (Figure 4.3). Since the VIF for each variable was <5, there was little concern with collinearity among variables. Water levels, total phosphorus, chlorophyll *a*, pH, turbidity, WMI, WQI values, and shoreline development were not significant and were excluded from the final RDA model. The first axis of the RDA explained 14% of the variation (RDA1; $\lambda1 = 0.06$) and was positively associated with water temperature (e.g., the Hay Bay sites were characterized by warmer water temperature). The second axis of the RDA explained 5% of the variation (RDA2; $\lambda1 = 0.02$) and was positively associated with an increase in easting location and time and was negatively associated with an increase in northing location and stranding.

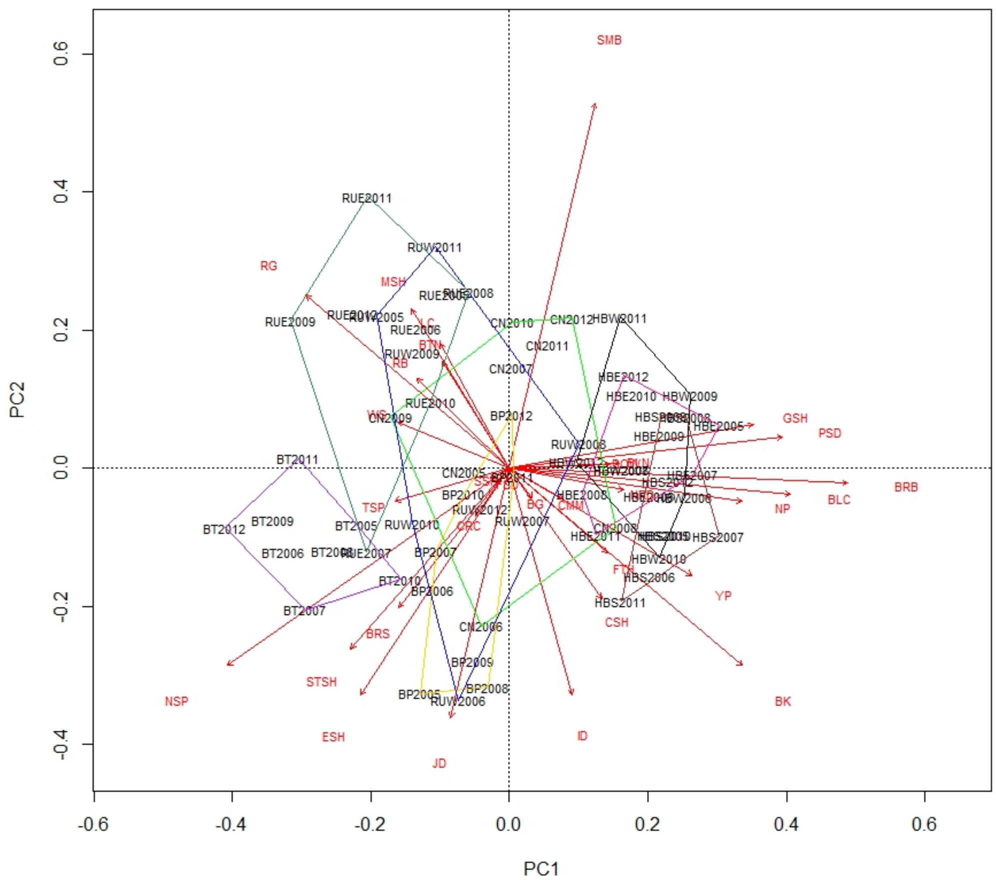

Figure 4.2 Principal Component Analysis (PCA) of fish presence-absence in each wetland/year. See Figure 4.1 for wetland codes and Table 4.2 for fish species codes.

Figure 4.4 displays the results of the distance-based multivariate control chart of fish presence-absence at each site. The 95% confidence limit decreased its deviation as more years were sampled and used to calculate the baseline. Exceedance of the 95% confidence limit was observed for RUE, RUW, and BT. RUE exceeded the confidence limit four times, defining it as the most variable site in the study. The mean sample richness for this site was significantly lower ($P<0.05$) than the other sites (e.g., $\overline{X}$ = 6.8 vs. 12.2 species/year), with rock bass (*Ambloplites rupestris*), bluntnose minnow (*Pimephales notatus*), and round goby being the most consistent. Of the 19 species found at this site, 11 were single sample records and 3 were captured twice. Transient open water species, such as lake chub (*Couesius plumbeus*), white sucker, and mimic shiner (*Notropis volucellus*), were captured more frequently in the later years. For RUW, the 2006 exceedance coincides with a two-fold increase in species richness (i.e., from 7 in 2005 to 14 in 2006), with a marked increase in phytophils, including golden shiner and blackchin shiner. Within the PCA, the shift between RUW2005 and RUW 2006 was very large as compared to the RDA for these same samples, suggesting the explanatory variables were only weak drivers of this assemblage change. The 2010 and 2011 exceedances coincide with a decrease in species richness (n = 7 and 8 species respectively) and both the PCA and RDA showed this as a large shift within the ordinations. BT exceeded the confidence limit in 2006 and 2008. The first record for round goby in BT was in 2005. Absent from the 2006 sample, as compared to the 2005 sample, was the benthic species johnny darter, whereas, benthopelagic species including ninespine and brook stickleback were first present in 2006. The RDA captures a movement to those species that are increasingly present with time. The 2008 exceedance at BT coincided with relatively low species richness (n=7 species), including the absence of the more common bluntnose minnow and common shiner (*Luxilus cornutus*).

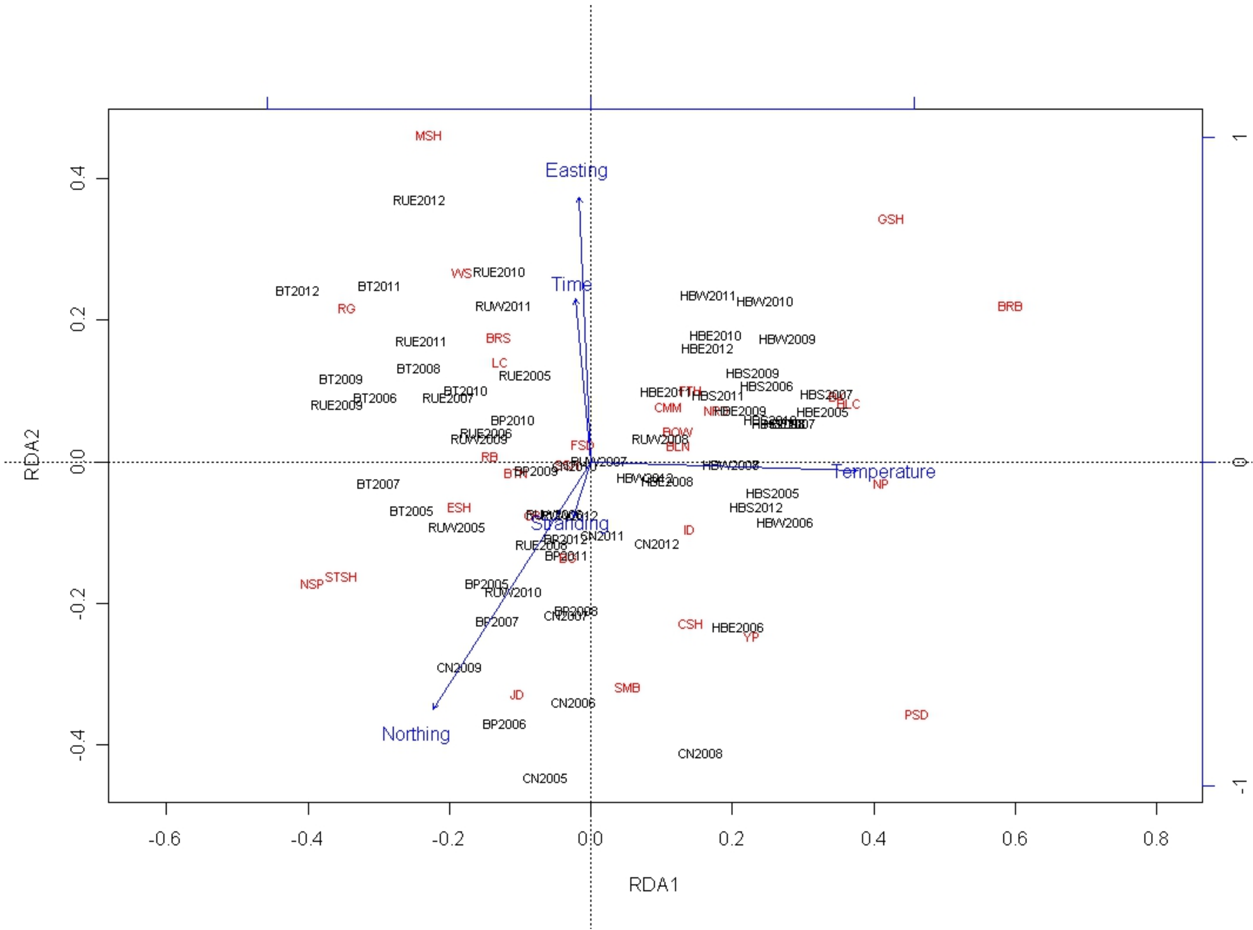

Figure 4.3 Redundancy Analysis (RDA) of fish presence-absence data. Significant environmental variables include water temperature (TEMP), location (Easting, Northing), year (TIME), and stranding. See Figure 4.1 for wetland codes and Table 4.2 for fish species codes.

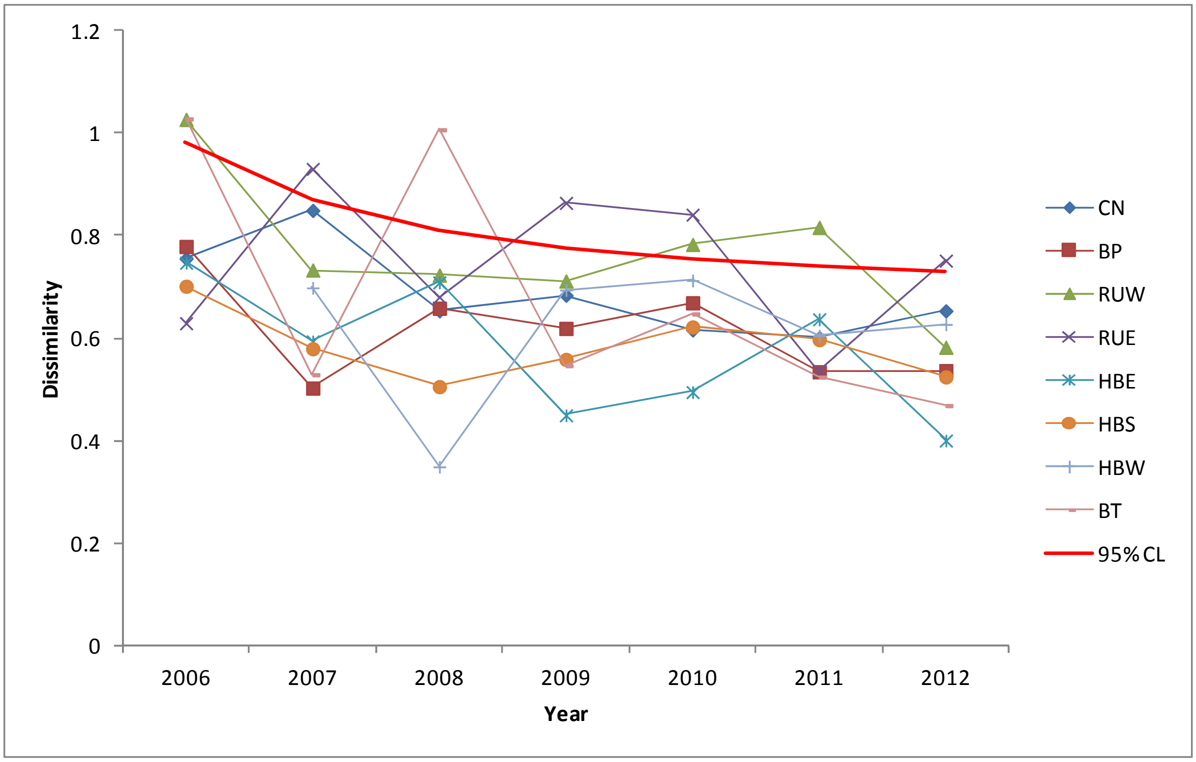

Figure 4.4 Control chart of fish presence-absence at each wetland with 95% confidence limit. See Figure 4.1 for wetland codes.

Discussion

Increased variance is recognized as an indicator of decreased resilience and a potential regime shift (e.g., Carpenter and Brock 2006; Scheffer et al. 2009; Dakos et al. 2012). Naturally, the ability to monitor and interpret such variability in complex systems, such as coastal wetlands, is challenging. Furthermore, in the study there were over 80 interacting and potentially confounding variables to consider, including species presence-absence and environmental factors. Given this context, there was a clear need to reduce the dimensionality of the data and still be able to monitor variability. The use of multivariate distance-based control charts offered a solution to this challenge. Originally developed for industry, control charts indicate when a system is going "out of control" by charting through time a measure of a stochastic process with reference to its expected value. Morrison (2008) compared control charts to other statistical monitoring methods, including regression analysis and parameter estimation with confidence intervals. He demonstrated that control charts are often more advantageous and informative than traditional statistical techniques that rely on statistical probability. Based on the experience of the Fathom Five study, the control chart method was intuitive and an exceedance was simple to identify.

In the study, distance in Euclidean space of Hellinger transformed wetland fish assemblage data provided the measure. Intuition suggested that fish assemblage be the focus of the analysis as it was the component of the system approaching a regime shift. The control chart method referenced a centroid baseline calculated as a mean of all previous year values. As an alternative, the establishment of a target baseline using an initial sample period or knowledge of the system is also possible (Anderson and Thompson 2004). The final choice reflected a desire to establish a longer time series on which to represent variability and still be able to detect pulse events. A risk with this approach is that slow ecological drivers can cause incremental change that may go unnoticed. Future iterations may benefit from utilizing both "target" and "all previous year" approaches to baseline determination. To provide decision-support, a value that exceeded the 95% confidence limit was reported as being the "alarm" (Figure 4.4). This limit was not based on empirical knowledge of the system or its ecological thresholds. The assessment was exploratory and intentionally designed to focus on major deviations. At 75%, for instance, most sites exceeded the limit at least once, thus challenging, and perhaps diminishing, the interpretation of results. Nevertheless, the establishment of a confidence limit remains flexible and may change with experience and comfort of those assessing the system.

Although the control chart showed exceedances at BT, RUE, and RUW, clear evidence of a pending regime shift was not apparent for the study period. However, given the fact that the first observation for the invasive round goby in the Tobermory area was in 2004 (personal observation S. Parker), significant change to the fish assemblage in some of the coastal wetlands (i.e., BT and RUE) may have been initiated before or as the study began. BT is the one site where round goby was consistently found every year and was captured in relatively high abundance (i.e., on average 1,439 round goby/sample for BT versus 4 round goby/sample for the other sites). The control chart exceedances noted for 2006 and 2008 may represent a period of instability as the BT system established its new regime. RUE and RUW may also have initiated a transition before the study began, but in their situation it may be due to the current period of low lake levels which was initiated in 1999. In the past century lake levels have fluctuated, but only remained low for a maximum of 5 years (Sellinger et al. 2008). As Midwood and Chow-Fraser (2012) observed, this prolonged change in lake fluctuations has affected coastal wetlands, including a homogenization of fish communities and habitat. Both RUE and RUW are vulnerable to stranding and isolation of vegetated fish habitat; in fact, the stranded pond in RUE was prone to complete evaporation. With the stranding or loss of vegetated areas, some species may have been forced from their natal habitat with little alternative, and more favourable conditions for cool water, lithophilic species were created. The circumstance was exacerbated by the fact that post-disturbance recovery, through colonization from the mainland or Cove Island, was restricted for many species by a barrier of cold, deep, open water (Leslie and Timmins 2001). Notwithstanding, schools of transient mimic shiner and emerald shiner were periodically captured in the samples. The RDA also identified time as being an explanatory variable. Perhaps as time increased, the decrease in lake fluctuations became more influential at stabilizing habitat conditions.

While the control chart sounded the alarm, ordination techniques (PCA and RDA) supported the investigation. They are complementary approaches in the sense that the fish assemblage data was similarly transformed into Euclidean space for both the control chart and the ordinations. Figure 4.2, as an example, illustrates the similarity between samples. Although the chart is limited to the first two principal component axes, and not the multidimensional space upon which the control chart analysis is based, one can begin to visualize the analysis process, i.e., measuring the distance from a sample to a baseline. For instance, the early exceedance at BT reflects the fact the ordination for the sample was of sufficient distance from the baseline (sample is in lower left quadrant of Figure 4.2). The 95% confidence limit is a percentage of the baseline value, and the baseline, as explained earlier, was a centroid value calculated as the mean of all previous year samples from all sites. Similarly, Figure 4.2 illustrates the comparatively high variability and movement in Euclidean space for RUE and RUW, versus the Hay Bay complex (e.g., HBE, HBW, and HBS), which tightly clustered together. The Hay Bay sites did not experience any control chart exceedances and maintained a strong complement of equilibrium species, including bowfin (*Amia calva*), brown bullhead, and pumpkinseed, which are found in more stable environments (Table 4.2; Strecker et al. 2011). Coincidently, the Hay Bay sites have a higher degree of connectivity amongst each other (e.g., support post-disturbance colonization) and are the least exposed to the waves and cold water effects of Lake Huron.

Of related interest is the concept of establishing a lower confidence limit. Increased autocorrelation (i.e., one year starts to look more like the past year) is also cited as a leading indicator of a regime shift (Scheffer et al. 2009). An initial exceedance of a higher confidence limit (e.g., BT's response to round goby colonization), followed by an exceedance to a lower limit (e.g., < 5%, as they establish a resilient monoculture with little variability) is a potential pattern to note in future study. In terms of resilience, functional and response diversity provide some "insurance" when a disturbance or driver threatens to push a system into a new regime (Folke et al. 2004; Chapin et al. 2010). Therefore a decrease in variability caused by reduction of species richness and functional diversity, and community homogenization would also be a concern.

Of the original 14 potential explanatory variables, the forward-selection RDA process found five to be significant ($P<0.05$). It is important to realize that some of the discarded variables may be explanatory, but if they were correlated with a variable already selected by the process, they may not have been added. For instance, in the initial stage of building the model, temperature followed by chlorophyll *a* captured most of the variation in the data. Temperature was therefore selected as the first variable. However, as the modelling progressed, chlorophyll *a* was eventually discarded as the largest proportion of its variation was already captured by temperature. So, while variables such as nutrients, coastal development, and macrophytes, are widely recognized for their importance in coastal wetlands, their absence in the RDA simply reflects the nature and bias of the modelling process.

Knowledge of gear bias is a factor in assessing any fish assemblage data. For instance, Breen and Ruetz (2006) reported that fyke nets may over-represent benthic species and under-represent water column species. Cvetkovic et al. (2012) observed that fyke nets captured a greater number of species and selected for larger piscivores than did electrofishing. In the Fathom Five study, common carp were observed swimming next to the sample nets, but were never captured. As well, incidents of in-trap predation by rock bass were suspected. This was particularly evident at RUW where a few sets were almost entirely composed of rock bass, yet other species were observed in the area. In spite of these limitations, it is recommended that the fyke net method continue to be used for long-term monitoring. It has proven to be a cost-effective and socially acceptable method of capturing fish in the park.

Further monitoring and analysis are required, but the method shows promise for interpreting multivariate ecological data and informing managers of potential concerns. In reality, it may take several decades of research and monitoring, as it did with lake (Scheffer and Carpenter 2003) and coral reef systems (Hughes et al. 2010), before sufficient understanding of system indicators and thresholds is available to help manage for resilient desired states (Contamin and Ellison 2009). Despite any monitoring limitations, the need to build and maintain ecosystem resilience within Fathom Five remains a management priority. The recommendations in this regard include:

- Manage for coastal connectivity (e.g., reduce stranding barriers, prevent phragmites colonization) and maintain replicate sources of ecosystem functions and structures;
- Research and monitor disturbances, functional diversity, and response diversity;
- Strengthen stewardship activities that support resilience goals, including habitat restoration, social learning, and conservation incentives; and,
- Improve governance structures, including regional scale partnerships and cooperative networks for coastal zone planning and conservation.

Conclusion

The structural and functional identity of coastal wetlands is characterized by dynamic processes that exhibit variability and adaptability. The ability to distinguish this baseline variability from something that may be indicative of a loss of resilience, and pending regime shift, is an important area of study with practical applications for managers of protected areas. The study reduced the complexity of a multivariate dataset and gained insight on the changing nature of fish assemblages in Fathom Five. Although monitoring variance can be undertaken without special knowledge of ecosystem dynamics (Carpenter and Brock 2006), coupled with other statistical techniques it can better explain the changes. Naturally, such understanding is important to best guide an adaptive response. With respect to management, it is also wise to support conservation efforts that generally build resilience and adaptive capacity within the ecosystems and governance domains. It is recommended that control charts continue to be utilized and interpreted in terms of system resilience.

Table 4.2 Fish species traits. Based on Eakins (2012) with exception of "Life History Class" from Strecker et al. (2011).

Family	Scientific Name	Common Name	Code	Native	Life History Class	Trophic Class	Turbidity Tolerance	Thermal Regime	Environment	Reproductive Guild Description
Amiidae	*Amia calva*	bowfin	BOW	Y	equil	carn	tolerant	warm	benthopelagic	G: Nest: Phytophils
Castostomidae	*Catostomus commersonii*	white sucker	WS	Y	per	invert; det	intermediate	cool	benthic	NG: Open: Lithophils
Centrarchidae	*Lepomis macrochirus*	bluegill	BG	Y	per	invert	intermediate	warm	benthopelagic	G: Nest: Lithophils
Centrarchidae	*Lepomis gibbosus*	pumpkinseed	PSD	Y	equil	invert; carn	intermediate	warm	benthopelagic	G: Nest: Polyphils
Centrarchidae	*Ambloplites rupestris*	rock bass	RB	Y	equil	invert; carn	intermediate	cool	benthopelagic	G: Nest: Lithophils
Centrarchidae	*Micropterus dolomieu*	smallmouth bass	SMB	Y	equil	invert; carn	intermediate	warm	benthopelagic	G: Nest: Lithophils
Cyprinidae	*Notropis heterodon*	blackchin shiner	BLC	Y	opp	invert	intolerant	cool	benthopelagic	NG: Open: Phytophils
Cyprinidae	*Notropis heterolepis*	blacknose shiner	BLN	Y	opp	invert; herb	intermediate	cool	benthopelagic	NG: Open: Psammophils
Cyprinidae	*Pimephales notatus*	bluntnose minnow	BTN	Y	opp	det	intermediate	warm	benthopelagic	G: Nest: Speleophils
Cyprinidae	*Luxilus cornutus*	common shiner	CSH	Y	opp	invert	tolerant	cool	benthopelagic	G: Nest: Lithophils
Cyprinidae	*Semotilus atromaculatus*	creek chub	CRC	Y		invert; carn	intermediate	cool	benthopelagic	NG: Brood: Lithophils
Cyprinidae	*Notropis atherinoides*	emerald shiner	ESH	Y	opp	plank	tolerant	cool	benthopelagic	NG: Open: Pelagophils
Cyprinidae	*Pimephales promelas*	fathead minnow	FTH	Y		det; invert	intermediate	warm	benthopelagic	G: Nest: Speleophils
Cyprinidae	*Notemigonus crysoleucas*	golden shiner	GSH	Y	opp	invert; herb	intermediate	cool	benthopelagic	NG: Open: Phytophils
Cyprinidae	*Couesius plumbeus*	lake chub	LC	Y	equil	invert; plank	intermediate	cold	benthopelagic	NG: Open: Litho-pelagophils
Cyprinidae	*Notropis volucellus*	mimic shiner	MSH	Y	opp	invert; herb	intermediate	warm	benthopelagic	NG: Open: Phyto-lithophils
Cyprinidae	*Chrosomus eos*	northern redbelly dace	NRD	Y		invert; plank	intermediate	cool	benthopelagic	NG: Open: Phytophils
Cyprinidae	*Cyprinella spiloptera*	spotfin shiner	SSH	Y		invert; herb	intermediate	warm	benthopelagic	NG: Open: Phyto-lithophils
Cyprinidae	*Notropis hudsonius*	spottail shiner	STSH	Y	opp	invert; plank	tolerant	cool	benthopelagic	NG: Open: Psammophils
Esocide	*Esox lucius*	northern pike	NP	Y	per	carn	intermediate	cool	benthopelagic	NG: Open: Phytophils
Fundulidae	*Fundulus diaphanus*	banded killifish	BK	Y	opp	invert; plank	intermediate	cool	benthopelagic	NG: Open: Phytophils
Gasterosteidae	*Culaea inconstans*	brook stickleback	BRS	Y	opp	invert; plank	intolerant	cool	benthopelagic	G: Nest: Ariadnophils
Gasterosteidae	*Pungitius pungitius*	ninespine stickleback	NSP	Y	opp	plank	intermediate	cool	benthopelagic	G: Nest: Ariadnophils
Gasterosteidae	*Gasterosteus aculeatus*	threespine stickleback	TSP	N		invert	intermediate	cool	benthopelagic	G: Nest: Ariadnophils
Gobiidae	*Neogobius melanostomus*	round goby	RG	N		invert	tolerant	cool	benthic	G: Choosers: Lithophils
Ictaluridae	*Ameiurus nebulosus*	brown bullhead	BRB	Y	equil	invert; herb; carn	intermediate	warm	benthic	G: Nest: Speleophils
Percidae	*Etheostoma exile*	Iowa darter	ID	Y		invert	intolerant	cool	benthic	NG: Open: Phyto-lithophils
Percidae	*Etheostoma nigrum*	johnny darter	JD	Y	opp	invert	intermediate	cool	benthic	G: Nest: Speleophils
Percidae	*Perca flavescens*	yellow perch	YP	Y	per	invert; carn	tolerant	cool	benthopelagic	NG: Open: Phyto-lithophils
Umbridae	*Umbra limi*	central mudminnow	CMM	Y	opp	invert	tolerant	cool	benthic	NG: Open: Phytophils

Legend: Native: native species Y=yes, N=No; Life History Class: opp = opportunistic (minimum clutch size, minimum juvenile survivorship, and minimum maturation size), per = periodic (maximum clutch size, minimum juvenile survivorship, and maximum maturation size), and equil = equilibrium (mean clutch size, maximum juvenile survivorship, and maximum maturation size); Trophic Class: carn = carnivore, invert = invertivore; det = detritivore, plank = planktivore, herb = herbivore; Turbidity Tolerance: tolerance to turbid waters; Thermal Regime: warm = prefers water temperatures > 25°C, cool = prefers water temperatures between 19 and 25°C, cold = prefers water temperatures < 19°; Environment: habitat type; Reproductive: G = guarder; NG = non-guarder; Nest = nest spawner; Open = open substratum spawner; Brood = brood hider; Choosers = substratum choosers; Lithophil = eggs in or on gravel or rocks; Phytophil = eggs in or on vegetation; Phyto-lithophil = eggs on plants or logs, gravel and rocks; Speleophil = eggs in hoes, cavities or burrows; Polyphil = eggs on no particular material; Psammophil = eggs in or on sand; Ariadnophil = eggs in a nest from vegetation bound together by viscous threads from a kidney secretions; and, Pelagophil = pelagic spawner.

Chapter 5. General Discussion

Introduction

Eventually all protected areas must face their vulnerabilities. These vulnerabilities can take on many forms, e.g., biodiversity or habitat loss, a suppressed disturbance regime, a governance culture that takes on inappropriate risks or is devoid of consequences, an increase in visitor impacts, or simply a lack of trust within the community and among staff. All these require a different response, but they have the same effect. They make the protected area less adaptive, less resilient, and more likely to collapse and reorganize when disturbed.

This thesis highlights the conservation challenges confronting Fathom Five National Marine Park, and proposes a novel resilience-based approach to resolve them. The concepts and methods are also of relevance to other freshwater protected areas, particularly those on the Laurentian Great Lakes (Hedges et al. 2011), which are similarly facing "extreme stress" and the potential for "irreversible and catastrophic" change (Bails et al. 2005). Primarily driven by invasive dreissenid mussel colonization, Fathom Five's offshore ecosystem is in the midst of an unexpected change to a less desired, and yet, potentially resilient state. The park's coastal wetlands are currently in a desired state, but will become less resilient with increased development, hydrologic alterations, and invasive species. Meanwhile, the complexity and uncertainty of the situation has amplified the management challenge and appears to have overwhelmed the park's governance domain. Governance is characterized as being in a less desired and resilient state. Naturally, the reasons for how the park arrived in these states are varied. As discovered, some aspects relate to: the adaptability of governance structures; the degree of cross-scale linkages; knowledge of regime shift thresholds and controlling variables; and, the capacity to protect ecological structures and functions.

Although, I demonstrated practical and readily implemented resilience-based methods to zoning (Chapter 3) and monitoring (Chapter 4), they represent a faint hope if the site fails to free itself from the persistent maladaptive trap that characterizes its governance domain (Carpenter and Brock 2008; Gunderson et al. 2010). After all, zoning and monitoring are simply part of the resilience toolkit, and to be most effective they need to be wielded in a context of cooperation, social learning, attentiveness, and adaptability. In light of this, a large part of this final chapter will discuss network and partnership possibilities. Just as an image emerges from the contrast between black and white, the contrast of Fathom Five to other institutions will provide a clearer understanding of the opportunities and the creative potential that exists for creating a more desired and resilient protected area. A general review of the resilience-based approach, including a final discussion on the zoning and monitoring experience, chapter summaries, and recommendations, are also included. It was my intent to provide a positive resilience-based solution to some very real concerns and challenges.

But first, is Fathom Five actually a protected area?

A False Promise?

An original contribution of this thesis is that it is centred on the application of a resilience-based approach to managing a freshwater protected area. However, once I began to assess resilience in Fathom Five, questions of its legitimacy as a protected area surfaced because of perceived concerns with the stalled establishment process and the nature of governance context. As referenced by Day et al. (2012), there is a point where an area being managed for resource extraction (e.g., fishing), can no longer meet the protected area definition, and therefore, should not be referred to as such. As introduced in Chapter 1, a protected area is: *"A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values"* (Dudley 2008). Table 5.1 evaluates Fathom Five against this definition.

I concluded that in spite of clear weaknesses, Fathom Five could fit the definition of a protected area[4]. This was, however, a judgment call biased by the original intentions and designs for the park. By actively resolving the public and government expectations with respect to the establishment process and by verifying that the site has effectively managed for ecologically sustainable use, as measured within the state of the park report (Parks Canada 2011), then the site

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[4] Coincidently, I co-authored the description of Fathom Five for the IUCN's "protected area of the week" for September 23, 2011 (www.iucn.org).

could more easily defend its protected area status[5]. The resilience-based approach and recommendations within this thesis are very much focused on furthering Fathom Five's capacity to openly address and resolve "…*legal or other effective means, to achieve long-term conservation*".

Table 5.1 A review of the protected area definition (Dudley 2008) with respect to Fathom Five. The establishment agreement (EA) (Canada and Ontario 1987) and management plan (MP) (Parks Canada 1998) are referenced. Islands are excluded from this review as they are scheduled under the Canada National Parks Act (Canada 2000) and not the primary focus of a NMCA.

Phrase	**Discussion**
clearly defined	Yes, mapped and defined in the EA, but not legally scheduled under any Act. Mainland boundary is contentious.
geographical space	Yes, as described in EA, the intention is to include a combination of land, water, and lakebed. Airspace is not discussed.
recognised	Yes, declared by both provincial and federal governments in EA.
dedicated	Yes, implies a binding commitment to long term conservation. Stated in EA and MP.
managed	Yes, assumes active steps to conserve values. Consistent application of existing federal and provincial regulations. Additional measures to manage some visitor experiences, excluding fishing and commercial operators, are in place (e.g., diving).
legal or other effective means	Partially, not recognized under statutory civil law. Uses other non-gazetted means. The extent to which it is effective at conserving species, habitats, and ecosystems is at question (e.g., sustainability of fishery).
… to achieve	Partially, implies a level of effectiveness. As described in state of the park report (Parks Canada 2011), several management objectives have not been met.
long term	Yes, intent of EA is that it be managed in perpetuity.
conservation	Partially, refers to the in situ conservation of ecosystems and habitat and viable populations of species. Examples of the application of this include protection of spawning and nursery areas, or protection of representative bioregions (Day et al. 2012). Capacity to protect remains a key concern for Fathom Five.
nature	Yes, Refers to biodiversity. Expressed goal of MP.
associated ecosystem services	Yes, includes provisioning services, supporting services, and cultural services, e.g., see MEA (2005). Recreational benefits are recognized at the site, but most other services are not accounted for or evaluated (e.g., food, water, nutrient cycling, nonmaterial benefits, etc.).
cultural values	Yes, the site contributes to marine heritage conservation (e.g., shipwreck conservation). No clear examples of traditional or cultural management practices.

[5] Addendum: The Auditor General of Canada recently concluded that Fathom Five has not met the requirements of a protected area, citing the need to complete the establishment process (OAG 2012).

Managing for Resilience

Fathom Five Situational Awareness

SWOT analysis is a commonly used planning method used to evaluate the strengths, weaknesses, opportunities, and threats involved in a project or venture (Humphrey 2005). The SWOT analysis in Table 5.2 was completed to identify the factors which are favourable and unfavourable to implementing a resilience-based approach at Fathom Five. It was based on my experience with the park while preparing this thesis. The analysis re-confirmed the recurring limitations and practicalities related to governance, but it also identified the strengths and opportunities that could be advanced. Enabling policies, problem-solving capacity, and potential partnerships are key elements in this regard. Loss of resilience, after all, occurs when variety or options are restricted, such as a decrease in species diversity or innovative ideas (McLaughlin and Krantzberg 2012). Coupling this analysis with an awareness of the phase of the adaptive cycle (Figure 1.5) the site is in, provides additional clarity and understanding of the path forward.

The four-phase adaptive cycle (Figure 1.5) provides insight on the patterns and dynamics of ecosystems and their management institutions (Gunderson and Holling 2002). Most institutions focus their time and efforts at becoming more efficient at implementing a set of policies (Gunderson et al. 1995). While this “fore loop” represents a period of growth, it tends to be myopic and inevitably results in a crisis when policy fails (Gunderson et al. 1995). How and why things bounce back from such a crisis is the domain of resilience. In analyzing the cycle, Gunderson et al (1995) provided numerous examples of how it fit various institutions and situations (including the Great Lakes, Francis and Regier 1995), and they also identified the groups of people that emerge at the various phases of the cycle (Table 5.3).

In light of this, it appears that while the bureaucracy of Fathom Five continued to focus on the scale of the park and its immediate interests, it entered the conservation phase of the cycle making it particularly brittle to the budget induced crisis that affected all of Parks Canada in 2012 (CPAWS 2012). To be adaptive and resilient, this is a critical time where institutional rigidity or the inability to renew or restructure needs to be overcome. In considering Table 5.3

and the discussions within Gunderson et al. (1995), there is a need for three important roles at this phase: a visionary activist; a wise, patient respected integrator; and, a rebel bureaucrat. It may be premature to say, but such roles or figures are not currently identifiable within the Great Lakes NMCA program. Management is by design, and the pragmatic manager would be wise to recognize these attributes (Table 5.3) and develop them to help guide Fathom Five through the next phases of the adaptive cycle (Westley 1995).

Table 5.2 A SWOT analysis for implementing a resilience-based approach at Fathom Five.

Internal Strengths	Internal Weaknesses
Potential networks exist with some good relations, (e.g., Fisheries and Oceans, Environment Canada, Park Advisory Committee, etc.). A biodiversity conservation "hotspot" (e.g., Wichert et al. 2005; Franks Taylor et al. 2010). Larger "study area" concept already practiced (e.g., Munawar et al. 2003). Support for ecosystem-based management and precautionary principle approaches within Act and guiding policies. Experienced and knowledgeable staff and a good database for field implementation. Public expectation that the area be protected and conserved. Enabling establishment agreement.	Lacks relevance and influence with the province of Ontario and Saugeen Ojibway Nations on fisheries management. Remains functionally isolated from region with focus on the "scale of the park". Little demonstrable engagement with Great Lakes organizations for funding, priority setting, and cooperation (e.g., Canada-Ontario Agreement, protected area network). Governance barriers to policy implementation, including changing corporate priorities (e.g., CPAWS 2012) and adequate tools to manage non-gazetted areas. Fiscal and human resource constraints. Data and knowledge gaps. Limitation related to representativeness, replication, and connectivity of critical features and habitat.
External Opportunities	**External Threats**
Great Lakes Water Quality Agreement, Great lakes Fishery Commission, Lake Huron Biodiversity Conservation Strategy, and other Great Lakes initiatives. Strong regional partner potential (e.g., Nature Conservancy, Environment Canada, Saugeen Ojibway Nations, etc.). An established "eco-tourism" market. Area features prominently in the public's eye as a protected area. Ecological linkages transcend planning, outreach, and education process.	Aboriginal relations and litigation process. Fisheries (e.g., chub, lake trout) and ecosystem changes (e.g., invasive species, climate change). Changing political direction and budgets. Impacts and sustainability of tourism in light of current growth and market demands.

Table 5.3 Attributes that appear to dominate in the various transitions of the adaptive cycle (Figure 1.5). Developed by Gunderson et al. (1995).

	Phase of Adaptive Cycle				
Attribute	**Conservation r-K**	**Release K-Ω**	**Reorganization Ω-α**	**Growth α-r**	**α-?**
Group type	Bureaucracy	Activists	Catalysts	Decision makers strategists	Evolutionary
Activity focus	Self-serving	Insurgence	Unlearning	New learning cooperation	Deep transformation cooperation
Strategy	"Do as before but more"	"Weathering the storm"	"Unlearning yesterday"	"Inventing tomorrow"	
Response to changes	No change	Conflict	Shedding old behaviours	Reframing strategies	Invention
Time horizon	Time of office (linear)	Present (discontinuous)	Time out (multiple scales)	Near future (multiple scales)	Distant future
Space horizon	Building and holding bounds	Destruction of old bounds	Suspension of bounds	Creating new bounds	
Nature of truth and reality	Constructed	Competing explanations	Discovering what works	Reconfiguring myths	New myths (visionary)

General Principles

This thesis has introduced and developed knowledge related to the management of freshwater protected areas to make them more effective at building or maintaining resilience. Table 5.4 summarizes the various strategies of this approach.

As has been repeatedly stated, learning is central to a resilience-based approach. Learning in this context is not simply about answering questions or understanding feedback from an adaptive management study. It involves a continuous and open process of interpretation, evaluation, and reformulation (Carpenter and Gunderson 2001; McLaughlin and Krantzberg 2012). Since managing for resilience draws on knowledge to prevent or navigate system change, it therefore needs to question and test underlying assumptions, policies, and priorities. As introduced by Argyris and Schon (1978) this review of the underlying goal versus simple repeated attempts at understanding the same problem, is termed double-loop learning. For example, the NMCA Act states that "*Marine conservation areas shall be managed and used in a sustainable manner that meets the needs of present and future generations without compromising the structure and* *function of the ecosystems*" (Canada 2002). What structures and functions are to be sustained? Used by whom? How? And how do we know when the NMCA is compromised? Acquiring knowledge therefore reflects an understanding of what to learn and how to learn (McLaughlin and Krantzberg 2012).

Table 5.4 Summary of resilience-based management strategies (Folke et al. 2003; IUCN WCPA 2008; Chapin et al. 2009; Scheffer 2009).

Reduce Vulnerability
- Minimize the intensity and nature of stress.
- Manage disturbance and disturbance regimes within a resilience framework with awareness of cross-scales.
- Maintain natural and social capital.
- Explore governance systems and identify vulnerabilities including responsibilities and rights.
- Avoid or mitigate impacts and cumulative impacts through environmental assessment processes.
- Safeguard against management uncertainties.

Increase Adaptability
- Foster social learning and networking on matters of system structure, function, and change.
- Support innovation and research that tests system resilience and adaptive management.
- Build governance systems and leadership to support resilience thinking.
- Maintain ecological and social diversity and support economic novelty and diversity.

Navigate Transition
- Develop an understanding of future scenarios, paths, and thresholds.
- Address perceptions, risks, and uncertainties.
- Actively navigate transformations to promote good transitions and prevent bad.

Build Resilience
- Protect key structures, keystone species, and ecological linkages (connectivity).
- Support system redundancy and protect a portfolio of variant forms of biodiversity or ecosystems.
- Establish refugia (breeding and foraging areas) and replicate examples of ecosystems or populations as insurance and source of "seed" for recovery. Choose sites which are more resilient to change.
- Restore lost or degraded ecosystems, with a focus on functional diversity and connectivity.
- Maintain long-term protection. Consider spill-over effects and adaptive management.
- Balance stabilizing and renewal feedbacks.
- Remain flexible, foster good governance across-scales, and be ready for "time-bombs".

Scaling Up

Zolli and Healy (2012) reviewed examples of resilience and found that most desired and resilient social-ecological systems are organized as a network of private and public interests working together in a provisional and respectful manner, and not through a command and control bureaucracy (Holling and Meffe 1996). They draw upon Alvin Toffer's (1970) term "adhocracy" to describe this mode of organization. Their examples of where this adhocracy has successfully functioned is extensive and ranges from: disaster recovery after the 2010 Haitian earthquake; CeaseFire violence interrupters in Chicago; establishing marine protected areas in Palau; creation of an alternative currency (WIR) in Switzerland; facilitating cooperation in the Middle East; and, so on. They also demonstrated the problem when a system becomes structurally over-connected, as was the situation in the recent global economic collapse. From their examples and others (e.g., Gunderson et al. 1995; Wangchuk 2007; McCook et al. 2010; Coleman et al. 2011), it is clear that resilience can be encouraged and maintained through influence and coordination within a regional scale. It is a context where bureaucratic silos are not the solution, but where interest and effort needs to be woven within a network of individuals and institutions.

"Network weaving" is a term coined by Krebs and Holley (2006), to describe the iterative process for improving connectivity and building resilient community networks. As described, the weaving process involves four phases of development. The first phase, "scattered fragments", involves clustering of individuals or organizations with shared interests and goals. This is a relationship based out of necessity, and in the Fathom Five context may represent the connection between commercial operators and park managers. The second phase involves the emergence of a "single hub and spoke" network. Translational leader(s) at the hub become the network weaver(s). The leader(s) have the vision and social skills to establish connections. It is a period where authenticity must be high and ethics must be strong, as the whole network depends on the leaders themselves. Examples of such leadership may be represented in the efforts of Stan McClellan, the first superintendent of Fathom Five Provincial Park, or the community members and officials who established Fathom Five (NMCA) by bridging federal, provincial, and private lands and interests (for details see Werhum 1994; Day 2012). In the third phase, leaders transition from connectors to facilitators, guiding the development of new network weavers throughout the community. If successful a "multi-hub small world network" is created. Cognitive diversity and innovation increases as ties between groups of different perspectives are formed. Resiliency improves, since the creation of a multi-hub network has redundancies to prevent failure and sufficient connectivity to improve learning and knowledge sharing. Such a network does not currently exist in Fathom Five. The potential may exist in the park advisory committee, but the membership focuses very little on aquatic ecosystem conservation outcomes. Similarly, Parks Canada itself maintains relatively weak ties, at best, to the other organizations involved in aquatic ecosystem governance (e.g., Environment Canada/Ontario Ministry of Environment and water quality, Ontario Ministry of Natural Resources/Saugeen Ojibway Nations and fisheries, Municipality/Bruce County and coastal zone planning). The final phase of Krebs and Holley's model is called "core/periphery" and represents a vibrant and sustainable community network. The network core contains a hub of strongly affiliated members. The network periphery contains a constellation of more weakly tied communities or resources that operate outside the scale or scope of the core. While the periphery is exposed to new ideas and information, the core is able to act on that knowledge. The Niagara Escarpment World Biosphere Reserve, of which Fathom Five is a core protected area, could potentially serve such a network function. However, the terrestrial focus of this network has meant that there is limited influence on aquatic conservation in Lake Huron (the Georgian Bay Biosphere Reserve is more leading in this regard, www.gbbr.ca).

Lake Huron Partners and Networks

There is no guarantee that network weaving will build sufficient resiliency to any and all disturbances. Limitations in adaptive capacity or internal competition can certainly influence a network's effectiveness. Nevertheless, building a network creates the context, trust, and system feedbacks necessary for building or maintaining resilience. To explore this further, Tables 5.5 and 5.6 were prepared to introduce some of the networks, partnerships, and initiatives that have functioned in Lake Huron-Georgian Bay. Naturally, the diversity of agreements and initiatives referenced in the Tables raise several questions related to governance complexity, coordination difficulties, and accountability challenges. These are very real problems and concerns for the Great Lakes that others have discussed in detail (e.g., Francis and Regier 1995; Bails et al. 2005;

McLaughlin and Krantzberg 2012). At this time, my intent is to simply consider these for the purpose of identifying prospective models or network ties that may be of relevance to Fathom Five.

It is interesting that most of the contemporary organizations have connected to the lake as a whole – not around a single species or issue. Evidence of "stand-alone" agreements and piecemeal approaches to environmental issues appears to be more common in the past, before the emergence of ecosystem management approaches. Resilience may not be stated explicitly, but the holistic, long-term vision, and concern for issues other than peak efficiency (e.g., maximum sustainable yield in fisheries), complements resilience thinking. Unless mandated and funded to work lake-wide, most of the partnerships on Table 5.5 reflect a place-based approach. There are logistical reasons for this, including travel distance, specific ecological concerns (e.g., beach algal fouling, low lake levels), and an inherent sense of place or community. Nevertheless, they appear to express an "act locally and think lake-wide" mindset.

The GB-5 (Table 5.5), as an example, appears to function in a more adaptive, innovative, and resilient manner and most resembles the final phase in Krebs and Holly's model. Each of the five non-governmental organizations has their own niche and independence, and through self-organization found a means to compete on their differences and collaborate on their similarities. Common ground includes, creating an awareness of Georgian Bay and local sustainability concerns, building support for community involvement, a "take action" fortitude, and state of the bay monitoring and reporting. Through the leadership of each member group, they expanded their governance influence by engaging governments at all levels, created a shared vision, and built organizational capacity. They may not own real property or have legal managerial authority, but they found a means to advance conservation in their area of concern (and influence). This degree of coordination and communication on the eastern shore stands in contrast to the western shore of Georgian Bay where Fathom Five and a multitude of environmental non-governmental organizations are relatively disconnected.

At the scale of the lake, partnerships and networks appear to be a bit more scattered. There are, however, key organizations, including the Nature Conservancy of Canada (NCC), International Joint Commission, Environment Canada, Ontario Ministry of the Environment, and Ontario Ministry of Natural Resources, which provide the "core" for networks. This hub appears to be organized through agreements, such as the Great Water Quality Agreement (GLWQA) and the Canada-Ontario Agreement, and functional success may be related to legal obligations or funding opportunities.

The Lake Huron Binational Partnership (Table 5.6) stands out for its inclusive nature and lake-wide scope. Formed as an obligation under the GLWQA, the Lake Huron approach is reported as being distinct from the Lakewide Management Plan (LaMPS) structure adopted by the other four Great Lakes (EPA and EC 2008). While the Partnership maintains a close association with remedial action plans, Great Lakes Fishery Commission, State of the Lakes Ecosystem Conference, and other governance initiatives, it is the pursuit of community-based activities and flexible issue-by-issue membership which distinguishes it. For instance, the Lake Huron Biodiversity Conservation Strategy [6], (EPA and EC 2010), and the Canadian Framework for Community Action (LHCA 2007), are both outcomes of the Partnership.

Table 5.5 Examples of partnerships and networks on Lake Huron-Georgian Bay.

Name	Mission or Goal
Great Lakes and St. Lawrence Cities Initiative	GLSLCI is a binational coalition of mayors and other local officials that works actively with federal, state, and provincial governments to advance the protection and restoration of the Great Lakes and the St. Lawrence River. Web: www.glslcities.org
Council of Great Lakes Governors	The Council is a non-partisan partnership of the Governors of the eight Great Lakes States and the Premiers of Ontario and Québec to protect the region's natural resources and sustain a world-class economy. Serves as secretariat to the Great Lakes Compact. Prepared the Great Lakes Charter, to conserve water levels and flows. Web: www.cglg.org
Canadian Framework for Community Action	A community-based organizing framework and charter designed to empower people to take action to protect Lake Huron. Four Principles: 1) Build Awareness and Capacity; 2) Support Community Involvement; 3) Take Action; and, 4) Measure Success and Adapt. Web: www.lakehuroncommunityaction.ca
Healthy Lake Huron	A partnership between government and local organizations, with a focus water quality issues (e.g., bacteria, algae) from Tobermory to Sarnia. A strong land-lake linkage, with priority watersheds for collaborative restoration efforts being identified. Web: www.healthylakehuron.ca
Southern Georgian Bay Coastal Initiative	To work through multi-jurisdictional management issues to more effectively protect and conserve the coast from Tobermory to Port Severn. Co-chaired by the mayors of Blue Mountains and Wasaga Beach, with membership from government and non-government organizations. Examples of initiatives include harmonized shoreline development and coastal

[6] I was on Steering Committee.

Name	Mission or Goal
	mapping. The Lake Huron Centre for Coastal Conservation is a notable non-government organization (lakehuron.on.ca) involved with this and other networks in the area.
The GB-5	Cooperative alliance between five established associations on the eastern shore of Georgian Bay. Projects examples include, "State of the Bay" reporting, coordinated wetland strategy, and a charter and communication plan. 1) Georgian Bay Biosphere Reserve (www.gbbr.ca): Committed to world biosphere reserve concept, including conservation, education, and sustainable development. 2) Georgian Bay Forever (www.georgianbayforever.org): A community response to the growing need for scientific research and public education on Georgian Bay's aquatic ecosystem and the environmentally sustainable quality of life its communities and visitors enjoy. 3) Eastern Georgian Bay Stewardship Council (www.helpourfisheries.com): Part of Ontario's Stewardship Network. The goal is to be an effective facilitator of community participation and voluntary efforts that foster the establishment of healthy, productive and self-sustaining natural ecosystems. 4) Georgian Bay Land Trust (www.gblt.org): Mission is to preserve archipelago and adjacent waters. 5) The Georgian Bay Association (www.georgianbay.ca): Work towards the careful stewardship of the greater Georgian Bay environment. Strong interest in lake levels.
Great Lakes Sea Grant Network	US network focused on the health and sustainability of the Great Lakes through an integrated program that engages universities and public and private sectors. It is part of the National Oceanic and Atmospheric Administration (NOAA) Sea Grant College Program, which includes over 300 institutions involving more than 3,000 scientists, engineers, educators, students and outreach experts. Web: www.miseagrant.umich.edu/greatlakes
Severn Sound Environmental Association	A partnership between nine municipalities in the Severn Sound Watershed. To sustain environmental quality and to ensure continued protection through implementing a legacy of wise stewardship of Severn Sound and its tributaries Web: www.severnsound.ca
Anishinabek / Ontario Fisheries Resource Centre	A non-profit corporation established to provide independent information on fisheries assessment, conservation and management, promoting the value of both western science and traditional ecological knowledge. Board with equal representation from Native and non-Native Directors. Active throughout Canadian side of Lake Huron with exception of Saugeen Ojibway Nations territory. Web: www.aofrc.org
Nawash – University of Guelph Partnership	Partnership is designed to ensure that the First Nations fisheries on the Great Lakes benefit from an effective mix of scientific rigour, participatory decision-making, and cross-cultural communication of ecological knowledge. With these research tools available to them, First Nations such as Nawash can ensure that they are protecting their fisheries and associated Aboriginal and Treaty Rights for future generations. Web: www.nawash.ca
Sources of Knowledge	A non-profit corporation established to share knowledge and perspective from the Bruce Peninsula. Its origin rests within the Park Advisory Committee to Bruce/Fathom Five and its membership represents a cross-section of regional interests. Web: www.sourcesofknowledge.ca
Saginaw Bay Watershed Initiative Network	A community-based, voluntary initiative that connects people, resources, organizations, and programs to improve the quality of life and sustainability in Saginaw Bay. Web: www.saginawbaywin.org
Bruce Resource Stewardship Network	A program by the Ontario Ministry of Natural Resources, to support environmental stewardship and partnership in Bruce County. An example of a successful outreach project is the "Grey Bruce Children's Water Festival" (www.waterfestival.ca). Web:

Name	Mission or Goal
	www.ontariostewardship.org
Great Lakes Regional Collaboration Of National Significance	In 2004, a Presidential Executive Order promoted the formation of a Regional Collaboration of National Significance for the US Great Lakes. The federal Great Lakes Interagency Task Force, the Council of Great Lakes Governors, the Great Lakes and St. Lawrence Cities Initiative, Great Lakes tribes and the Great Lakes Congressional Task Force moved to convene a group known as the Great Lakes Regional Collaboration (www.glrc.us). In 2009, President Obama announced a new Great Lakes Restoration Initiative (GLRI) to advance the GLRC strategies and committed new funding toward Great Lakes restoration (glri.us/index)
Great Lakes United	A non-government organization concerned with the health of the Great Lakes. Not a clear network or partnership, but included here since it is a unifying body whose membership can include organizations and individuals. Web: www.glu.org.

Table 5.6 Related agreements and other initiatives.

Name	Mission or Goal
Great Lakes Water Quality Agreement (GLWQA)	A commitment to restore and maintain the chemical, physical and biological integrity of the waters of the Great Lakes Basin Ecosystem. Reaffirms the rights and obligation of the *1909 Boundary Waters Treaty*. Committed to the conservation of native species and habitat by identifying protected areas, conservation easements and other conservation mechanisms. Web: www.ijc.org.
International Joint Commission (IJC)	Established under the *Boundary Waters Treat*y to act as an independent international organization charged with preventing and resolving disputes over the use of water shared by the U.S. and Canada. Under the GLWQA, assesses progress to restore and maintain the integrity of the waters. Investigates and reports on transboundary air and water pollution, persistent toxic substances, exotic species, and other matters of common concern along the international boundary. Approves projects, such as dams or water diversions that affect water levels and flows across the boundary. Utilizes services of the Water Quality Board and the Science Advisory Board. Web: www.ijc.org.
Great Lakes Executive Committee	Formerly called Binational Executive Committee (BEC) is composed of senior-level representatives of Canadian and U.S. federal, state, provincial, and tribal agencies who are accountable for delivering major programs and activities that respond to the terms of the GLWQA.
Canada-Ontario Agreement (COA)	Canadian federal-provincial commitments to a healthy, prosperous and sustainable Great Lakes. Implementing the Agreement contributes to meeting Canada's obligations under the GLWQA. With respect to Lake and Basin Sustainability the Parties agree to "Conserve and protect aquatic ecosystems, species and genetic diversity of the Great Lakes Basin". Web: www.ec.gc.ca/grandslacs-greatlakes.
Lake Huron Binational Partnership	Its origin (ca. 2002) relates to the Great Lake Water Quality Agreement and stands as partnership to coordinate lake-wide environmental activities between Canada and the US. Co-chaired by Environment Canada and the US Environmental Protection Agency. Membership includes government, non-government organizations, Tribes/First Nations, and the public. Facilitates information sharing and priority setting for binational environmental protection and restoration activities. Web: binational.net

State of the Lake Ecosystem Conference (SOLEC)	In accordance with the GLWQA, a conference every 2 years since 1994. Independent, science-based reporting on the state of the health of the Great Lakes. Strengthens decision-making and environmental management. Provides a forum for communication and networking. Web: binational.net.
Great Lakes Fishery Commission (GLFC)	Established by the *Convention on Great Lakes Fisheries* between Canada and the United States in 1955. Coordinates research programs, recommends measures, which will permit the maximum sustained productivity of fish stocks and, implements programs to eradicate or minimize sea lamprey populations. Developed fish community and habitat objectives for Lake Huron. Web: glfc.org
Lake Huron Biodiversity Conservation Strategy	A binational effort to summarize information about the lake's ecological systems, natural communities, species, and threats, and propose an international strategy for conserving the biodiversity of Lake Huron. With input from nearly 400 individuals and over 100 agencies Web: conserveonline.org
The Great Lakes Basin Compact	"To promote the orderly, integrated and comprehensive development, use and conservation of the water resources of the Great Lakes Basin". The Compact created the Great Lakes Commission, a nonpartisan agency with statutory responsibility. The Commission is involved with policy development, coordination, and advocacy on issues of regional concern, as well as communication and research services. All eight US states are members and Ontario and Québec are associate members. Web: www.glc.org. The Commission also manages the Great Lakes Information Network (GLIN), a partnership that provides online information relating to the Great Lakes Web: www.great-lakes.net
Great Lakes Public Health Network	All 37 public health units and key federal and provincial departments sharing information on environmental health issues (e.g., fish consumption, beach closings, air pollution, etc.).
Canada-US Air Quality Agreement	A 1991 agreement between Canada and the US that provides a mechanism to address shared concerns for trans-boundary air pollution. Web: www.ec.gc.ca/Air
Great Lakes Binational Toxic Strategy	Canada - US Strategy to work toward the goal of virtual elimination of persistent toxic substances resulting from human activity, particularly those which bioaccumulate. Web: binational.net/bns/strategy
(proposed) Great Lakes Protection Act	The proposed Act (June 2012) would empower the province of Ontario to take targeted action to improve water quality, and protect coastlines, beaches and wetlands, with the overall intent of helping to attain Great Lakes that are *drinkable, swimmable, and fishable* Web: www.ebr.gov.on.ca.

It is interesting to note the degree to which institutions are organized around the Great Lakes ecosystem. Whereas, we do not readily identify Canada – US agreements to protect species within the Eastern Great Lakes and Hudson Lowlands terrestrial ecoregion, we do see binational agreements in place to protect species within the aquatic ecosystems of the Great Lakes (Table 5.6). Furthermore, the single issue focus (e.g., pollution, fisheries) of the past, evolved into an ecosystem management approach, and more recently includes the maintenance of ecosystem resilience within the Great Lakes (e.g., Bails et al. 2005; IJC 2012a). For instance, the formation of the Great Lakes Fishery Commission (GLFC) advanced a coordinated binational program for sea lamprey control and fisheries research. Early objectives for the GLFC in Lake Huron were very much focused on maximum sustainable yield of single species, however in more recent years this emphasis has shifted to communities and entire ecosystems (Desjardine et al. 1995), and the word resilience can now be found in the latest environmental objectives (Liskauskas et al. 2007). Similarly, the 2012 Great Lake Water Quality Agreement (IJC 2012a), now includes an Annex 7, whose purpose is to conserve, protect, maintain, restore and enhance the resilience[7] of native species and their habitat, as well as support essential ecosystem services. While the incorporation of resilience goals is significant, the demonstration of international cooperation and ecosystem management is also of importance. Not only does this provide a role model for partnership behaviour, it creates opportunity for community scale projects through priority setting, program funding, and support.

The Canada-Ontario Agreement Respecting the Great Lakes Basin Ecosystem (COA) is the federal-provincial agreement to support the GLWQA. It identifies conservation priorities and helps to coordinate and fund interagency efforts. Parks Canada is a signatory to COA, but to date has played a relatively minor and inactive role in the Agreement processes. COA is currently under re-negotiation and given the 2012 Annex 7 obligations related to species and habitat protection, this could be an opportunity for Fathom Five to become more relevant and representative on Lake Huron-Georgian Bay. Furthermore, Ontario’s Great Lakes Strategy (Ontario 2012) refers to protecting natural habitats, biodiversity, and resilience of the Great Lakes, and the province has also committed to developing aquatic class provincial parks (Ontario 2006). Few agencies have the experience or mandate like Parks Canada to establish and manage protected areas. Contributing to the delivery of Annex 7 and collaborating and networking with the province in protecting the Great Lakes, would provide needed context, connectedness, and feedback for Parks Canada and potentially strengthen resilience at Fathom Five.

The *National Framework for Canada's Network of Marine Protected Areas* provides strategic direction for the design of a national network of marine protected areas (Canada 2011). It was approved by Canada’s federal, provincial, and territorial members of the Canadian Council of

[7] Personal communication with the Annex 7 lead for Environment Canada in September 2012 confirmed that the concept of resilience and applicable tools are yet to be defined and developed.

Fisheries and Aquaculture Ministers. The vision for the network is: "*An ecologically comprehensive, resilient, and representative national network of marine protected areas that protects the biological diversity and health of the marine environment for present and future generations*". As introduced in Chapter 1, Parks Canada is the only federal agency with a mandate to establish representative protected areas. Since the province of Ontario has a similar mandate (Ontario 2006), the potential for collaboration in network establishment is clearly furthered by the direction of this framework (Canada 2011).

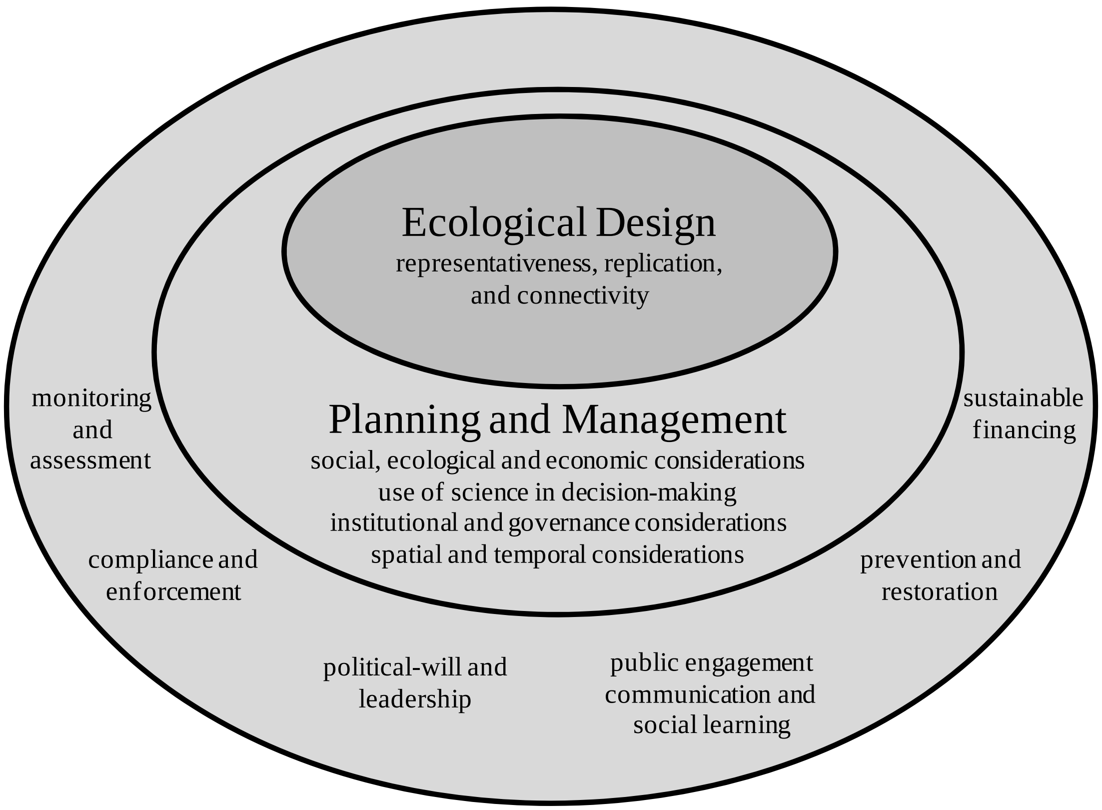


Figure 5.1 Important elements of a network (adapted from, IUCN WCPA 2008). In Fathom Five the potential network should be seen as including crown and non-governmental organization lands (e.g., NCC, Ontario Nature, Escarpment Biosphere Conservancy, etc...) and other civic interests.

While Tables 5.5 and 5.6 provides examples of integrative networks, partnerships, and initiatives, additional considerations and practicalities emerges from the review. Figure 5.1 illustrates the overlapping sets of practices and processes that are important to developing a sustainable and resilient network that includes protected areas. For Fathom Five to become a more networked and collaborative management body, the park may want to consider the following:

- Conduct a regional gap and network analysis (e.g., Langhammer et al. 2007) to identify important biodiversity areas, conservation opportunities, and essential design elements such as corridors, stepping stones, and buffer zones. Recognizing that well-planned networks improve resilience by maintaining connectivity and ecosystem processes, and help to spread the risk associated with local disaster or management failure (National Research Council 2001).
- Establish a network for existing protected areas on Lake Huron-Georgian Bay (e.g., coastal provincial parks, NCC, and municipal lands). Initially, the network may focus on learning from experience and collaboration on shared concerns.
- Develop a resilience-based communication strategy: to provide key messaging to the community, partners, and other government departments; to create media interest; and, to integrate with regional partnerships and decision-makers (e.g., NCC, municipality, Southern Georgian Bay Coastal Initiative, SON, etc…).
- Encourage regional stewardship and involvement programs (e.g., restoration, inventory, monitoring). Enhance education and research opportunities. Create learning opportunities related to concepts such as connectivity, conservation, and resilience and develop a resilience toolkit (e.g., similar to the Reef Resilience Toolkit, www.reefresilience.org).
- Develop mechanisms for partner support, such as sustainable funding and in-kind contributions. Again, develop a resilience toolkit, and also include support for partnerships and projects (e.g., similar to the Wetkit, www.wetkit.net, with policies, data, best management practices, etc…).
- Identify a partner and network coordinator for Fathom Five whose responsibilities and accountabilities are tied to building relationships, awareness, and opportunities. The coordinator would maintain a partner/network database, and recognize and acknowledge accomplishments.
- Develop a regional social and ecological science advisory board to review key problems and consider emerging issues.

- Contribute to a governance watch program that monitors and evaluates activities and decisions across-scales.
- Develop harmonized policies and procedures where possible, e.g., shoreline development permitting, ecological monitoring and inventory. The intent is to share knowledge and better integrate in decision-making processes.

Databases

As stated by Zolli and Healy (2012), "adhocracies thrive on data". They cite examples of how modern open data source platforms are revolutionizing resilience-based projects worldwide, such as the crisis reporting capacity of Ushahidi (www.ushahidi.com) and the water and sanitation reporting capacity of FLOW (www.waterforpeople.org). During the course of this study, I benefitted from the accessibility of open source software, such as R (www.r-project.org) for statistical analysis and Marxan (www.uq.edu.au/marxan) for geospatial decision support, and also important data sources. As an observation, with respect to Lake Huron I found that American institutions did a much better job of data sharing than Canadian institutions. Leading American examples included the Great Lakes Information Network (www.great-lakes.net), National Oceanic and Atmospheric Administration's (NOAA) Great Lakes Environmental Research Laboratory (www.glerl.noaa.gov), and ArcGIS Online (www.arcgis.com). GeoConnections (geoconnections.nrcan.gc.ca) and the Hydrographic Service (www.waterlevels.gc.ca) were examples of Canadian sites that had some Lake Huron data. I sensed that the difference between the two nations reflected America's higher capacity for data collection and stronger culture for data sharing (e.g., it is legislated in the "America COMPETES Act" of 2007). In time, this disparity may resolve itself if the intended outcomes for better information and data sharing as specified in Canada's Action Plan on Open Government (Canada 2012a) are realized.

The natural outcome of openness and accessibility to data is the potential for better collaboration and more informed conservation planning. As mentioned briefly in Chapter 3, the Ecosystem-Based Management (EBM) Tools Network (www.ebmtools.org) maintains a comprehensive repository of coastal and marine decision-support tools. A query of their database for resilience tools revealed several promising examples to assist protected areas and their communities map thresholds, rehearse different outcomes, and plan for a desired and resilient state. For example, the Marine InVEST software (www.naturalcapitalproject.org/InVEST.htmlsoftware) is designed to work with stakeholders to identify critical management decisions and to develop future management scenarios with different options (e.g., climate change, population growth). The outputs include maps and other information about alternative costs, benefits, tradeoffs, and synergies. As another example, CommunityViz (placeways.com/communityviz/) is a software extension of ESRI's ArcGIS which is able to create alternative scenarios, organize information, and form a framework for cooperative decision-making. This tool, coupled with NatureServe Vista (www.natureserve.org/prodServices/vista), was, for instance, important to the "Creating Resilient Communities Initiative" in South Carolina (Hittle 2011). Marxan with Zones is also found within the EBM Tools database. As I demonstrated in Chapter 3, it is a decision-support tool that can be used to solve spatial conservation planning problems. Obviously, all such tools are dependent on data and the socio-political context they are utilized.

Zoning

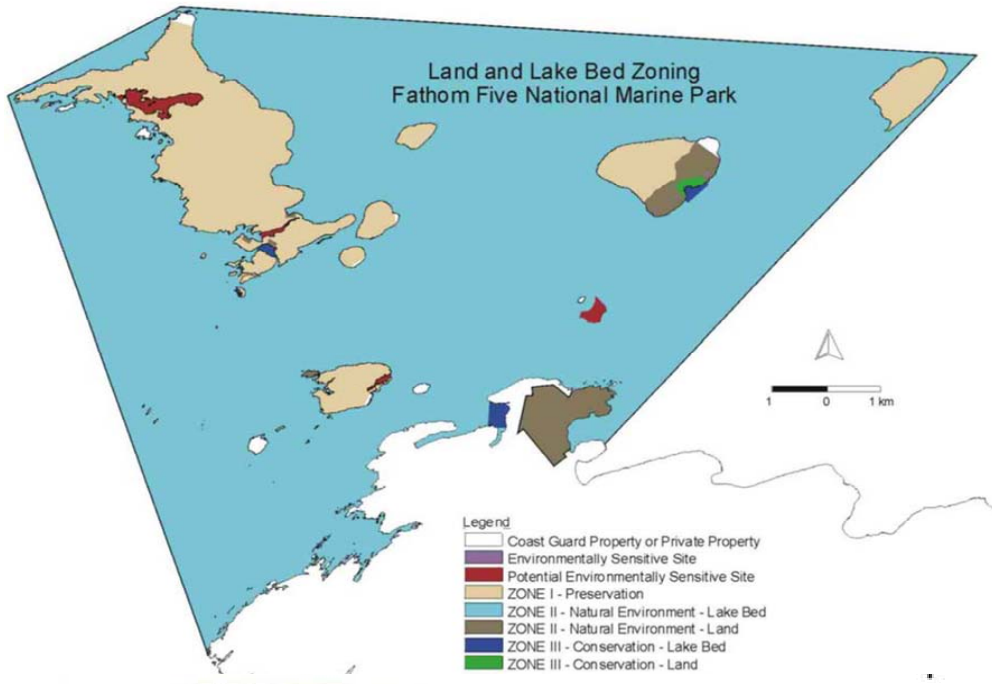
As described in Chapter 3, zoning is a spatial planning tool that designates areas according to social and ecological attributes and sensitivities. It is routinely applied within protected areas to minimize user conflicts and provide a basis for protection (Day 2002; Geneletti and van Duren 2008; Klein et al. 2009). A weakness of the current zoning plan for Fathom Five (Parks Canada 1998) was the fact that it failed to fully protect representative or important features in the aquatic ecosystems of the park (Figure 5.2 (A)). The resilience-based approach developed in Chapter 3 was able to incorporate: structural and functional diversity of the desired state; elements that support general resilience and system recovery, including connectivity, representativeness, and replicates; and, recognized governance, ownership and other potential constraints.

Databases, including GIS layers, related to aquatic ecological structures and functions were initially very limited. However, in the course of the study I was able to generate a classified lakebed map, fish habitat models, chlorophyll *a* productivity layer, fetch models, and ice coverage layer using contemporary mapping techniques including multibeam sonar and remote sensing imagery. This provided a suite of basemaps for the Marxan analysis, but also highlighted data inadequacies and needs. For instance key uncertainties with respect to currents (e.g., larval distribution), socio-economic costs, deepwater ecosystem inventories, and other features remain. As well, future iterations would benefit from larger scale datasets and analysis.

While the Marxan outputs (e.g., Figures 3.2, 3.3) can provide efficient and effective solutions, they may not be in a form ready for operational implementation. Describing zones for legal purposes or simplifying to meet visitor needs is challenging enough on water, and becomes more so if the zones are patchy and irregular. To this end, Figure 5.2(B) represents my operational interpretation of the Marxan results and a draft example of a final zoning plan that could be implemented from Fathom Five. Headlands, bathymetric depths, and lines of latitude/longitude are used to facilitate geo-referencing. However, to gain public support and general compliance, this final zoning plan interpretation exercise, as with all stages in the Marxan process, would benefit from meaningful public and partner engagement in the process (Kenchington and Day 2011). Figure 5.2 provides a contrast between the existing zoning context (A) and the advances in resilience-based conservation (B) that I am proposing. The most noticeable difference is the presence of Zone 1 preservation areas in the resilience-based approach.

Post-implementation monitoring and assessment of zoning plans is important to validate the model and determine if the protected area goals are being met (Davis 2005). The zoning plan can be treated as part of an adaptive management study design (sensu Holling 1978), with explicit goals and monitoring components. This would not only provide a foundation for learning and adaptive management, but would provide openness and transparency to overall governance. Intuitively, facilitating efforts to establish sympathetic or complementary zoning within the greater park ecosystem would more likely be adopted if success within Fathom Five could be demonstrated.

(A)



(B)

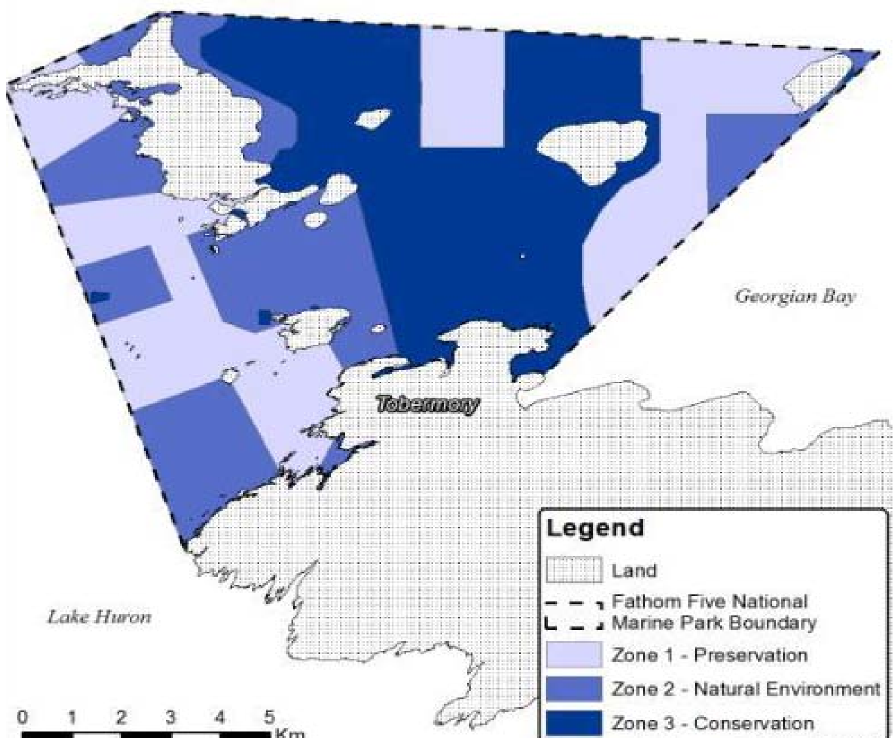


Figure 5.2 Fathom Five zoning. (A) represents the approved plan (Parks Canada 1998). Note the absence of full protection zones, (Zone 1) within the aquatic ecosystems. (B) represents a draft of an operational interpretation of the Marxan results in Figures 3.2 and 3.3. Islands were not zoned as part of this study. See Table 3.2 for zone descriptions.

Although the outputs from the Marxan zoning exercise in Chapter 3 demonstrated a proof of concept, the opportunity to include this approach within the park planning process is currently on-hold along with the entire planning process. Future iterations will require working through the process again with the park and community to build consensus around conservation targets and trade-offs[8]. Such engagement can support social learning and build relationships and trust with those involved. Moving forward with a shared understanding of the risks and uncertainties is important, there is no certitude that the outcomes will necessarily be the right solution or resilient to all disturbances. However, as stated by Zolli and Healy (2012), *"A community that learns to discuss one possible disruption is better prepared to deal with any possible disruption*".

Monitoring

In 1973, Holling opined about monitoring resilience, that "...*measures require an immense amount of knowledge of a system and it is unlikely that we will often have all that is necessary*" (Holling 1973). Decades later, the development of measures is still constrained by sufficient data and analytical techniques (Hastings and Wysham 2010), and complex, nonlinear, and self-organizing ecosystem behaviour (Kay and Boyle 2008). However, Carpenter and Brock (2006) observed that the variance of lake phosphorus increased prior to a regime shift and that such an increase in variance may be applicable to other ecosystems and regime shifts. This system response has been confirmed by others (e.g., Kerkhoff and Enquist 2007; Guttal and Jayaprakash 2009; Scheffer et al. 2009; Dakos et al. 2010), but the wide-spread development of predictive measures has been limited.

The investigation described in Chapter 4 was an attempt to understand the condition of Fathom Five's coastal wetlands and develop a method to monitor system variability in terms of resilience. The traditional approach to monitoring these wetlands was based on indices developed by Dr. Pat Chow-Fraser and colleagues (Chow-Fraser 2006; Croft and Chow-Fraser 2007; Seilheimer and Chow-Fraser 2007) (see Appendix 3 for more monitoring results). The

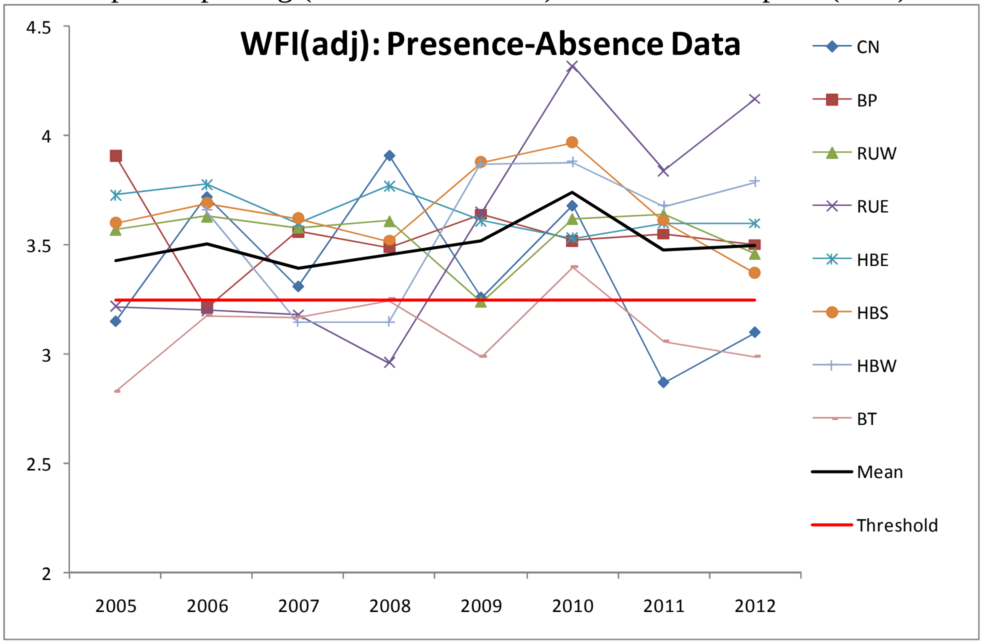
[8] I presented preliminary resilience-based concepts to the Fathom Five management planning team in 2011, but the management planning process is officially on-hold as of December 2012.

wetland fish index, for example, is derived from an ordination of over 150 coastal wetland throughout the Great Lakes (Seilheimer and Chow-Fraser 2007). As Figure 5.3 (A) illustrates, the mean value for all samples in a given year is plotted against a pre-established condition value threshold. Thus, it provides a method to report on the condition of the park wetlands by comparison to other sites on the stress gradient (anthropogenic impacts). While this effectively answers specific monitoring questions related to the relative condition of the wetlands, it does not report on system variability.

The resilience-based approach (Figure 5.3(B)) utilizes a control chart method (Anderson and Thompson 2004) to assess and monitor system dynamics within the study area. As was introduced, an increase in variability is perceived to be an indication that system feedbacks, and hence resilience, are weakening. Although Chapter 4 explored and discussed explanatory variables, an exact understanding of the cause is not necessary, i.e., the method is sensitive to fish assemblage change. Both monitoring methods have merit, but the control chart provided a unique insight into system dynamics, and a potential alarm to either prevent or guide a regime shift in a timelier manner.

In addition to monitoring for a regime shift, a well-designed monitoring program can help a protected area to: support an adaptive management project; improve accountability and management effectiveness; justify resource needs; build community and partner support; and, identify planning and priority needs (IUCN WCPA 2008). Although Fathom Five has developed its own state of the park reporting (Parks Canada 2011) for the park scale, integrating with the lake-wide program (i.e., SOLEC 2009) would provide needed perspective, better data, and the benefit of collaboration.

(A) Wetland Fish Index (WFIadj) calculated from presence-absence data (Seilheimer and Chow-Fraser 2007). Threshold (red line) is the line between good (>3.25) and fair (<3.25) wetland condition and the mean (black line) for all site is assessed against this for state of the park reporting (Stabler et al. 2011). A threshold to poor (<2.5) also exists.



(B) Resilience-based approach using a control chart method (Chapter 4).

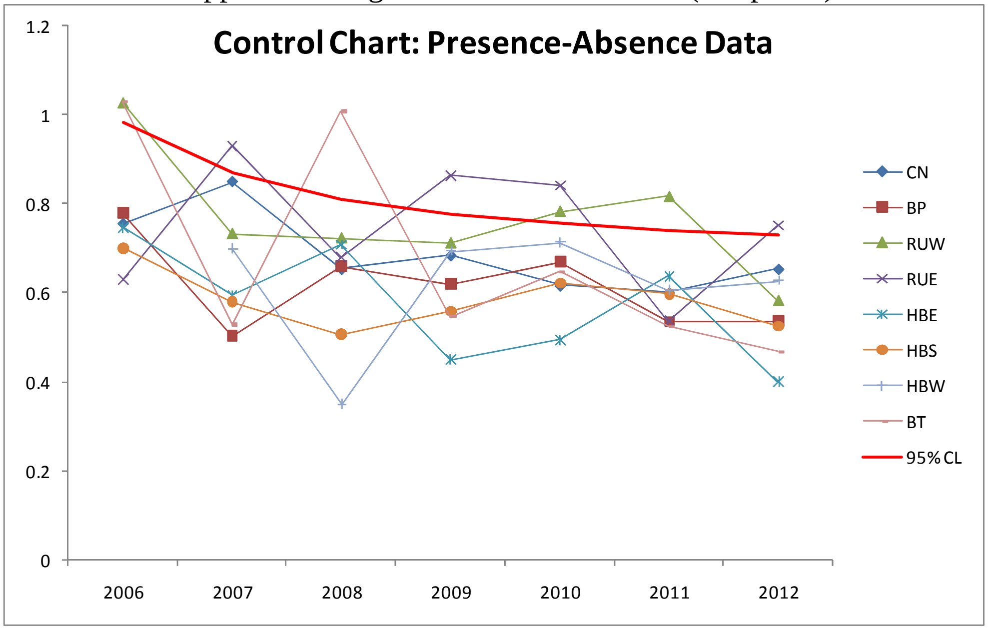


Figure 5.3 Two different methods to analyze monitoring data from Fathom Five's coastal wetlands. (A) is the current approach and is an index value for the mean of all sites representing good, fair, or poor condition. (B) is the proposed resilience-based approach and uses a control chart to assess increases in variability at each site. Sites codes on Table 4.1.

Recommendations

The general purpose of this study was to understand and apply the concept of resilience within a freshwater protected area. Specific objectives included the development and testing of resilience-based methods for zoning and monitoring. As was learned, managing for resilience can be categorized into several actions: those that aim to reduce the vulnerability of a site to disturbance; those that promote recovery and renewal; and, those that attempt to navigate transitions to alternate states (Gunderson et al. 2010). Having reviewed the thesis with these thoughts in mind, the following recommendations are provided to advance resilience thinking at Fathom Five.

- Engage partners and stakeholders in a process to identify the desired social-ecological system state at the park and regional scales. Integrating a cross-scale of perspectives to define resilience *of* what, *to* what, and *for* whom is important (Carpenter et al. 2001; Lebel et al. 2006).
- Experiment with new policies and practices at the local scale to achieve strategies identified in Table 5.4, and support policy reform and management tool development at the national NMCA program scale. This includes citing resilience as a goal and adopting double-loop learning processes.
- Repeat the Marxan zoning method (Chapter 3) within the next management plan review and public consultation. Then treat the zoning outputs as part of an adaptive management study (sensu Holling 1978), where the zones form the basis of a hypothesis in which to be monitored, evaluated, and modified as needed. Recognize the importance of representativeness, replication, and connectivity of biodiversity and ecosystems in the zoning process.
- Include the control chart method for monitoring coastal wetlands within the state of the park reporting.
- Complete a network analysis of the regional social-ecological system, including governance structures. The development and sharing of common base layers and on-line database's would contribute to regional resilience-based projects, including research, monitoring, education, and planning initiatives.

- Foster collaborative governance through regional and lake-wide partnerships and networks. Continue to resolve governance issues including park establishment and fisheries management issues. Where possible, harmonize policies and practices (e.g., shoreline development permitting process) with other agencies. The intent is to create a more accountable, adaptive, and participatory governance structure.
- Encourage cross-cultural immersion and secondments of park staff with other organizations on Lake Huron. Ideas and innovation can help break down established pathological behaviours.

Chapter Summaries

Chapter 1 provided an introduction to the theories and concepts of resilience. Resilience relates to a system's capacity to absorb disturbance and still maintain its identity. Managing for resilience involves an appreciation of the system's thresholds, alternate states, and linked adaptive cycles. Thesis purpose and objectives were also provided.

Chapter 2 demonstrated how the theories and concepts of resilience can be applied in a practical sense by incorporating within a protected area management cycle of assess, plan, and implement. The approach was able to describe and assess the attributes of a resilient and desired state in Fathom Five. Although variable and adaptive, the desired state was defined by key structures, functions, and feedbacks. This moved the conservation goal from a traditional focus on historic conditions and species composition, to one that was more centred on the general identity of the system. Given the drivers and context of ecological change on the Great Lakes, the resilience perspective and chapter recommendations provided important management options to embrace such change, complexity, and uncertainty. From this Chapter, it appeared that the interplay between the governance and ecosystem domains are the most important challenge at this time. Governance has been defined as the, "*interactions among structures, processes and traditions that determine how power and responsibilities are exercised, how decisions are taken, and how citizens or other stakeholders have their say*" (Graham et al. 2003). Being able to agree on a desired state, with all its political and ecological tradeoffs and priorities, and then manage for resilience, with capacity for self-organization, flexibility, adaptation, and learning, is clearly a daunting task. Especially in light of the issues related to legitimacy, accountability, and connectivity identified for Fathom Five (Appendix 1). Specific recommendations to strengthen resilience (Table 2.3) were based on the general strategies summarized on Table 5.4.

Chapter 3 demonstrated an original approach to zoning by incorporating resilience-based features within the geospatial decision support tool Marxan with Zones (Watts et al. 2008a; Watts et al. 2009). The analysis was able to meet target values of representativeness, replication and connectivity of desired structures and functions. Replicates of representative structures and functions help to mitigate the risk associated with disturbances. They act as sources of “seed” and when connectivity is maintained, can assist in system recovery (Elmqvist et al. 2003, Folke et al. 2004). The results and target values are however only a proof of concept, a hypothesis, and similar to the results of Chapter 1, provide a context and framework for an adaptive management design.

Chapter 4 provided an analysis of eight years (2005-2012) of multivariate coastal wetland data (i.e., fish, environmental, and plant), which I collected, to assess variability in fish assemblages. It has been reported that dynamics begin to fluctuate, including a rise in variance, when a system approaches a regime shift (Carpenter and Brock 2006). The analytical methods, including ordination and control chart techniques (Anderson and Thompson 2004), reduced the data and provided insight on changing patterns of system behaviour. The results did not show evidence of a pending regime shift, but given the relatively short period of sampling, such an outcome was not expected. The control chart method showed merit for monitoring resilience, and with future sampling the confidence intervals will continue to tighten and allow the signal of change to be heard more loudly in the noise of natural variability.

Conclusion

While there is no single path towards resiliency, every traveler must explore in an iterative and honest manner the vulnerabilities, feedbacks, and thresholds within their own system. I am confident that I have demonstrated how resilience can be incorporated within the management practices of a freshwater protected area. Looking through a resilience lens not only provided a valuable perspective on ecosystem behaviour, but was also an opportunity to reflect on social learning and governance needs. As Lake Huron continues to experience profound ecosystem changes, protected areas like Fathom Five will be forced to rethink their stewardship efforts. Although resilience will not provide certainty, I feel it will better prepare the park for whatever comes next.

Appendix 1. Supplement to Chapter 2: System thinking in Fathom Five.

Introduction

The purpose of this appendix is to provide a more detailed understanding of the context and challenges facing Fathom Five National Marine Park. It begins with Table A1.1, which provides a chronology of the critical events and actions that have influenced Lake Huron and Fathom Five. From here, more specific descriptions and models are provided for the offshore, coastal, island, and governance systems or domains. The review provides a general sense of the feedbacks, context, and connectedness of the respective components. The content is drawn from Parker and Munawar (2001), the Lake Huron Environmental Objectives (Liskauskas et al. 2007), and the Lake Huron Binational Partnership Action Plan (EPA and EC 2008) and additional citations are included as needed. A summary of the spatial and temporal factors affecting Fathom Five is provided on Table A1.3. Scientific name for fish species are referenced in Table A3.6.

Table A1.1 A timeline for Lake Huron with emphasis on the events and actions that have changed the social-ecological composition, structure, and function of Fathom Five.

Time	Social	Ecological
B.C.E.		
10,000		Laurentide Ice Sheet retreats. Initially tundra-like with such species as grizzly bears, woolly mammoths, and lemmings. Succeeded by boreal forest (e.g., spruce, jack pine) and such species as giant beavers, Scott's moose, flat-headed peccaries, Jefferson mammoth and American mastodon. Early fish colonization from Mississippian refugia.
9,000		Inundated by pro-glacial Lake Algonquin. Sediment laden waters deposit thick layers (>35m) glacio-lacustrine clays in park area.
8,000	Palaeo Period (9,500-7,500B.C.), first people, nomadic hunters. Sheguiandah site on Manitoulin Island.	Mass extinction of most large mammals (e.g., short-faced bear, giant beaver, mammoths and mastodons).Submerged rooted tree stumps in park are from this general time period,
7,000	Archaic Period (7,800-1,700B.C.), increase in lithic materials and copper. Maritime adaptations. Sites within park.	Water levels drop and flow north-eastward from Lake Stanley to Lake Hough through river channels in park area. Temperature and precipitation increased creating favourable conditions for red/jack pine, white pine, hemlock and deciduous forests.
3,500		Isostatic rebound closes outlet at North Bay, lake levels reach high of 195m asl inundating area. Eventually water levels became what they are today with establishment of St. Clair River drainage.

Time	Social	Ecological
1,000	Woodland Period (1,000 B.C. – 1,650 A.D.) characterized by use of ceramics. Introduction of agriculture and more permanent settlements, however only campsites found in park area. Area part of trade route between Lake Superior and Gulf of Mexico.	
C.E.		
1000		Several still living cedar trees of today are from this generation.
1300	Odawa on Manitoulin Island made seasonal excursions for fishing, hunting and gathering. Fish dominated trade (rather than beaver) for corn, nets, and shell beads at Huron-Petun village near Port Elgin. An estimated 60,000 – 177,000 people live in Great Lakes Basin.	
1610	Étienne Brûlé is the first European to travel to Georgian Bay. In 1612 he returns as the guide to Samuel de Champlain. Bay titled "Sweetwater Sea".	
1640s	Guns enter fur trade. Bruce Peninsula was depopulated by the Odawa during and following Iroquois Wars (1641-1701).	
1670s	Report of Jesuit mission in park area.	
1679	*Le Griffon* first sailing vessel in upper Great Lakes.	
1700s	Ojibway, including Ottawa, resettle area.	
1763	Royal Proclamation ensuring the protection of Aboriginal lands, including Saugeen Ojibway Nations.	
1800		Beaver populations near extinction.
1812	War of 1812, followed by Rush-Bagot agreement (demilitarization of Great Lakes) and establishment of Royal Navy station at Penetanguishene.	
1815	Lake Huron-Georgian Bay charted. Sail commonplace.	
1834	Local commercial fishing license implemented due to concerns with U.S. fish companies.	
1855	Township surveyed.	
1827	Treaty surrender of "Western District".	
1829		Welland Canal opens allowing ocean going vessels and invasive species (e.g., sea lamprey) to enter upper Great Lakes.
1830s	Captain Alexander MacGregor commercially fishes area and names Tobermory.	
1836	Treaty No. 45 ½, Surrender of Southern Saugeen and Nawash Territories.	
1846	Bruce Mines first commercially successful copper mining area in Canada.	
1854	Treaty No. 72, Surrender of the Saugeen Peninsula.	
1855	Railway to Collingwood, Owen Sound, Midland offers short cut to eastern markets.	
1858	Cove Island lighthouse lit.	
1860s	Fishing stations at Cove and Russel Islands.	
1863	Oil found in Petrolia	
1867	Canadian Confederation.	
1869	Bury Rd surveyed and slashed out (Tobermory to	

Time	Social	Ecological
	Lindsay Township).	
1871	First settler in Township.	
1870s	Lumbering begins (Cook & Brothers Lumber Company of Toronto) and the boom ends early 20th century. Illegal stone quarry operated in Tobermory harbour. Logging boom for pine, hemlock, cedar ties (1870-1910).	
1880s	Control of fishery in area rests with a few large enterprises (e.g., Buffalo Fish Company). Lumber mill in Tobermory. Pathmaster's assigned to maintain road to Tobermory.	
1882	First steam tugs in Tobermory.	
1886	The town plot of Bury (Tobermory) opened for sale. Sail power in decline.	
1901	Population of Tobermory 623 (highest until 1970s). Tourists begin to venture into Tobermory.	
1909	Boundary Waters Treaty, led to formation of International Joint Commission (IJC) in 1912.	48 lb lake trout caught in Tobermory.
1912	Wireless station built in Tobermory.	
1913		Great Lakes storm disaster (November 7-10, 1913).
1916	The Migratory Birds Treaty created.	
1920s		Rainbow smelt introduced.
1921	Harry Tucker, a barrister in Owen Sound, advocates for inclusion of Flowerpot Is. in national park,	
1930	Flowerpot Island established as part of Georgian Bay Islands National Park (GBINP) at a cost of $165. Gas powered tugs in service.	Sea lamprey enters and begins to devastate commercial fishery. Followed by alewife.
1931	S.S. Kagawong initiates ferry service between Tobermory to Manitoulin. Fish guiding starts.	Remedial work to protect sea stacks on Flowerpot Is initiated (and again in 1933, 1956).
1935	Channel deepened and landing dock installed to improve boat access to Flowerpot Is.	
1936	Flowerpot Is. trails built,	
1940s	Industrialization of Great Lakes – chemical, rubber, steel, and other materials to support war.	
1950s	Steel-hulled diesel "turtle" tugs characterize local gill-net fleet. Area explored by scuba divers. Chainsaws introduced.	Lake trout population collapses while alewife populations explode. Fishery focussed on lake whitefish and bloater chub.
1954	Canada-US Convention on Great Lakes Fisheries leads to formation of the Great Lakes Fishery Commission (1955). Hwy 6 completed.	
1960s	Recreational fishery develops. Nylon gill net.	Sea lamprey control and stocking pacific salmon species (to control alewife).
1964	Scuba diving potential and pillaging of *W.L. Wetmore* generates idea for an underwater park.	
1968	A University of Waterloo term paper, "Shipwrecks of the Bruce Peninsula: A Recreational and Historical Resource", by D.A. Good (1968), inspires Ontario Ministry of Natural Resources (OMNR) to propose an underwater park.	
1970s	Era of growing public concern with chemical pollution. Tobermory tourism economy grows.	Persistent, bioaccumulative, and toxic chemicals such as PCBs, DDT, dieldrim, dioxins, and furnans are found in fish. Since the 1970's a decline in the concentration of many has occurred.
1971	Fathom Five Provincial Park boundary legislated.	

Time	Social	Ecological
	1973 park opened. Recognized as Canada's first underwater park.	
1972	Great Lakes Water Quality Agreement first signed.	
1973	Niagara Escarpment Planning and Development Act enacted, includes Fathom Five.	
1974	MS Chi-Cheemaun operational. Fathom Five mainland "land base" purchased.	
1980	Additional islands added to GBINP, including Cove, Bears Rump, Russel, North Otter and South Otter.	
1984		Spiny water flea introduced.
1985	The Great Lakes Charter created, annex on large-scale water diversion formed in 2001.	
1986		Record high lake level (~ 1.7m higher than 2012).
1987	Fathom Five National Marine Park establishment agreement signed. Park Advisory Committee established. Great Lakes Water Quality Agreement amended, identifies 43 Areas of Concens.	
1990	Designated a core area in UNESCOs Niagara Escarpment World Biosphere Reserve.	
1990s		Invasive zebra and quagga mussels and round goby introduced and begin spread into Lake Huron.
1993	R. v. Jones and Nadjiwon case reaffirmed Saugeen Ojibway's Aboriginal and Treaty Rights to fish for and trade/barter in traditional waters.	Decline in Diporeia begins.
1994	Guiding Principles and Operational Policies: national marine conservation area policy released	
1996	Echo Island added to park.	
1998	Fathom Five Management Plan approved.	Increase in Type E botulism death in aquatic birds.
1999	Northern Bruce Peninsula Municipality amalgamation.	
2000	Fisheries agreement between Parks Canada, OMNR and Saugeen Ojibway Nations (SON) collapses. However, SON and OMNR enter cooperative fisheries management agreement. $14 million buyout of 10 non-native commercial operators, commercial fishery in area is now exclusive to SON members.	Bloater decline. Four of the six deepwater cisco species extinct or extirpated. Period of prolonged low lake levels begins.
2003		Collapse of alewife. Zooplankton, prey fish and salmon biomass decline.
2005	Fathom Five lakebed transfer to Parks Canada reaches an impasse.	
2006	Permanent park visitor centre opened.	
2008	Great Lakes--St. Lawrence River Basin Water Resources Compact ratified which includes a ban on new large-scale water diversions outside of Great Lakes basin.	
2010	Lake Huron Biodiversity Conservation Strategy completed. Over 37 million people live in Great Lakes basin. Fathom Five hosts over 400,000 visitors (ferry included), 10,000 boaters and 5,000 divers annually.	Lake trout and lake herring populations recovering. 185 known non-native aquatic species in Great Lakes. Only isolated pockets of Diporeia remain.
2012	Fathom Five Management Plan review on hold. Great Lakes Water Quality Agreement revised. Canada-Ontario Agreement renewal in review.	Oligotrophication continues (total phosphorus <4 µg/l). Lake Huron 3rd largest freshwater lake in world in terms of area and 6th in volume. Average

Time	Social	Ecological
	Approx 3,800 year-round and >50% more seasonal residents in municipality. Aging demographic with no population growth in municipality projected. 2.5 million people live in Lake Huron watershed.	retention time 22 years.

System Descriptions

Offshore Ecosystem

The offshore ecosystem of Fathom Five (Figure A1.1) straddles the transition zone between the main basin of Lake Huron (59,570 km^2) and Georgian Bay (15,108 km^2). The basin water is characterized as oligotrophic, with generally deep (> 30 m), cold (average temperature < 10^{o}C) waters, which are typically low in productivity with low nutrient depletions in the epilimnion (surface) and a high oxygen concentration (> 95%). There is relatively little evidence of pollution in the pelagic waters (Munawar et al. 2003). In the area there is a net outflow of waters from Georgian Bay into Lake Huron at all depths. The residence time for Georgian Bay waters is approximately 7 years and Lake Huron 22 years (Sly and Munawar 1988).

The offshore ecosystem continues to change. Historically, the species complex in the deeper colder parts of the lake consisted of lake trout, walleye, members of the whitefish subfamily, burbot, and sculpins, with deepwater ciscoes, lake herring, and sculpins serving as the principal prey for lake trout. 105 species of fish have been recorded in Lake Huron, including 89 indigenous species, 16 non-native species, 5 extirpated species, and 1 extinct (Roseman et al. 2009). The early commercial fishery harvested 1.79 kg/ha/yr and targeted lake trout, lake whitefish, and cisco. Now it is 1/3 that and is mostly lake whitefish. By the 1940s the impact of over-harvest and invasive species including sea lamprey, rainbow smelt, and alewife had further destabilized the ecosystem and by 1959 the lake trout population had collapsed and cisco eventually collapsed as well in the late 1990’s.

A second wave of instability started in the early 1990s with the introduction of zebra mussels (*Dreissena polymorpha*) and quagga mussels (*D. bugensis*). The recent crash in the benthic invertebrate *Diporeia* sp. (e.g., at one time densities >1,000 m^2) coincides with this dreissenid mussel invasion. The mussels appear to be better adapted (e.g., metabolically, competitively) to the offshore lakebed environment. Currently, there is a lake-wide nutrient/energy pathway regime shift under way, from what was once an efficient pelagic system to a benthic system. This lakebed shunt is primarily due to the filter feeding efficiency and nutrient sequestration capacity of quagga mussels (e.g., Hecky et al. 2004; Vanderploeg et al. 2010). Historically, native benthic species would process organic matter, energy, and nutrients which settled to the lakebed, and then other species, such as forage fishes, would feed on them, returning the nutrients and energy to the pelagic realm. Although some species feed on mussels, the nutrient/energy cycling process is not as efficient as it once was and the mussel dominated environment becomes a nutrient/energy sink.

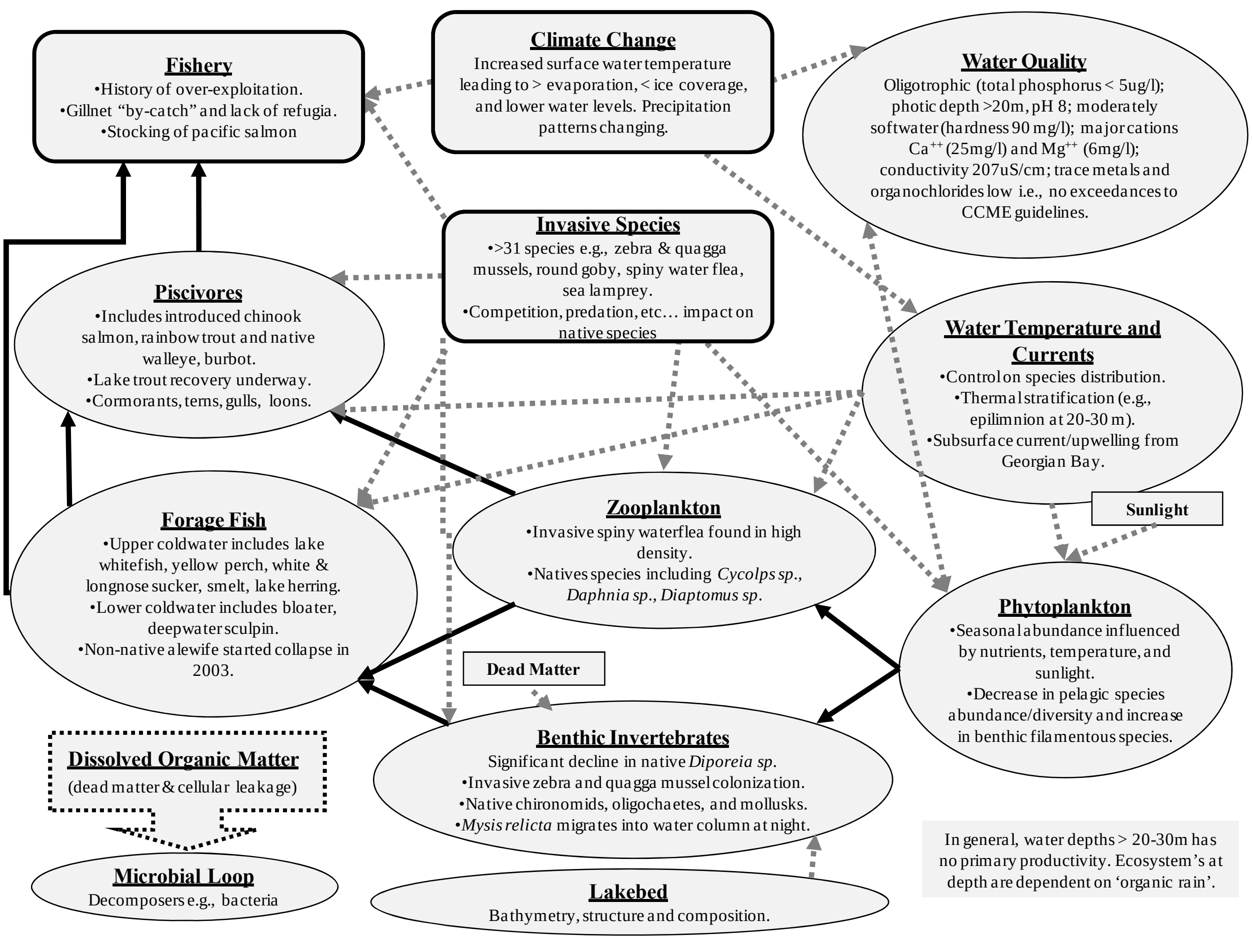


Figure A1.1 A conceptual model of the Fathom Five offshore ecosystem, illustrating system structures, functions, and drivers.

Alewife, the once dominant invasive fish, has recently experienced a population collapse. Sea lamprey control measures appear to be effective and in some ways conditions are more suitable now than they have been in the past 50 years for lake trout and lake herring recovery. However due to the mussel nutrient/energy shunt, primary productivity (phytoplankton) is noticeably reduced. This has a cascade effect and limits productivity of the entire foodweb.

It is worth observing the temporal changes to the water column. In the spring, the water column, from top to bottom, is generally the same temperature (1-4 ^{o}C) and density and therefore mixing of the deeper and surface waters is facilitated. Available nutrients, including phosphorus, nitrogen, and silica (often from the depths) support phytoplankton growth, in particular a spring diatom bloom. Along with spring melt water, the algal blooms have historically contributed to a slight increase in water turbidity. However, with the ongoing nutrient shunt by quagga and zebra mussels (Figure A1.2), spring diatoms blooms have recently diminished due to nutrient limitations (n.b., Lake Huron spring total phosphorus concentrations are now less than Lake Superior (<4 μg/l) and silica concentrations are increasing as diatom populations decrease) and as a result, water turbidity has decreased (Evans et al. 2011).

As the season progresses, increased sunlight, penetrating to depths of 20-30 m, heat the surface waters. Zooplankton abundance increases with warmer temperatures and their grazing on phytoplankton also decreases turbidity. Freshwater is its densest at 4 ^{o}C and as the surface water continues to warm it forms a layer (epilimnion) on top of the deeper colder water (hypolimnion). By summer the surface temperature is >20 ^{o}C and the water at depth (e.g., > 30m) remains at 4 ^{o}C, and given the density differences, they do not mix. At this time nutrients that have settled to depth are not readily available to phytoplankton at the surface. The transition zone between these layers is called the thermocline. The depth of the thermocline varies with time of year and even daily due to strong inertial waves set up by seiche and Coriolios effects (i.e., it surges up and down between the 20m and 30m depths on a 16-hour cycle) (Wells and Parker 2010). The thermal stratification creates two environments; a sun lit, shallow, cool water zone and a dark, deep, cold water zone. Species tend to associate with one or the other, e.g., bloater chub in deeper waters, Chinook salmon in shallower waters.

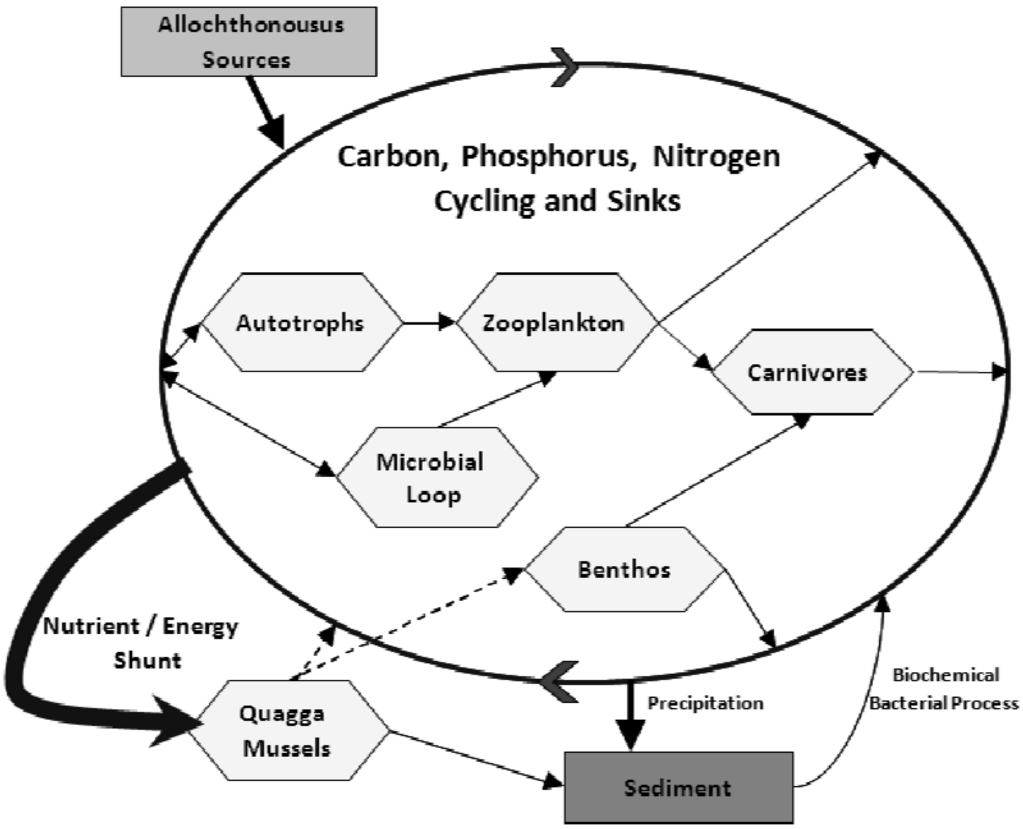


Figure A1.2 Nutrient and energy shunt (Hecky et al. 2004). The introduction and spread of quagga mussels in Lake Huron in the early 1990's have resulted in a transition from an efficient pelagic ecosystem to a benthic system. This is primarily due to their abundance and filter feeding efficiency. Nutrients such as phosphorus as well as energy are being shunted to the lakebed and sequestered or left as feces/pseudo-feces by the mussels. Historically native benthic species would process the organic matter, energy and nutrients which settled to the lakebed, and then other species such as forage fishes would prey on them and bringing that energy back into the pelagic realm. Species such as whitefish do feed on mussels, but there is still a net loss in nutrients.

By the fall, the water begins to cool and in November stratification is lost. Since the water column is the same density it can mix again (a fall algae bloom may occur as nutrients once trapped in the hypolimnion become available). Lake trout and lake whitefish can be found spawning on shallow reefs at this time of year. In winter, ice is less dense than water at 4 ^{o}C, so it floats on the surface. Ice coverage in Fathom Five varies from year to year, but on average 45-75 cm of ice is found throughout by February. Ice dampens winter storm affects by protecting shores, limiting lake effect snow, and protecting lake trout and whitefish spawning beds. Recent trends have reported a decrease in ice coverage for Lake Huron (Wang et al. 2012). By mid-April the ice is gone.

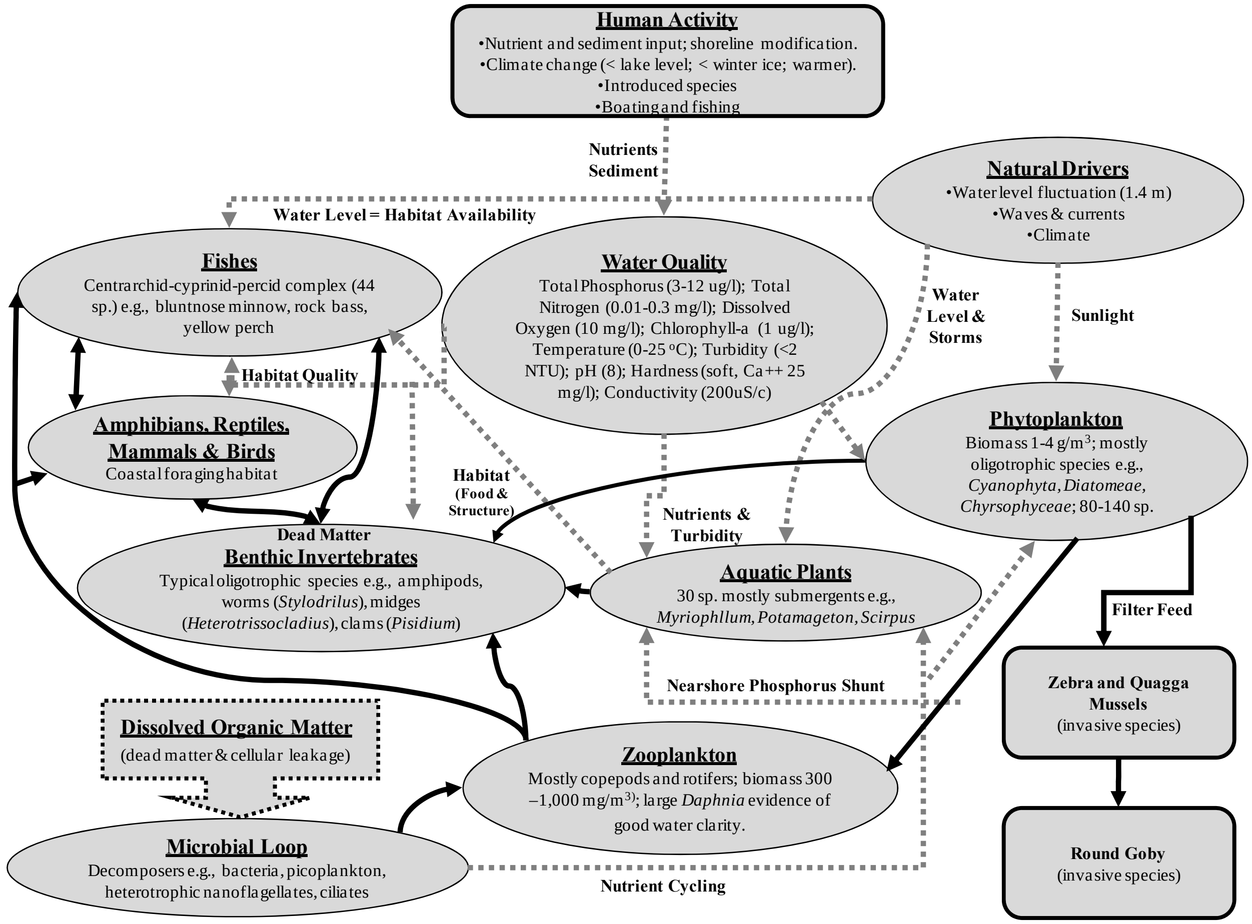


Figure A1.3 A conceptual model of the Fathom Five coastal ecosystem, illustrating system structures, functions, and drivers.

Coastal Ecosystem

The Fathom Five coast is mostly exposed and rocky, however coastal wetlands have established in the few protected bays (e.g., Hay Bay, Russel Island, and western shore of Cove Island). These coastal wetlands are highly productive and biologically rich areas. They are utilized for fish spawning, nursery, and adult habitat (e.g., habitat for 30-40 species of fishes) and foraging by other species (e.g., terns, raccoons, water snakes, etc...). A good entry point to the coastal ecosystem model is the water quality ‘bubble’ (Figure A1.3). In particular the influence that phosphorus (i.e., a limiting nutrient) and turbidity (i.e., suspended matter that limits light penetration) has on plant growth and diversity. Lake levels naturally fluctuate on daily (cm’s), seasonally (dm’s), and longer-term (1.4 metres/30 years) periods (Trebitz 2006; IJC 2009). This disturbance is natural to coastal wetland integrity; however climate change may lower lake levels further and affect resilience (e.g., connectivity, habitat availability; Figure A1.4).

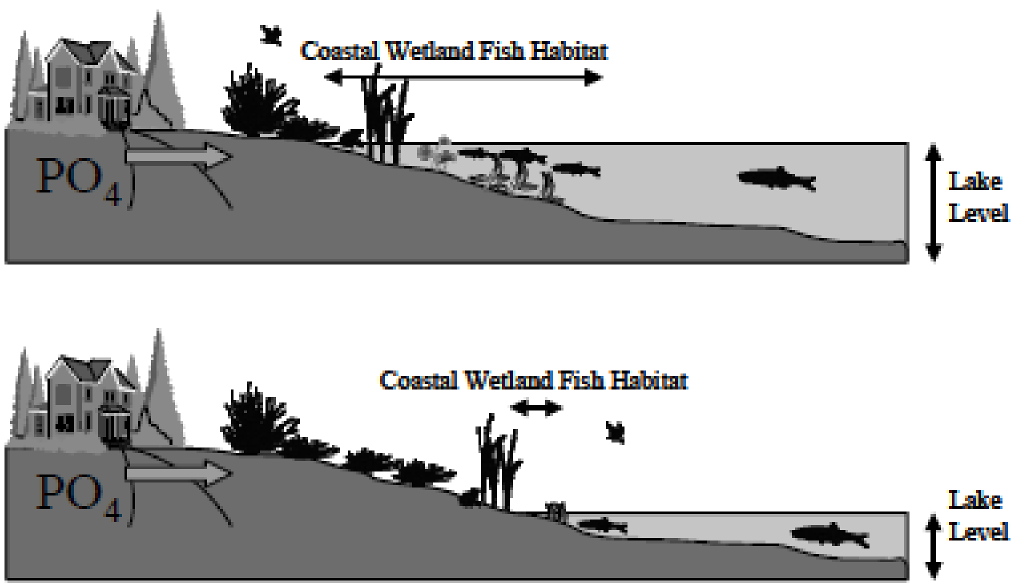


Figure A1.4 Coastal processes and dynamics. Phosphates (PO_4) from septic systems and fertilizers can reduce water quality and negatively affect fish and aquatic plant assemblage. Macrophyte habitat is determined by, among other things, sedimentation processes and protection from wave exposure. Lake levels affect the amount of available habitat.

The ultimate impact of invasive species is still uncertain. Eurasian watermilfoil (*Myriophyllum spicatum*) is found in a few areas (since at least the early 1980’s) forming dense mats that exclude other species, affect circulation, and water quality. Zebra and quagga mussels (first observed in 1992) are very efficient filter feeders and move considerable suspended material (nutrients/energy) from the water column to the lakebed. Their waste products affect water quality and increase nutrients for periphyton algae growth and favourable conditions for Type *E* botulism (n.b., increased seabird bird mortality from consuming contaminated goby/mussel has

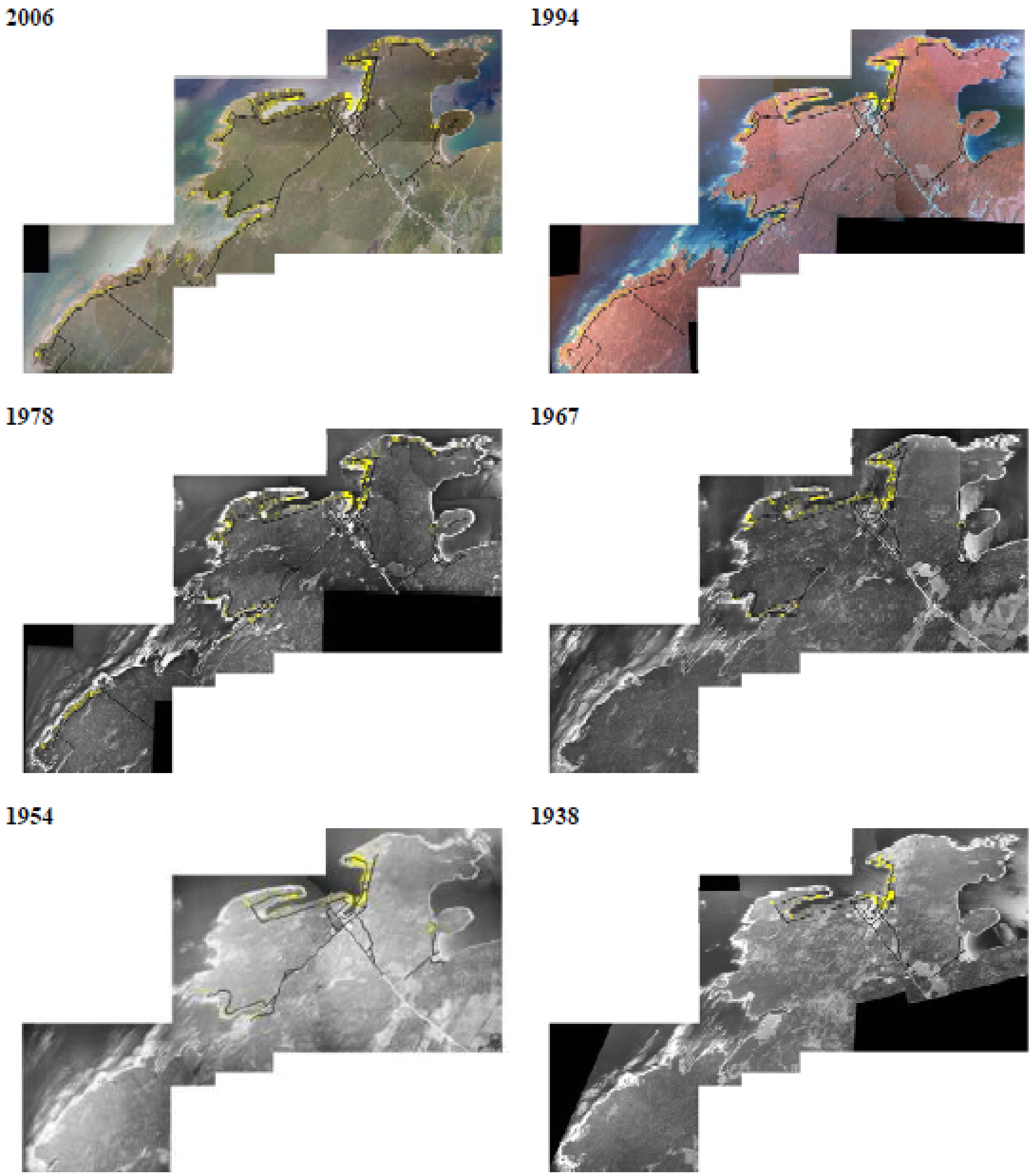


Figure A1.5 Coastal development (yellow) within and adjacent to the mainland boundary of Fathom Five digitized from available air photo series. For the period from 1967 to 2006 development has increased at the following rates: buildings 3.5%/yr, laneways 3.3%/yr, manicured landscapes 0.8%/yr, and, in-water development 2.2%/yr.

been observed). Round gobies (first observed in 2005), can dominant the lakebed (by the thousands) and easily out compete native benthic fishes (e.g., sculpins, darters) and crayfish and prey on other fish eggs such as lake trout and whitefish. Round gobies feed on zebra/quagga mussels resulting in the bioaccumulation of the Type *E* botulism toxin.

Fathom Five's coastal wetlands are in relatively good condition, however, the island sites, which are less disturbed by human development, typically score higher than the mainland sites (see wetland scores on Table A3.3). Figure A1.5 illustrates the nature of coastal development along the mainland boundary of Fathom Five.

Island Ecosystem

The Fathom Five archipelago consists of fourteen islands and several islets, comprising a total area of 13.5 km^2 or 12% of Fathom Five (Figure A1.6). Cove Is. is the largest island at 8.4 km^2, Flowerpot Is. is the next largest at 2.1 km^2, and most of the other islands are less than 10 ha. Most islands are within a 2-3 km stepping stone distance of an adjacent island or the mainland. Island biogeography effects have been studied (Hager and Nudds 2001) (Figure A1.7). The larger islands and islands closer to the mainland tend to have more species than the smaller and more remote islands. Some interesting observations include: rattlesnake only on Cove Is.; no hibernating mammal species found on the islands; in the absence of competition some species expand their niche, for example, red squirrels normally arboreal are found on Flowerpot Is. to nest in rock piles.

Only Flowerpot Is. has public infrastructure. Visitation has increased significantly in the last few years, with 20,000 visitors in 2008 increasing to 40,000 visitors in 2012. A visitor quota or carrying capacity limit has not been established. Interestingly, a 1997 visitor survey, the last visitor survey to be completed for the island, concluded that a 10% increase in visitations would be perceived negatively by most visitors (Kettle 1998).

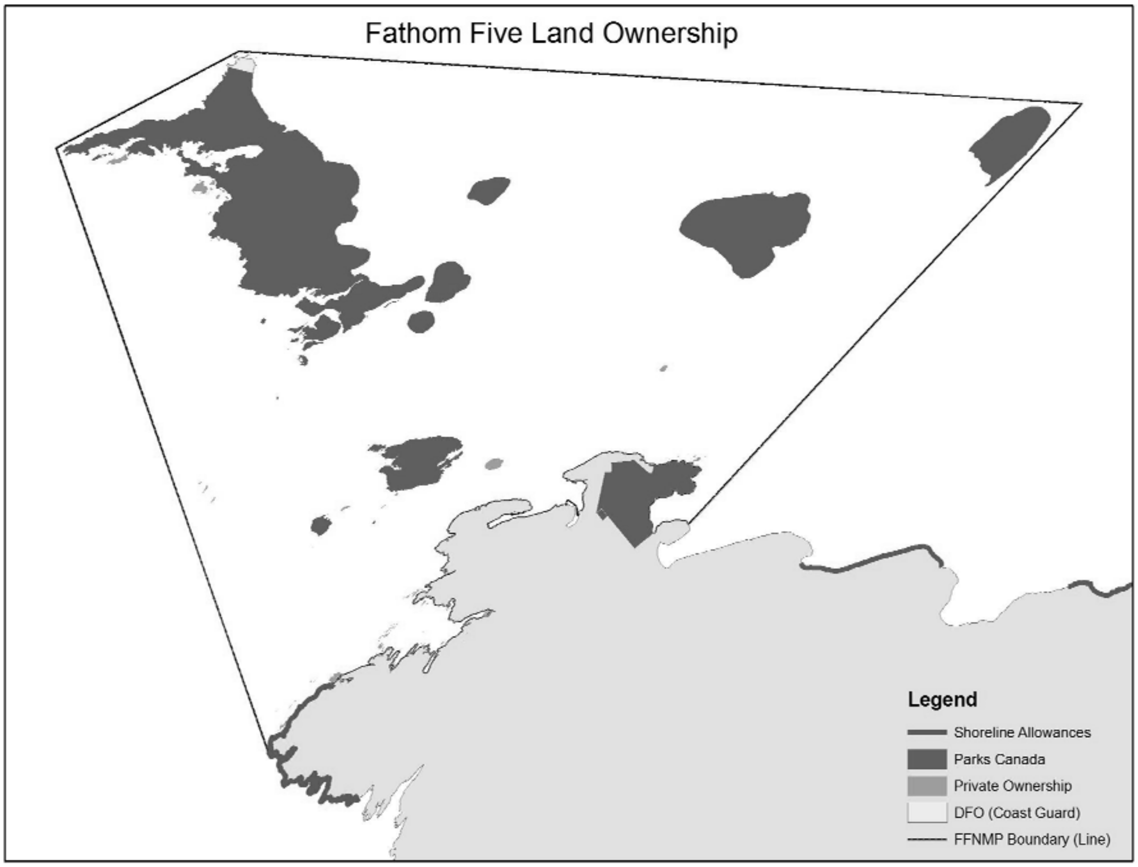


Figure A1.6 Land ownership in Fathom Five.

Current lake levels are 176m ASL (above sea level). Post-glacial levels have fluctuated from a high of Lake Algonquin (269m ASL; 11,000-10,000 BP (before present)) to a low of Lake Stanley and Lake Hough (116 m ASL; 9,000-8,000 BP) and up to a high of Lake Nipissing (194m ASL; 6,000-4,000 BP) (Blasco 2001). Therefore the opportunity to colonize the islands has been affected by fluctuating lake levels. The three largest islands and mainland have high enough elevation that at least part of them would have been exposed since 9,000 BP (i.e., Cove Is., max 190m ASL, Flowerpot Is., max 220 m ASL, and Bears Rump, max. 221 m ASL). The other dozen or more islands and islets would have been flooded in the last high and therefore have only been exposed in the last 4,000 years. Naturally the mechanism of colonization would vary by species, e.g., walk land/ice bridge, fly, swim, raft on floating debris, etc.

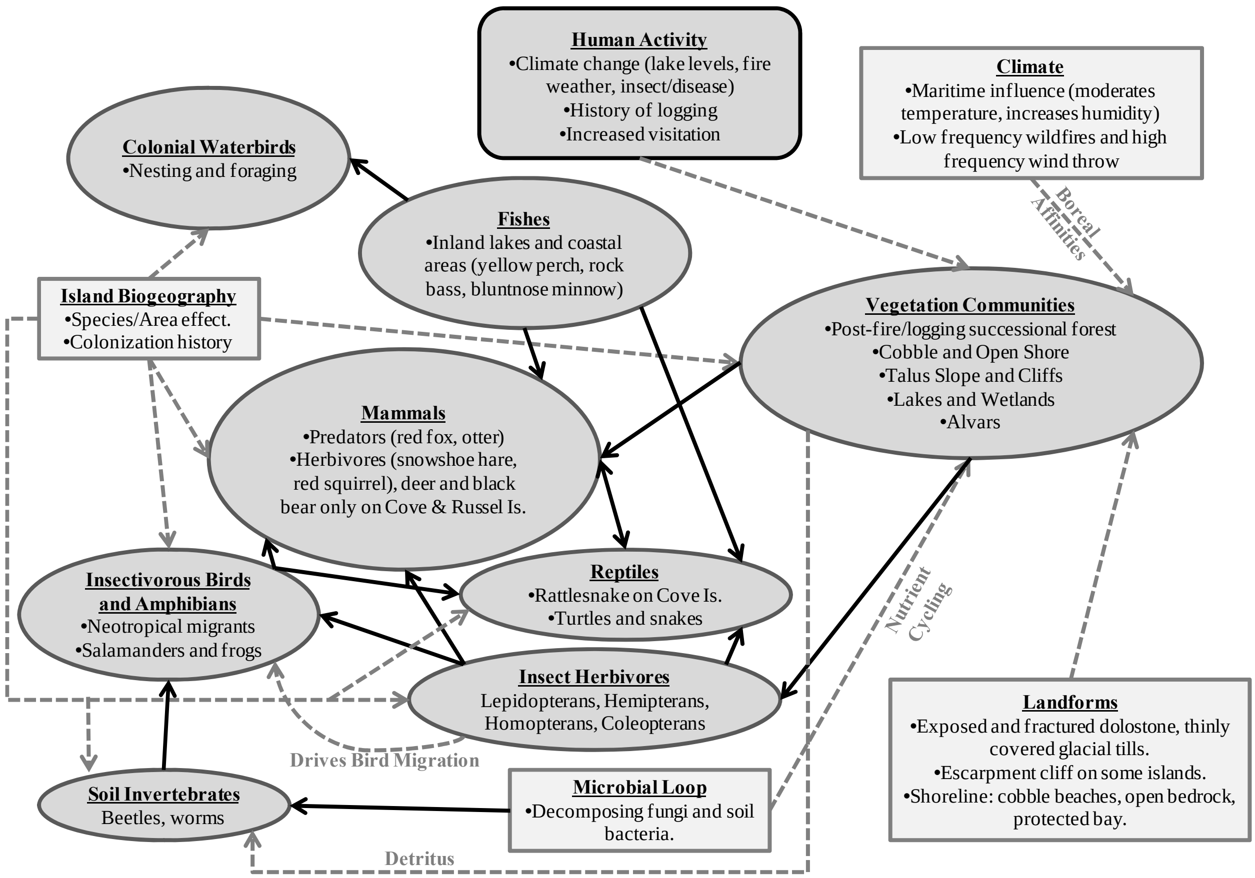


Figure A1.7 A conceptual model of the Fathom Five island ecosystem, illustrating system structures, functions, and drivers.

Most of the islands were logged in 1880's, followed by some second growth harvest in the early part of the 20th century. As a result most are covered in a mixed to conifer successional forest of white cedar, balsam fir, white birch and trembling aspen. Wetlands occur throughout and alvars are found on Cove and Bears Rump Islands. The maritime climate has a moderating affect. Both southern and northern affinities can be found.

Governance Domain

Relative to Parks Canada's terrestrial system of national parks, its complementary marine system of NMCAs is in its infancy with respect to establishment and management practices. In some regards it is the dominance of a terrestrial worldview that has limited our ability to comprehend the complexity inherent to aquatic ecosystems and respond to the conservation imperative with some parity. Although the NMCA Act introduces management concepts such as ecosystem management, the precautionary principle, and ecologically sustainable use, there is no NMCA specific policy or underlying heuristics to guide such management actions. Therefore, NMCAs such as Fathom Five are established in complex situations, involving intricate interactions of social and ecological factors, and moreover managers are faced with decision-making with limited tools in a constantly changing context (e.g., invasive species, biodiversity loss, changing demographics).

Effective management is dependent on explicit objectives, clear responsibilities, unambiguous accountabilities, adequate authority, good support, and information. Fathom Five's management context is complex and in some regards uncertain. Although a Federal-Provincial Agreement was signed in 1987 to establish Fathom Five (Canada and Ontario 1987), it is still not formalized under the NMCA Act and significant steps, including ownership transfer, have not occurred. Legal and managerial authorities are very much the same as they were before the Agreement, with the exception of Parks Canada's attempt to coordinate management responsibility through a variety of federal and provincial legislation in the 'spirit' of the NMCA Act.

Most of the islands are scheduled (gazetted) as part of Georgian Bay Islands National Park and therefore managed under the authority of the Canada National Parks Act (Canada 2000). Ownership to the Fathom Five land base at Dunks Point was transferred to the federal government and is now managed under the Federal Real Property and Federal Immovables Act (Canada 1991). Private and Department of Fisheries and Oceans (DFO) lands (e.g., for navigational aids) exist within the boundaries.

Along the mainland, the coastal boundary of Fathom Five remains unclear and unresolved. The federal-provincial agreement describes the ordinary high water mark (OHWM), but this not been legally scheduled under any Act. In areas where a planned subdivision or shoreline allowance exists, then the OHWM is a clear boundary between crown and private land. There is uncertainty where such an allowance does not exist. Some private landowners assume "riparian rights" and extend their sense of ownership to the water's edge. Case law also exists (e.g., Ontario vs. Walker et al., 1974) supporting the water's edge not the OHWM in some situations. Regardless, Parks Canada does not currently own the coast, but manages with a variety of legislation. The

Fisheries Act (Canada 1985a), administered by the DFO, and the Canada Shipping Act (Canada 2001) and Navigable Waters Protection Act (Canada 1985b), administered by Transport Canada, are applied.

Since the lakebed and water column was not transferred to Parks Canada after the Agreement, they currently remain under provincial ownership. Provincial legislations such as the Trespass to Property Act (e.g., to manage visitor conduct) or the Vessel Operation Restriction Regulations (e.g., to manage vessel access to and on dive sites) (Canada 2009) may be utilized for management purposes by Parks Canada. Mineral rights rest with the province. As well, since Fathom Five Provincial Park is no longer recognized, the Provincial Parks and Conservation Reserves Act (Ontario 2006) and regulations no longer apply within Fathom Five.

Fish habitat is managed by DFO and the Ontario Ministry of Natural Resources (OMNR) manages the recreational fishery. The OMNR and the Chippewas of Nawash and Saugeen First Nation (Saugeen Ojibway Nations, SON) have a process for managing the commercial fishery. Considerable conflict has occurred over this in the past. As it stands both the OMNR and SON have their independent assessment programs and meet in plenary to discuss. In practice, only SON people are involved ('licensed') in commercial fishery in this area.

In 1994, the SON filed a lawsuit in the Ontario Supreme Court against both Canada and Ontario. The Parks Canada position is that Treaty 72 effectively extinguished all Aboriginal title/right in the areas covered by the Treaty, which includes all of the Bruce Peninsula. While the litigation remains outstanding, a SON-Parks Canada partnership agreement has been drafted to maintain relations and facilitate consultation.

A review of the objectives and commitments stated within the 1998 park management plan (Parks Canada 1998) was undertaken as part of the State of the Park Report (see Table 10, Parks Canada 2011). Significant shortfalls to implement the plan were identified including the lack of a fisheries strategy, a monitoring program, and a cumulative impact assessment framework. As well, limited regional integration and inadequacy of zoning were also identified.

In addition to being relevant, the site is also challenged to be more representative. The NMCA program is based on establishing a representative network of protected areas (Mercier and Mondor 1995). Fathom Five comprises an extremely small area in a much larger multi-jurisdictional lake (e.g., 0.002 % area of Lake Huron). Fathom Five was established to represent the Georgian Bay marine region. However, the boundary reflects those of Fathom Five Provincial Park which was opportunistically acquired as part of the Bruce Peninsula National Park negotiations. Fathom Five only represents 49% of this region, but through expansion could represent 98% of the Georgian Bay marine region and 76% of the Lake Huron Region (Figure A1.8) (Beak Consultants Ltd. 1994; Parker 1998). Although the path to boundary expansion would have many social and political hurdles, if it were to be realized there would certainly be advantages in terms of representation and relevance as a protected area.

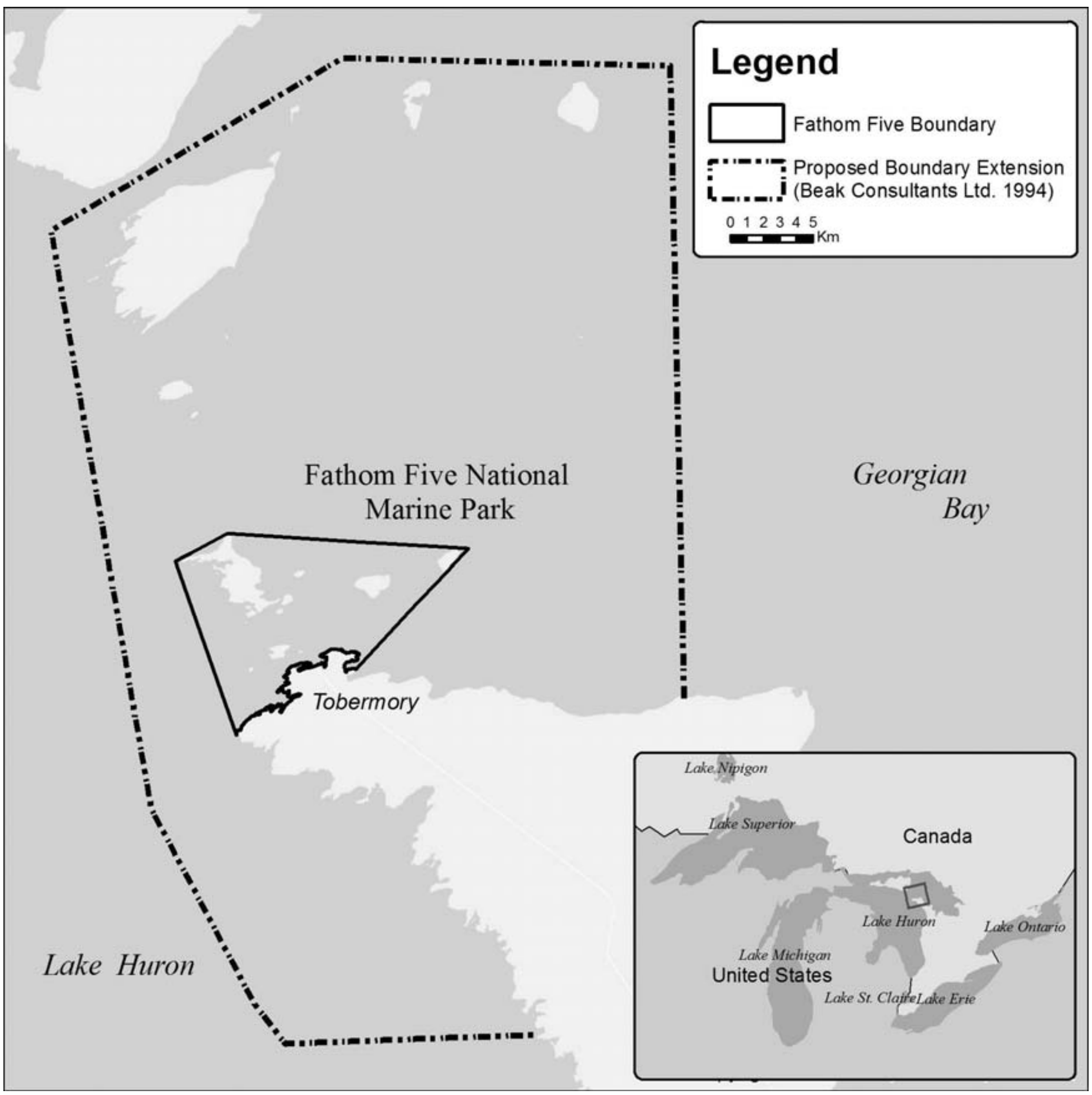


Figure A1.8 Fathom Five's boundary adequacy.

In Holling and Meffe's (1996) review of the pathology of natural resource management, they reported that institutions can lose resilience, becoming gridlocked and myopic. Applied in this context, pathology involves a decline ecosystem health and resilience due to institutional factors. Features of the pathology include a lack of monitoring of outcomes, isolation of employees from the system being managed, management's insensitivity to public concerns, and discouragement of innovation. More recently, Mclaughlin and Krantzberg (2012) appraised the management of the Great Lakes in terms of this pathology using the symptoms identified by Briggs (2003). Table A1.2 introduces Brigg's six symptoms and provides a brief comment on Fathom Five's context. Diagnosing the problem can help to create more accountable, adaptive, and participatory governance structures.

Table A1.2 Symptoms exhibited by institutions suffering from the pathology of natural resource management, as identified by Briggs (2003) with comment on Fathom Five.

Symptoms	Reflections on Fathom Five
(i) They delay dealing with problems, then try quick fixes, usually with a big stick.	Little response to deteriorating conditions such as invasive species and fishery. Crisis management appears to be common.
(ii) They announce and instigate new natural resource management programs repeatedly, without evaluating the effectiveness of current or previous programs.	There appears to be little assessment of the efficacy of past programs and efforts (e.g., see Table 10, Parks Canada 2011). Consultation fatigue may be a concern. No adaptive management projects.
(iii) They instigate multiple, often incompatible plans and planning processes.	Challenges integrating visitor experience (use) and resource conservation (in general see, OAG 2005). Several plans/strategies not implemented or coordinated.
(iv) Institutions with the pathology have closed cultures which suppress ideas within the organization, and resist new ideas or information from outside.	Isolated from other government departments and initiatives on the lake. Risk averse culture (may reflect a lack of expertise to manage) that encourages "loyal implementation". Resistance to innovation may become a trap
(v) They shed extension officers, often in favour of regulatory officers, and then expect scientists and planners to take on the extension role.	Disengagement in regional monitoring or stewardship projects as well as lake governance. 2012 staff reductions.
(vi) Natural resources institutions with the pathology fail to develop effective incentive schemes for conservation on private land.	Not necessarily Parks Canada role to allocate public funds for private lands. However, better regional integration is needed to support adaptive and participatory management initiatives.

It is evident that social learning, trust building, and cooperation and collaboration between protected area governments, the private sector, and civil societies (including voluntary and non-profit sector) is necessary to influence and manage the issues of today (Graham et al. 2003; Lebel et al. 2006; Lockwood 2010). In many regards, now is an opportune time for Fathom Five to invite itself within regional governance systems, as interest is relatively high for freshwater protected areas (Hedges et al. 2010), water quality (IJC 1987), sustainable fisheries (GLFC 2007, 2008), control of invasive species (GLFC 1988), biodiversity conservation (Franks Taylor et al. 2010), and ecosystem reporting (SOLEC 2009).

Summary of Factors affecting the Social and Ecological Context

As a final step to describe the context and changes at Fathom Five, Table A1.3 provides an overview of the spatial and temporal factors affecting structures and functions. The factors are classified spatially at the scale of Fathom Five, Lake Huron, and the world. They are temporally classified as slow (>100 years), medium (10-100 years), and fast (<10years).

Table A1.3 Spatial and temporal factors affecting Fathom Five's context. Adapted from Slocombe (1990)

	Social		
	Fast (<10 years)	**Medium (10-100 years)**	**Slow (>100 years)**
Fathom Five	Recreational and tourism demands. Problem perception and action. Social carrying capacity and visitor expectations.	Governance structures and planning approach. Social learning and trust building. Sustainability of fishery. Relationship with Saugeen Ojibway Nations. Political support.	Labour demands.
Lake Huron	Public opinion and cultural diversity. Management efforts, e.g., fisheries, research, communication.	US-Canada partnerships and agreements. Population growth. Settlement and demographic patterns. Pollution control. Changes to resource economies. Ecosystem and adaptive management approaches.	Religion and culture.
World	Transportation and communication. Travel and immigration patterns. Media and marketing.	Economic restraint.	Free trade and protectionism.

	Ecological		
	Fast (<10 years)	**Medium (10-100 years)**	**Slow (>100 years)**
Fathom Five	Weather events. Coastal development.	Lake level change. Species assemblage change. Management efforts - restoration and fisheries. Habitat formation (e.g., wetland). Networked with other protected areas.	Colonization and extinction.
Lake Huron	Agriculture and land conversion. Nutrient and energy pathways. Water temperature.	Invasive species. Water pollutants – persistent and new.	Isostatic rebound. Speciation. Water balance.
World	Long-range air pollution.	Climate change. Demand for freshwater. Movement of goods and materials.	Domestication.

Appendix 2. Supplement to Chapter 3: Related GIS layers and other data utilized in Marxan with Zones analysis.

Note: From 2005 to present, I was the project manager for the lakebed mapping project in Fathom Five. Although the early focus of this project was related to studies of post-glacial lake levels and submerged archaeological sites, the lakebed classification and fish habitat models within this Appendix (and associated Marxan analysis) are original contributions of this thesis.

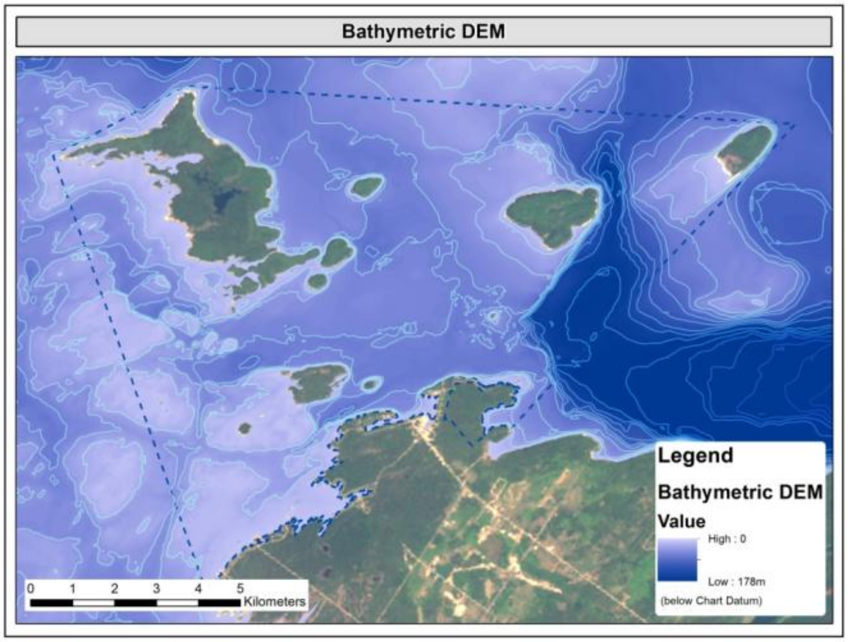


Figure A2.1 Bathymetry. Lake Huron 10 m DEM, NOAA and Canadian Hydrographic Service Chart data (Chart 2274 and 2235).

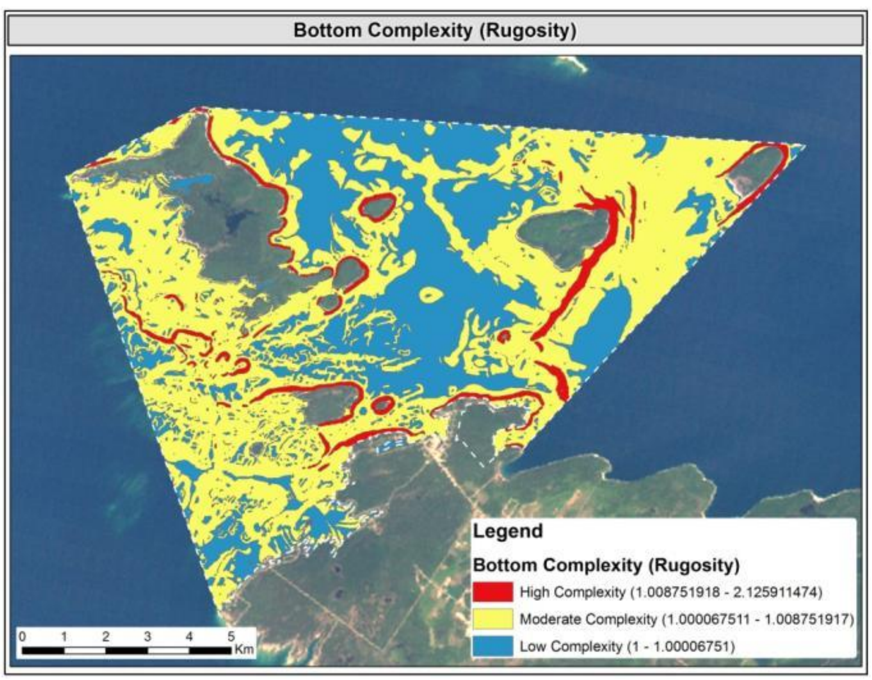


Figure A2.2 Complexity (rugosity) was modeled within ArcGIS using benthic terrain rugosity tool. Divided into 4 categories (0-3) using a Geometric Interval/Smart Quantile.

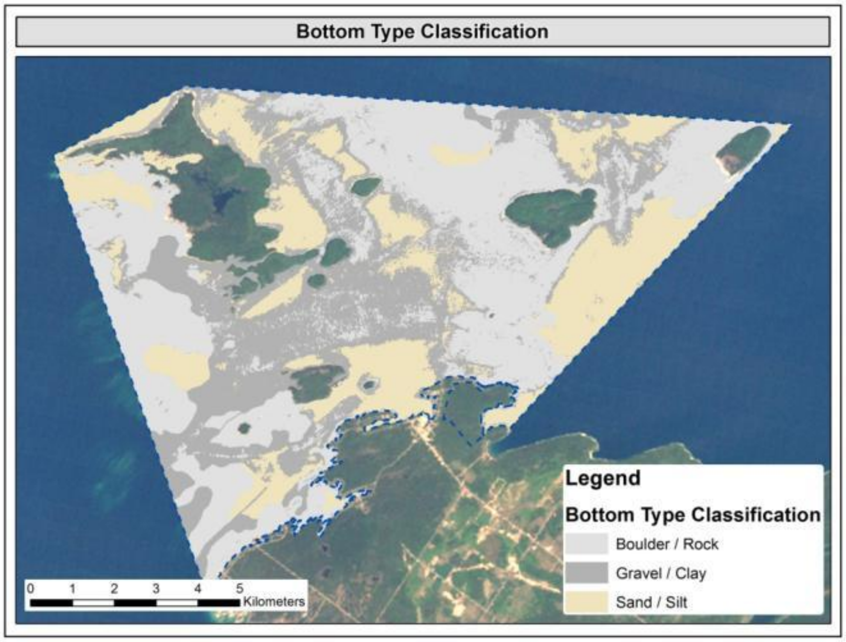


Figure A2.3 Composition of lakebed. Multibeam backscatter layer was separated into three general lakebed composition classes (i.e., boulder/rock, gravel/clay, sand/silt) by using a principal component analysis and Kruskal-Wallis rank sum test and validated by lakebed video and sediment grab samples. In areas where multibeam sonar coverage was absent (e.g., < 2m depth), the lower resolution bottom type data found on hydrographic charts was utilized.

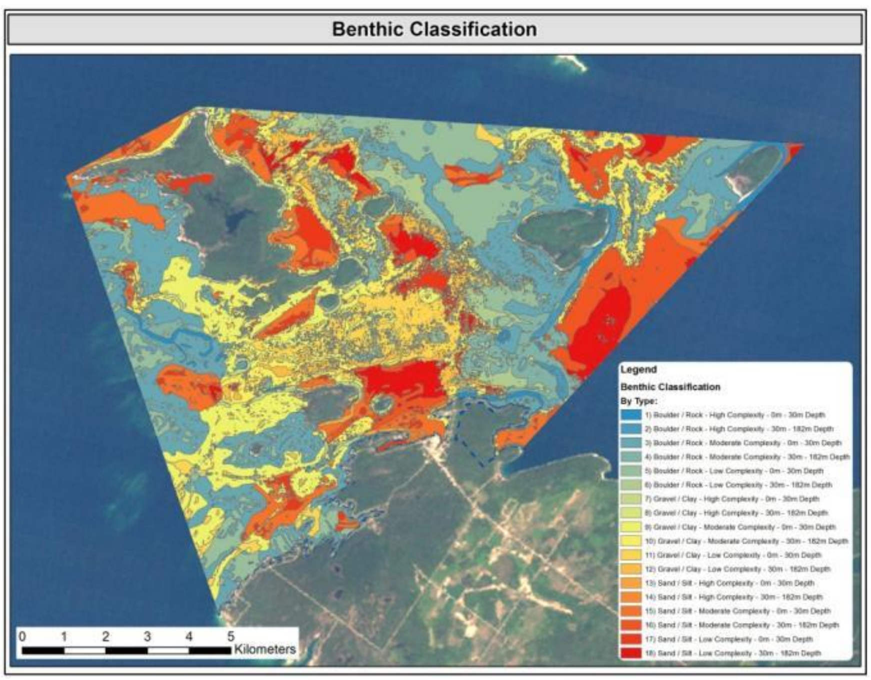


Figure A2.4 Benthic classification. Based on data from Figures A2.1, A2.2, and A2.3.

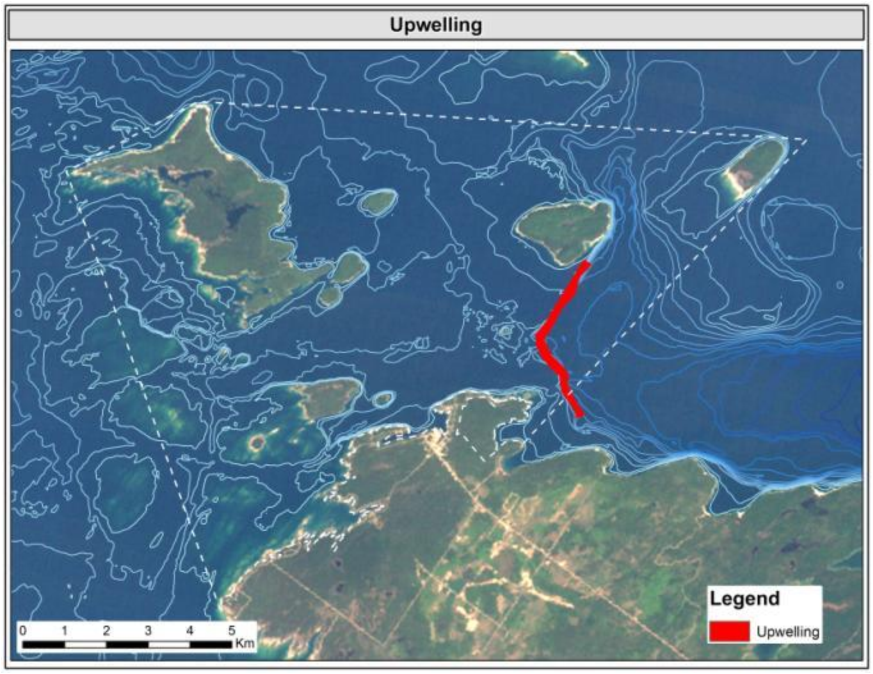


Figure A2.5 Upwellings based on local knowledge.

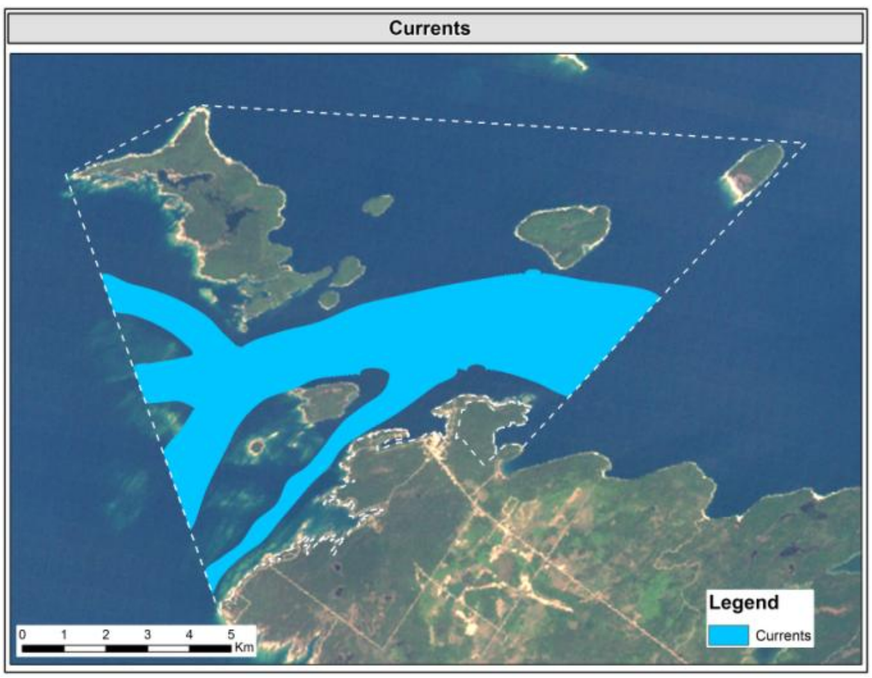


Figure A2.6 Currents based on local knowledge and Bennett (1988).

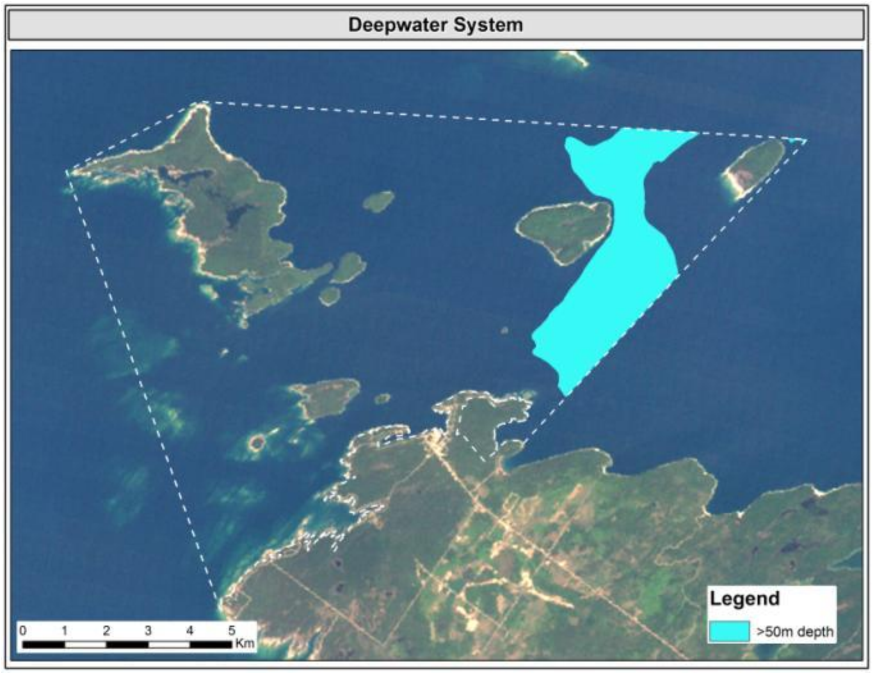


Figure A2.7 Deepwater ecosystems based on classified digital elevation model.

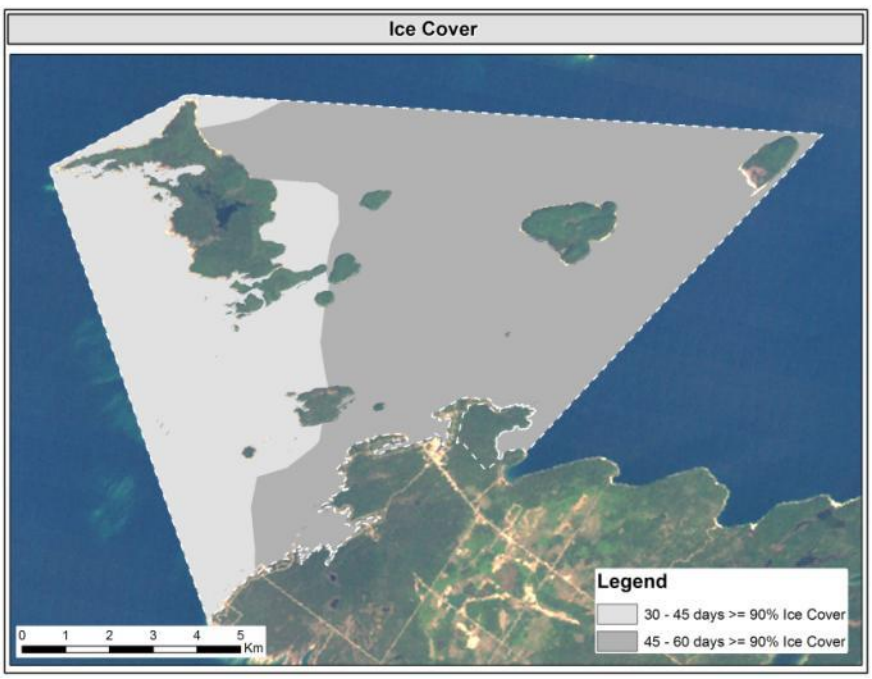


Figure A2.8 Ice coverage determined using maximum mean ice coverage between 1973-2002 from NOAA's Great Lake's ice data (www.glerl.noaa.gov/data/ice/atlas).

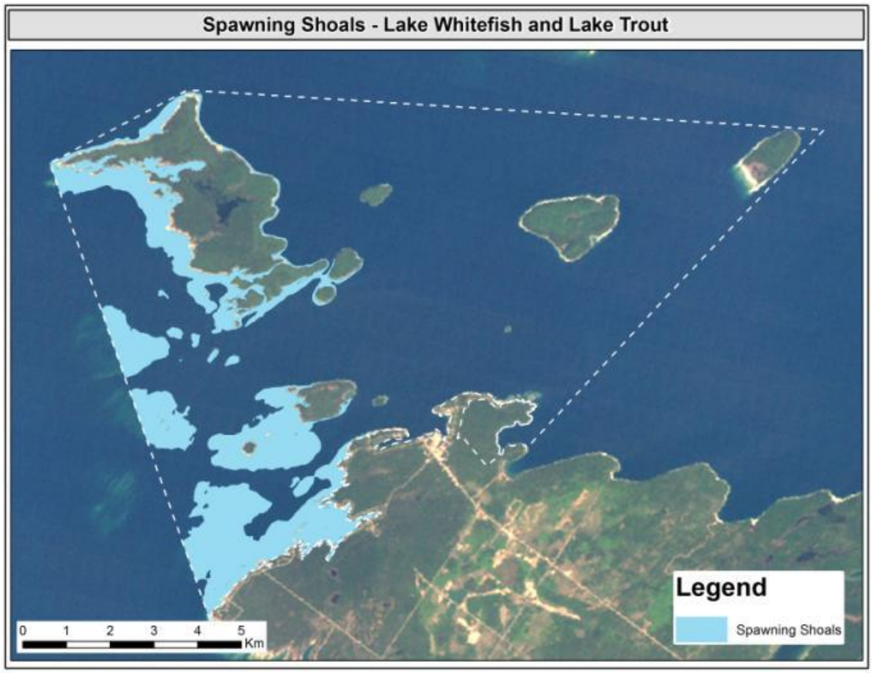


Figure A2.9 Spawning shoals based on local knowledge and Goodyear et al. (1992).

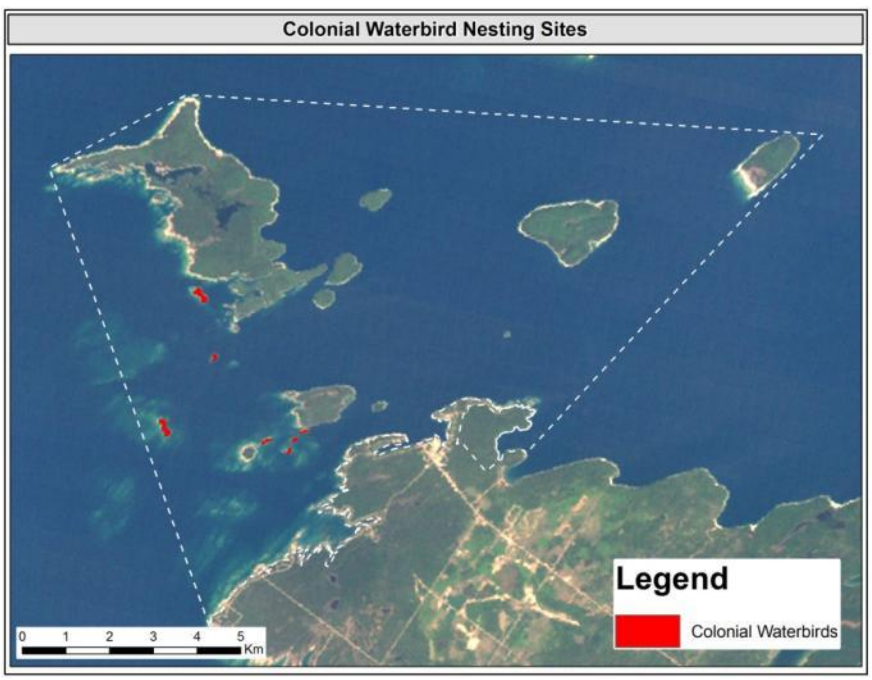


Figure A2.10 Colonial waterbird nest sites. Confirmed active 2009-2012. Species include herring gull, ring-billed gull, double-crested cormorant, and common tern.

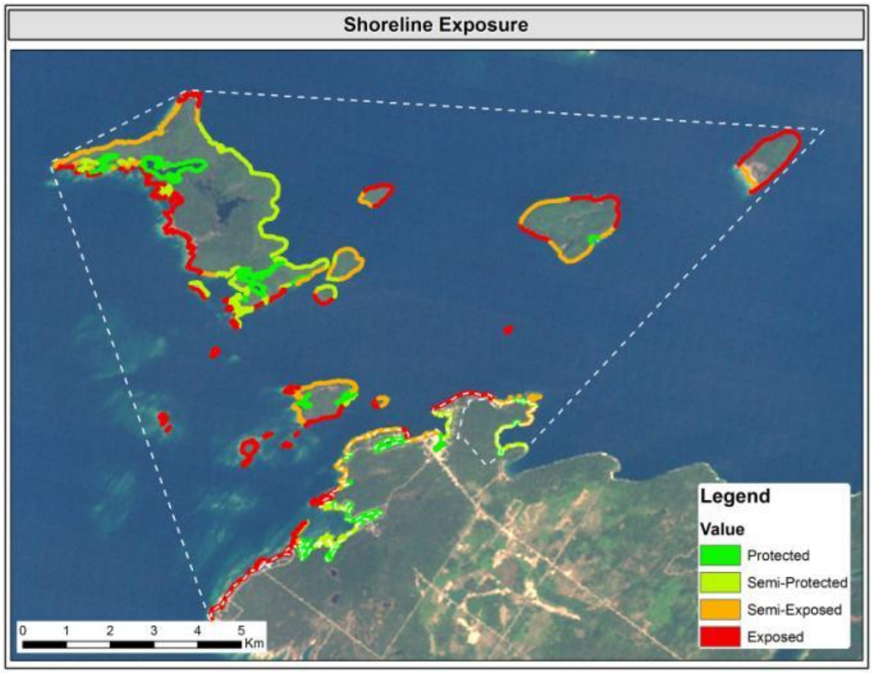


Figure A2.11 Shoreline exposure based on a USGS fetch model (www.umesc.usgs.gov) and dominant wind vectors.

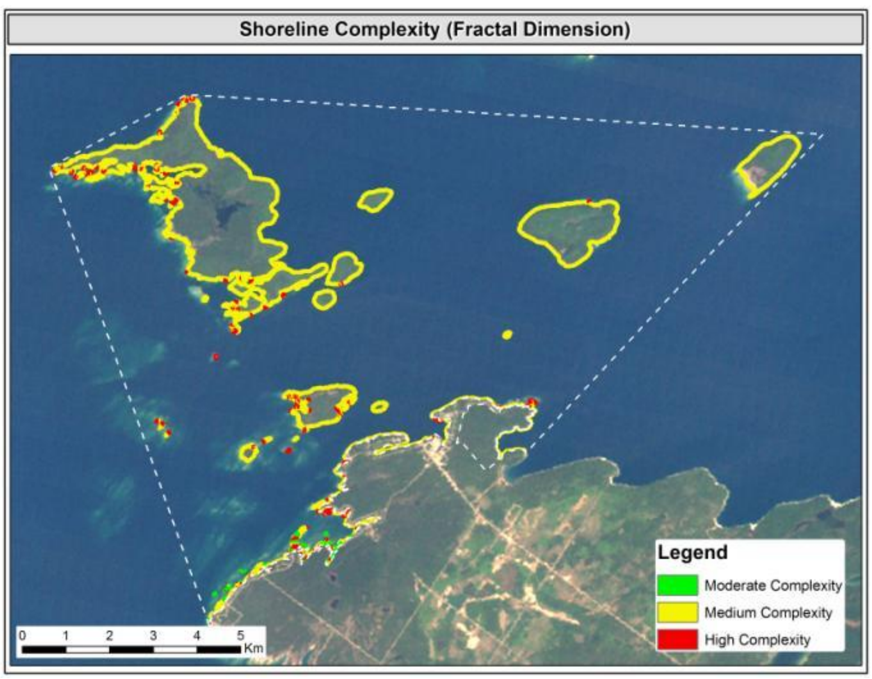


Figure A2.12 Shoreline complexity modeled using a fractal dimension model in ArcGIS (Hawth's Tools). Ontario Base Map shoreline divided into 100m segments. Fractal dimension calculated for each segment, then categorized into 4 classes (0-3) using Geometric Interval.

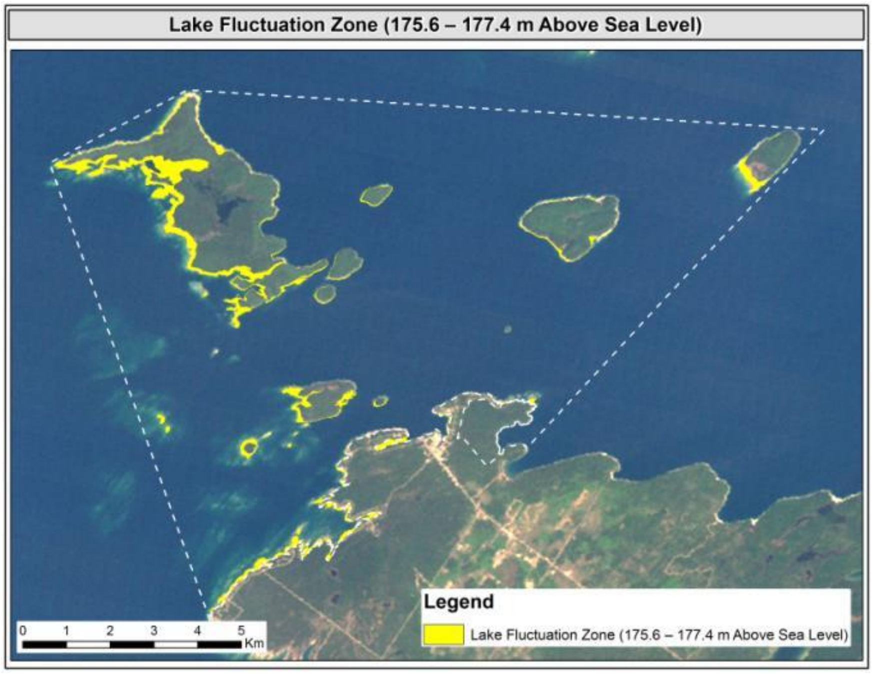


Figure A2.13 Lake level fluctuations were based on historic monthly mean minimum and maximum water level values from 1918-2010 (www.waterlevels.gc.ca).

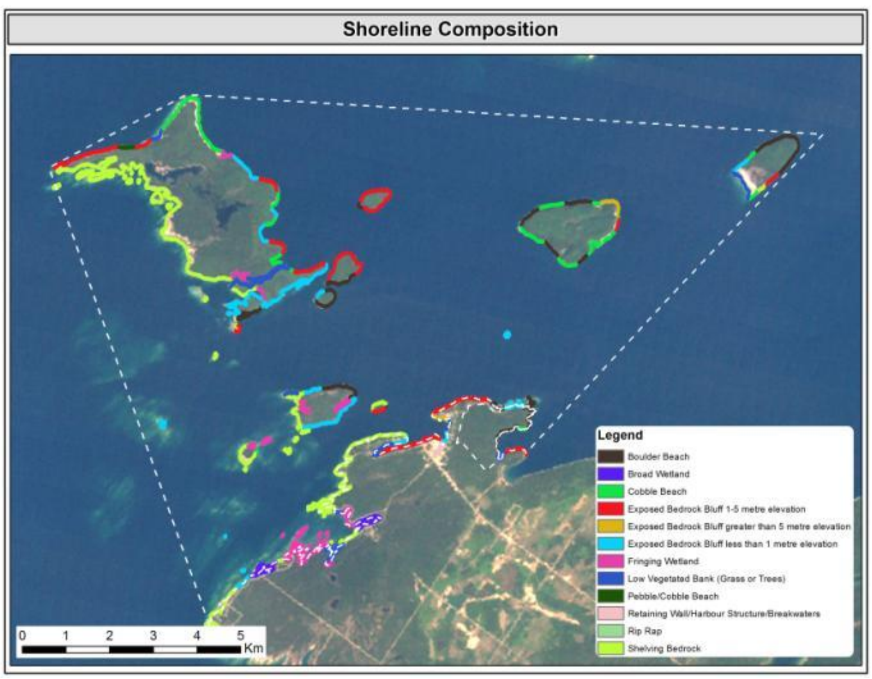


Figure A2.14 Coastal structure classification based on the Environmental Sensitivity Atlas for Lake Huron (Environment Canada 1994).

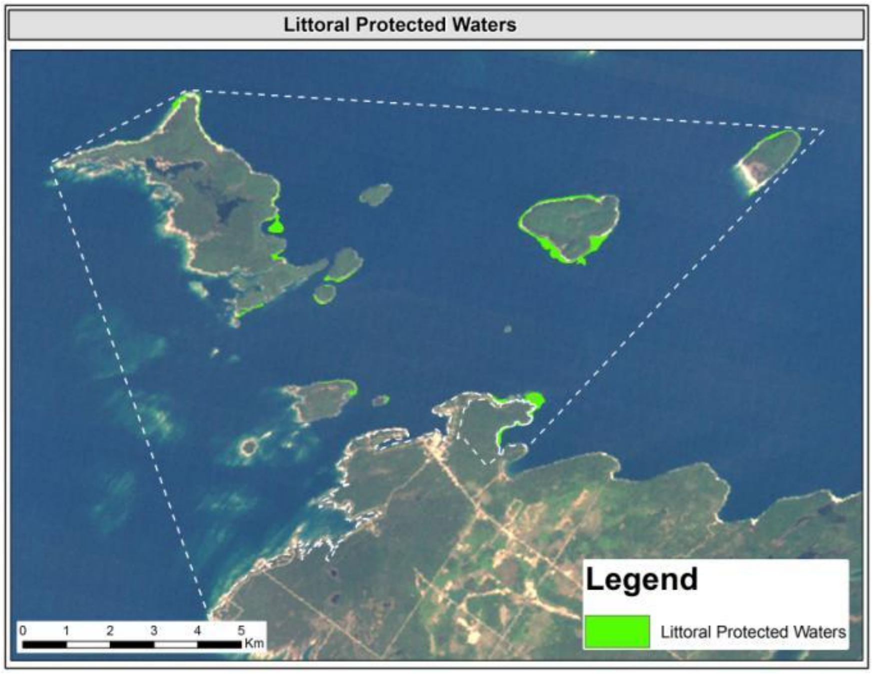


Figure A2.15 Littoral protected waters based on site inventory.

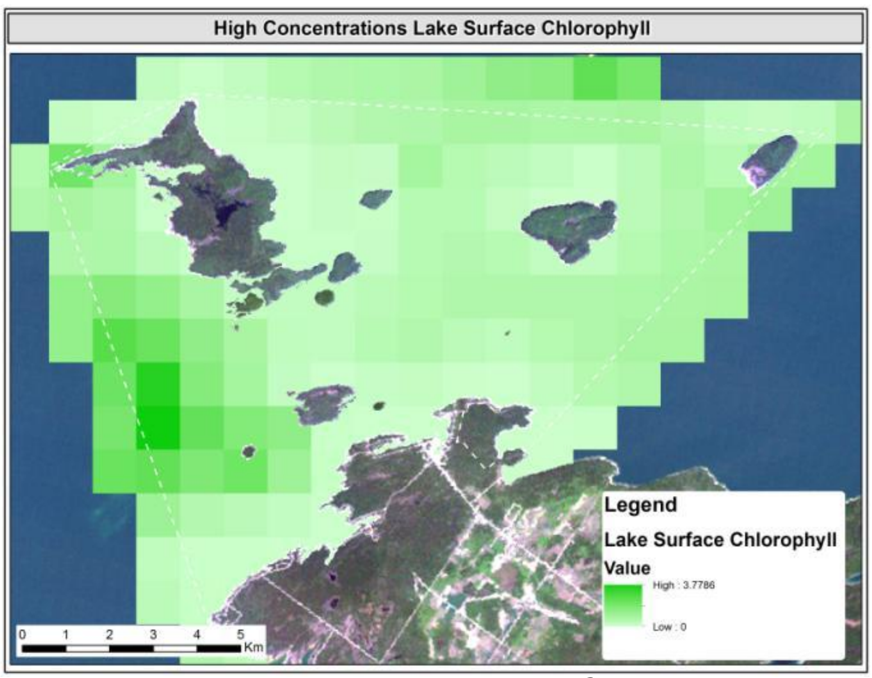


Figure A2.16 Relative productivity of chlorophyll *a* in 1 km^2 pixels was derived from SeaWiFS (sea-viewing wide field-of-view sensors) surface chlorophyll radiance data acquired from NASA (oceancolor.gsfc.nasa.gov). A mean value layer for the spring algal bloom was calculated using 5 sample days for each month (April-June) from 1999-2009.

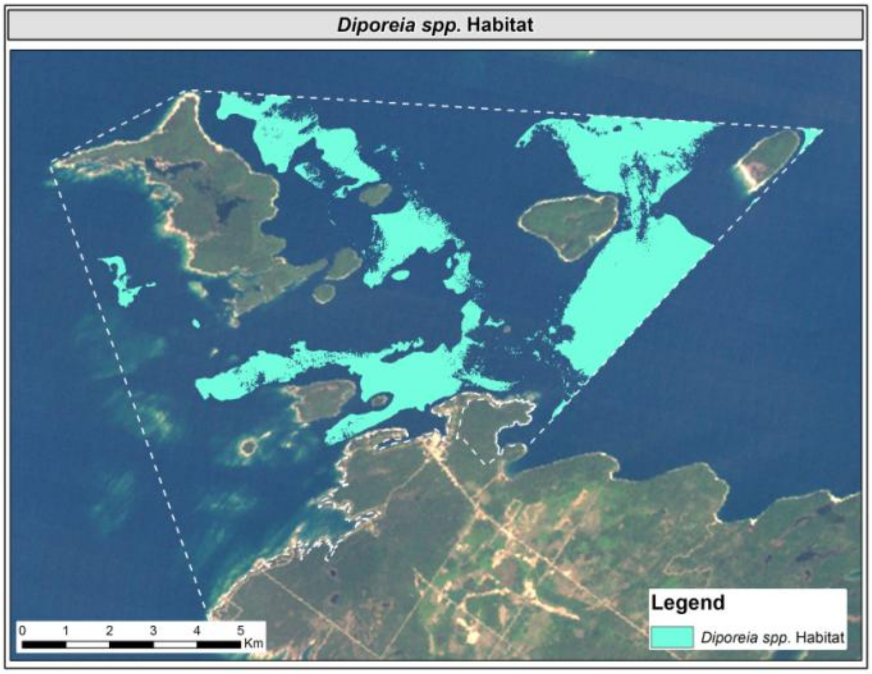


Figure A2.17 *Diporeia* spp. habitat classified as >30m water depth and soft sediment.

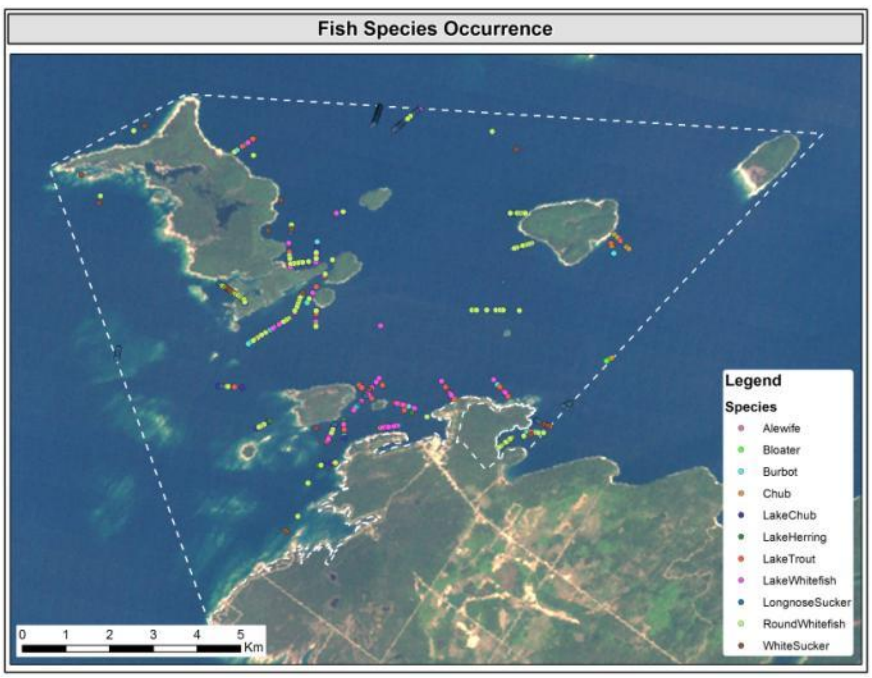


Figure A2.18 Fish occurrence data collected by indexed gillnet survey (n=533 species occurrences). Survey's completed as collaboration between Stephen Gile (Ontario Ministry of Natural Resources) and Scott Parker (Parks Canada). Raw data in OMNR project code LHA_IA07_105, LHA_IA09_105, and LHA_IA10_105. Fish habitat models developed using this occurrence data and influential bathymetric features (i.e., water depth, rugosity, and slope) in a DOMAIN model (Carpenter et al. 1993).

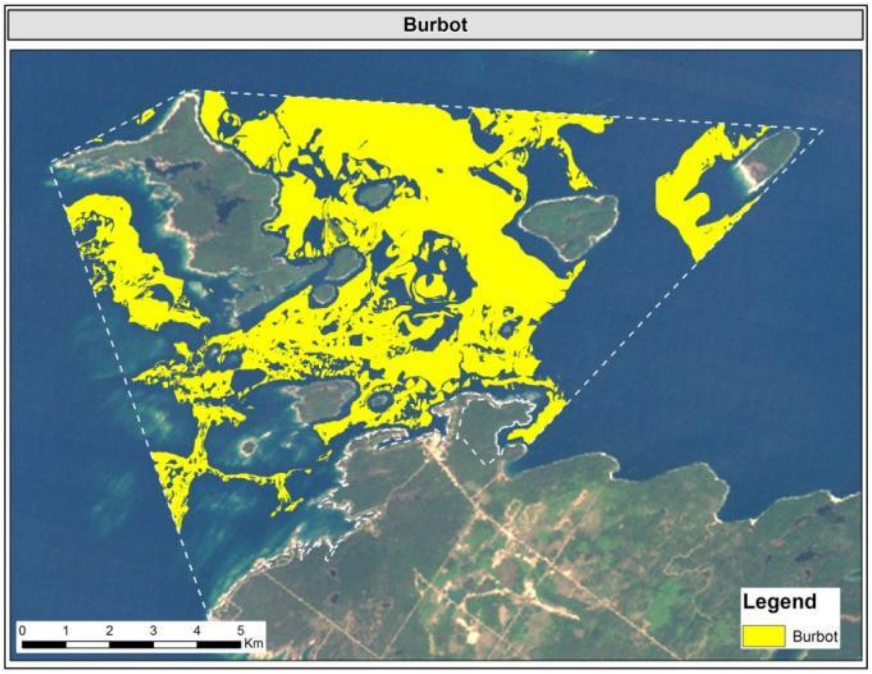


Figure A2.19 Burbot habitat based on Figure A2.18.

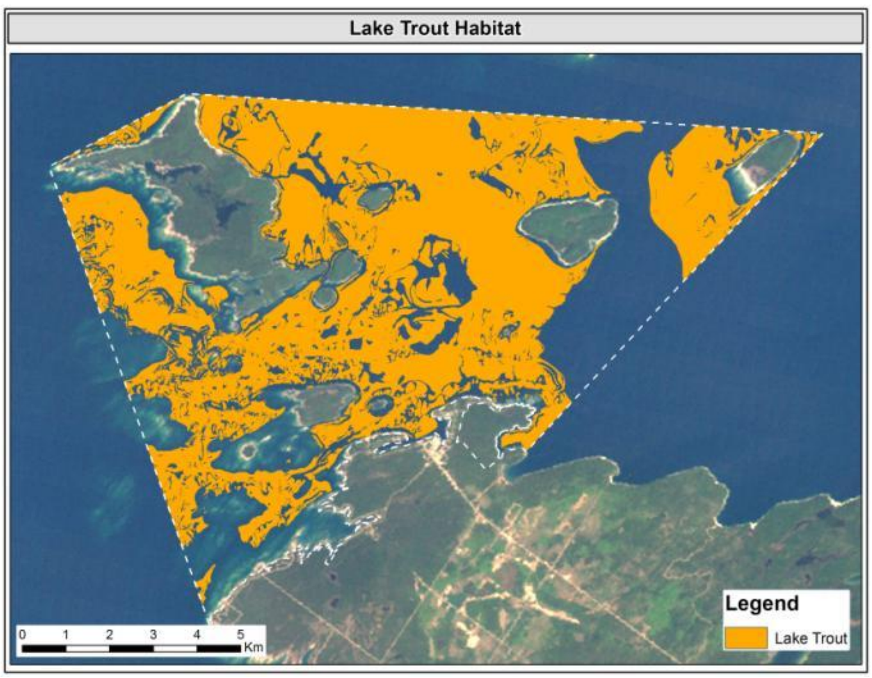


Figure A2.20 Lake trout habitat based on Figure A2.18.

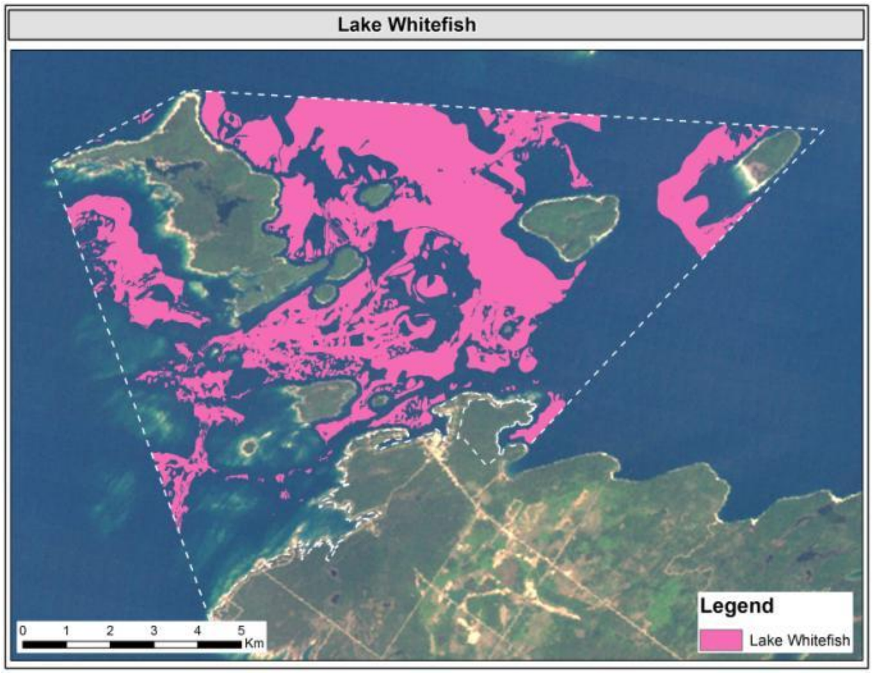


Figure A2.21 Lake whitefish habitat based on Figure A2.18.

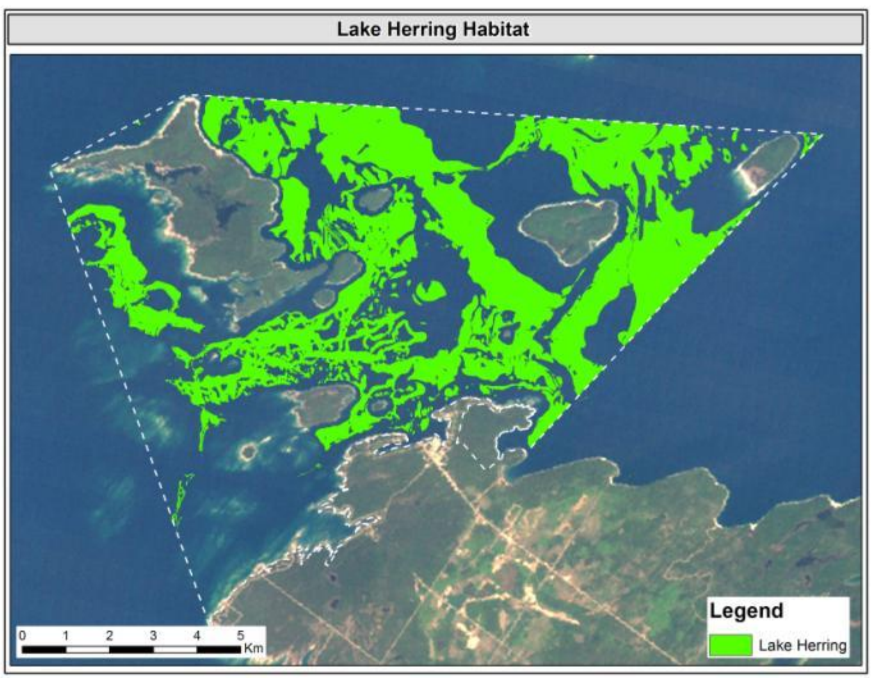


Figure A2.22 Lake herring habitat based on Figure A2.18.

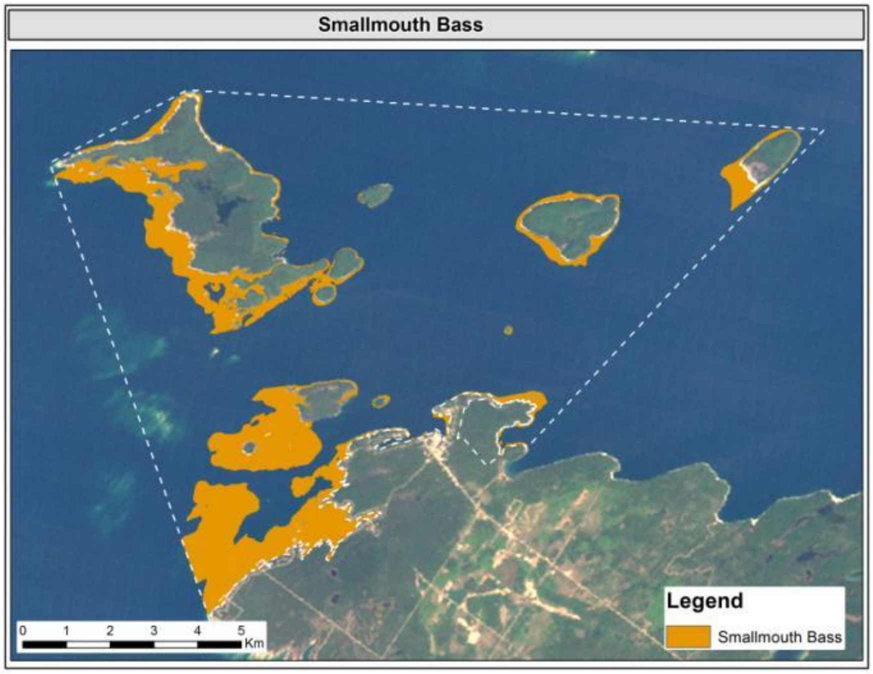


Figure A2.23 Smallmouth bass habitat classified as <10 m water depth.

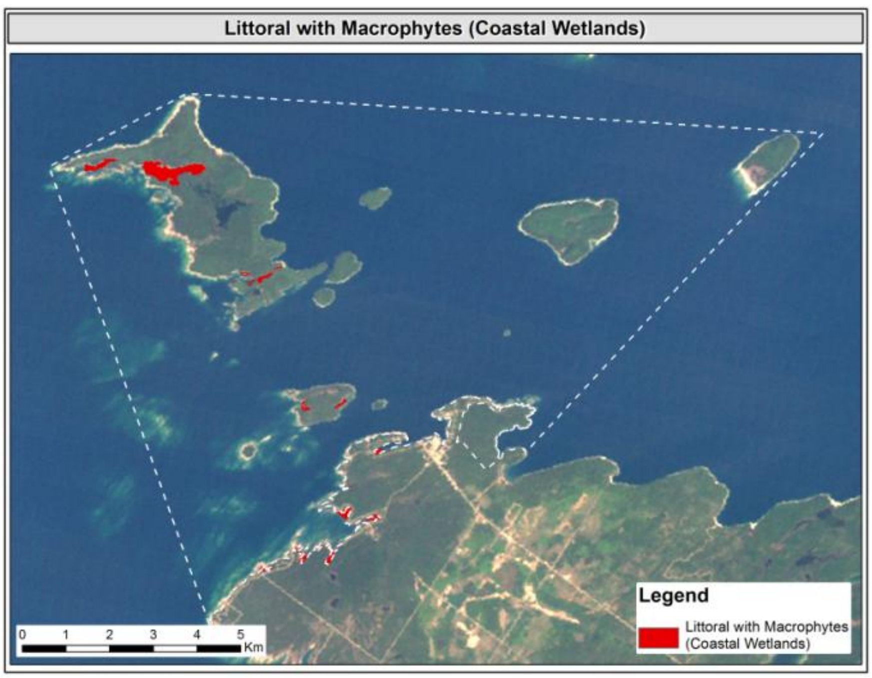


Figure A2.24 Littoral area with macrophyte species based on visual inspection.

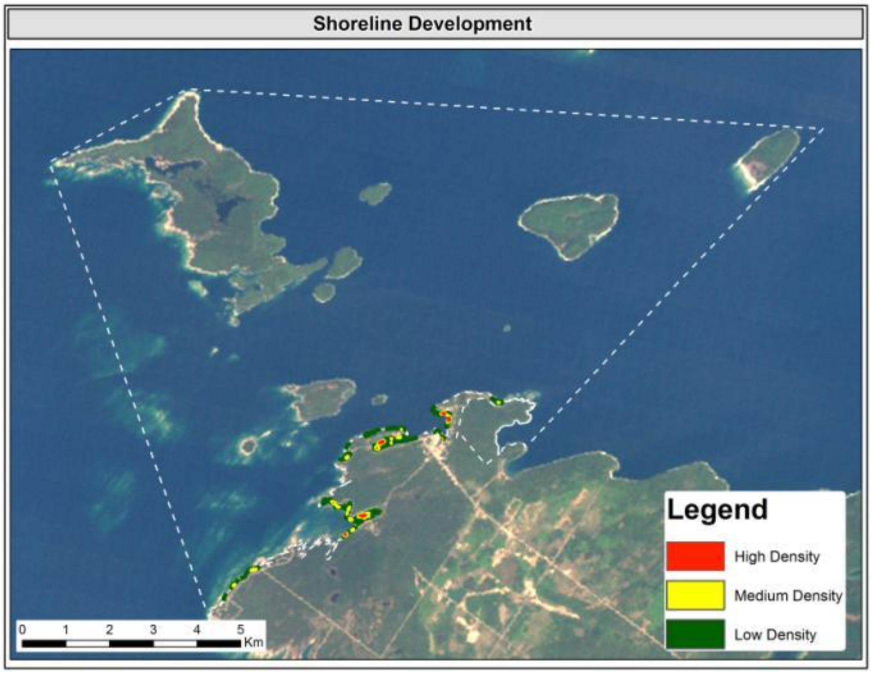


Figure A2.25 Shoreline development, represented as evidence of physical work or infrastructure (e.g., docks, water lines, etc...) found below the ordinary high watermark was digitized from orthorecitified aerial photographs from 2006. Polygon features were converted to 10m grid cells and a point density model was calculated (<2 = low, 2-4 = medium, >4 = high).

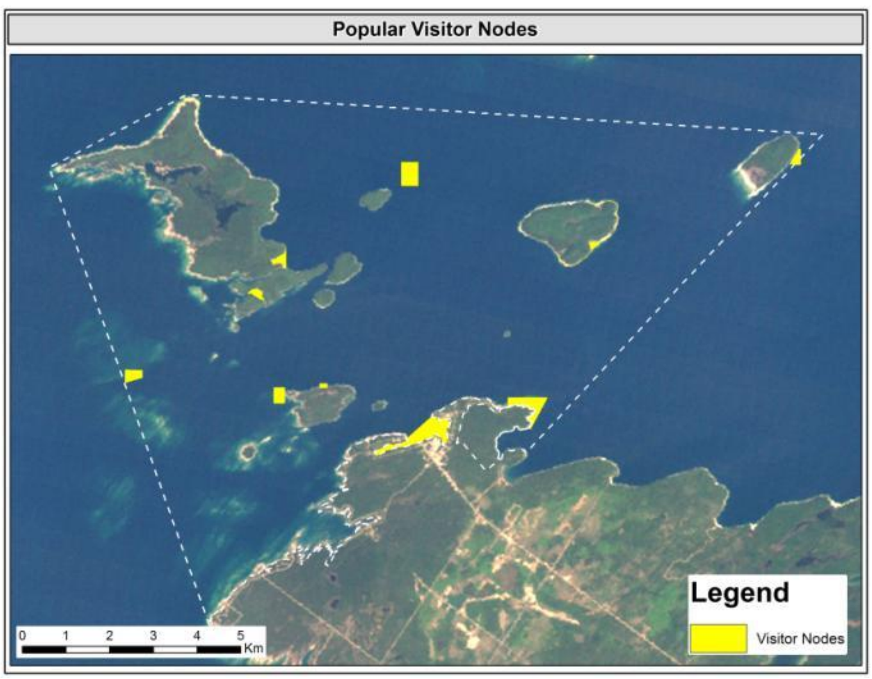


Figure A2.26 Visitor nodes based on dive sites, commercial harbours, popular shoreline day use areas, and overnight anchorages.

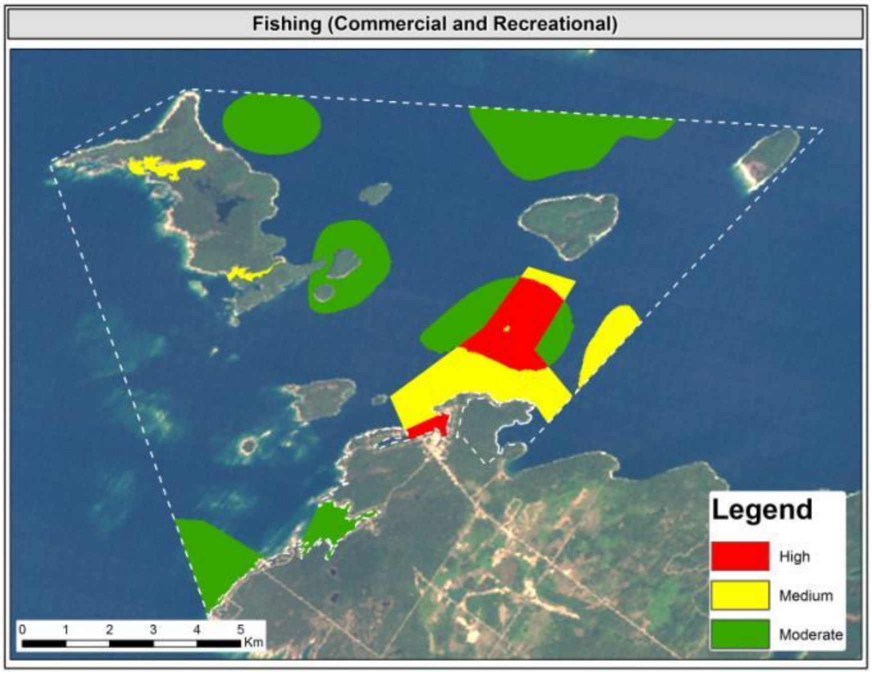


Figure A2.27 Commercial fishing areas based on data provided from interviews with fishers (Beak Consultants Ltd. 1990) and recreational fishing areas defined from personal observations.

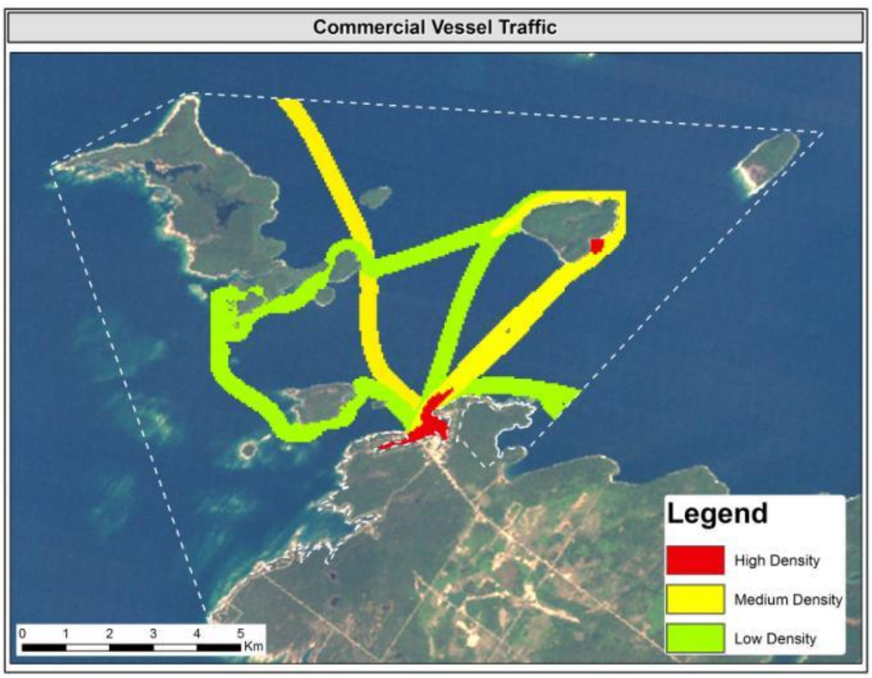


Figure A2.28 Established vessel traffic lanes, including commercial ferry and tour boats.

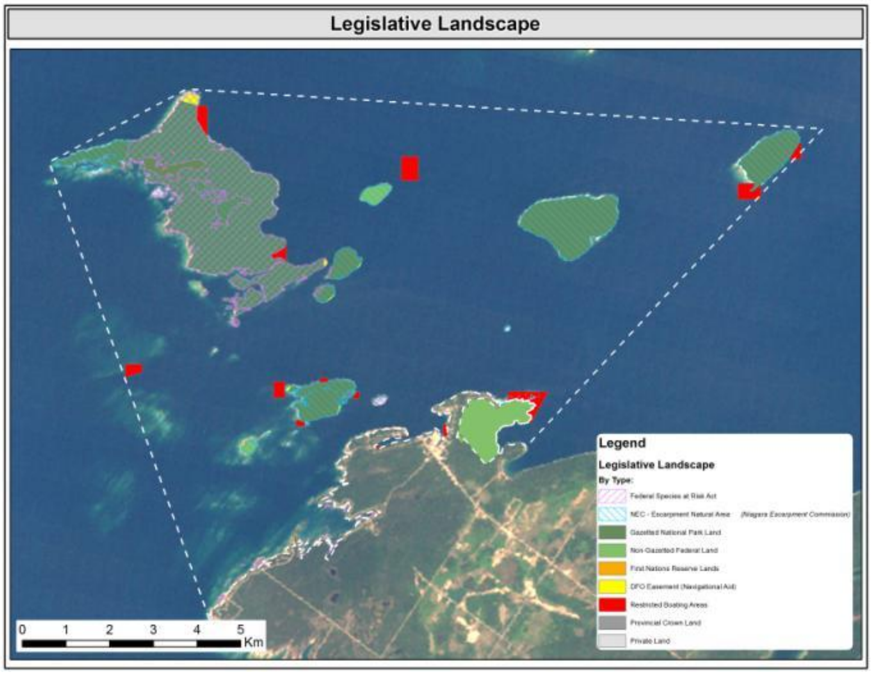


Figure A2.29 Governance was interpreted by spatially mapping relevant legislation and jurisdiction (e.g., Canada National Parks Act, Species at Risk critical habitat, Niagara Escarpment Planning area, etc...).

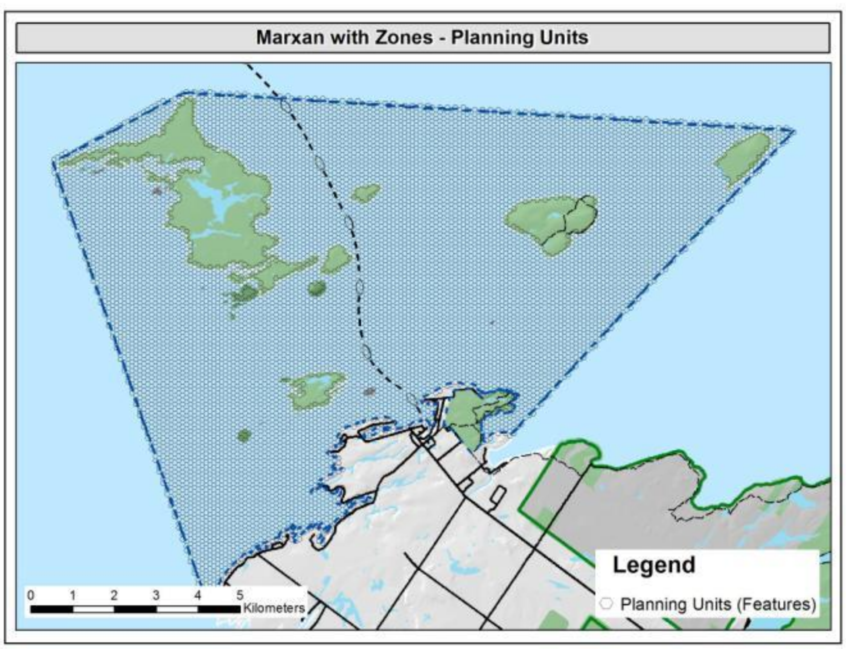


Figure A2.30 Marxan planning units, 1 ha hexagonal polygons.

Figure A2.31 CSL Merlin, multibeam sonar launch. Multibeam bathymetric data was collected by the Canadian Hydrographic Service using their survey launch CSL Merlin equipped with a Kongsberg-Simrad EM 3002 multibeam system. The system produced 254 beams spanning an arc of 120 degrees with a ping rate of up to 40 times per second. The swath of lakebed surveyed with each line is 3 to 4 times the water depth. Line spacing is approximately 1.5 times the water depth to provide ensonification overlap between lines. The system is calibrated and all data collected is corrected for roll, pitch, heave and yaw. The differential GPS used for navigation provided an accuracy of +/- 3 m. Survey speed averaged 10 knots resulting in a data collection rate of about 1.2 km^2/hr in water depth of 40 m with 100% overlap. The raw backscatter data was post-processed by the Geological Survey of Canada and TEKmap Consulting Ltd. In depths less than 10m the resolution is generally 0.5 x 0.5m xy and 1 cm z.

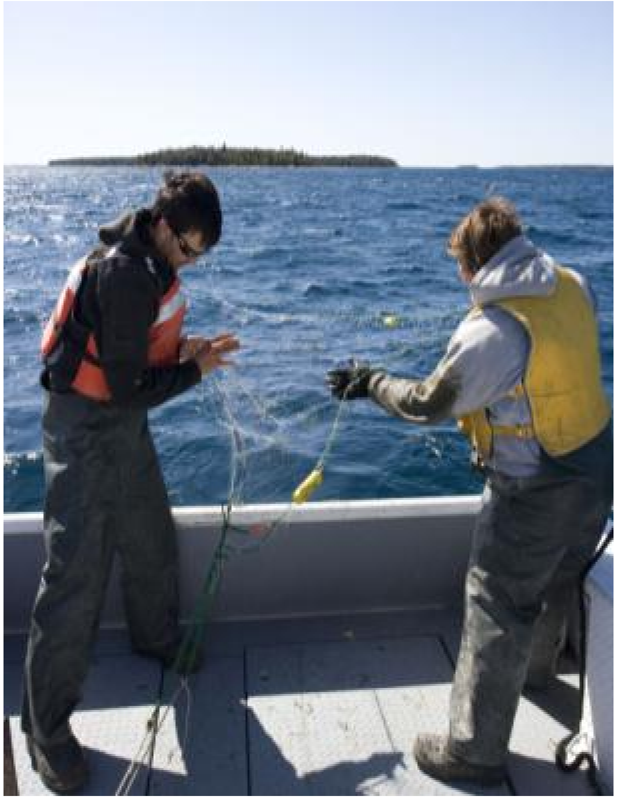


Figure A2.32 2007, 2009 and 2010 offshore fish community survey. Data used to build habitat models. 2010 field crew, from left to right lower image: Stephen Gile (Ontario Ministry of Natural Resources), and Cavan Harpur, Kirk Gibbons, and Scott Parker (photographer)(Parks Canada).

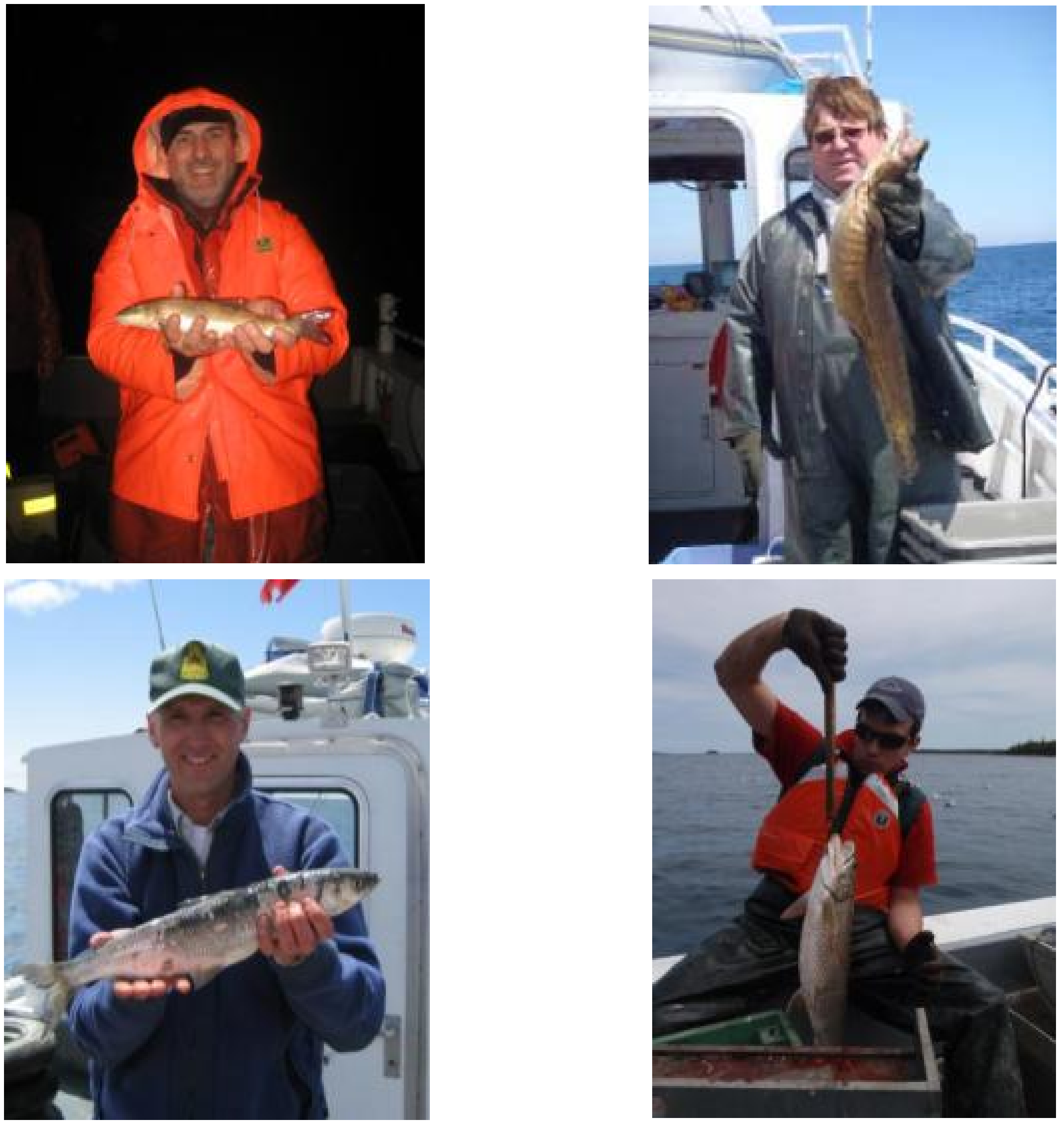


Figure A2.33 Example of fish species captured during the offshore fish community survey. Clockwise: longnose sucker, burbot, lake trout and lake herring.

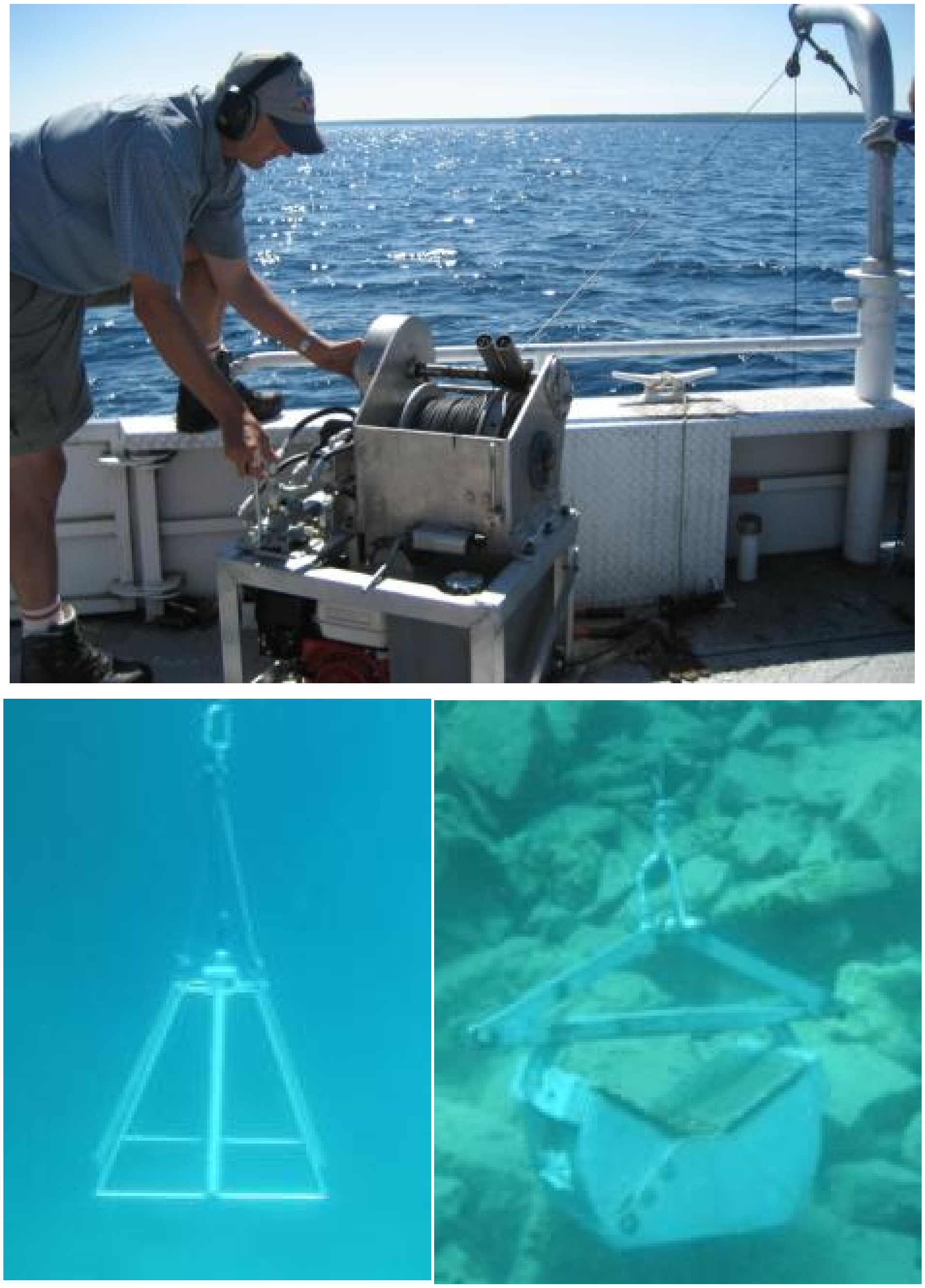


Figure A2.34 Lakebed video and sediment grab samples to train multibeam sonar (n=120 samples).

Table A2.1 Lakebed classification data. Original data collected in a collaborative field survey between Lisa Tutty (University of Toronto), Steve Blasco (Geological Survey) and Scott Parker (Parks Canada). This classification represents an interpretation by S. Parker of video and grab samples.

Easting	Northing	Description	Sediment Veneer	Driessenid Mussels	Periphyton	Pit Karren	Clay	Silt	Sand	Gravel	Boulder Cobble	Backscatter (Db)
449174	5012774	rock	1	1	1	1	0	0	0	0	1	-25.98130035400
449175	5012772	rock	1	1	1	1	0	0	0	0	1	-22.80380058290
448633	5013839	rock	1	1	1	1	0	0	0	0	0	-23.20369911190
450065	5013648	rock	1	1	1	1	0	0	0	0	0	-26.52779960630
448898	5013694	rock	1	1	1	0	0	0	0	0	1	-27.05559921260
449162	5013714	rock	1	1	1	1	0	0	0	0	1	-22.27779960630
449166	5013707	rock	1	1	1	1	0	0	0	0	1	-26.61109924320
449430	5013698	rock	1	1	1	1	0	0	0	0	0	-27.04630088810
449534	5013999	rock	1	1	1	0	0	0	0	0	1	-22.86109924320
449665	5018043	rock	1	1	1	0	0	0	0	0	0	-20.27869987490
448898	5013690	rock	1	1	1	0	0	0	0	0	1	-24.30559921260
450068	5013640	rock	1	1	1	1	0	0	0	0	0	-22.00000000000
449115	5013942	rock	1	1	1	0	0	0	0	0	1	-23.15740013120
449431	5013689	rock	1	1	1	1	0	0	0	0	0	-24.00000000000
448814	5014004	rock	1	1	1	0	0	0	0	0	1	-26.86109924320
448818	5014003	rock	1	1	1	0	0	0	0	0	1	-25.92589950560
450290	5018472	rock	1	1	1	0	0	0	0	0	1	-21.33959960940
450073	5013635	rock	1	1	1	1	0	0	0	0	0	-26.36109924320
450140	5018445	rock	1	1	1	0	0	0	0	0	1	-23.45369911190
450140	5018448	rock	1	1	1	0	0	0	0	0	1	-23.90740013120
450136	5018449	rock	1	1	1	0	0	0	0	0	1	-22.21299934390
449554	5014013	rock	1	1	1	0	0	0	0	0	1	-22.08329963680
450398	5017838	rock	1	1	1	1	0	0	0	0	1	-23.03720092770
450629	5018007	rock	1	1	1	0	0	0	0	0	1	-23.16349983220
449263	5013742	rock	1	1	1	0	0	0	0	0	1	-25.38890075680
448906	5013339	rock	1	1	0	0	0	0	0	0	0	-24.00000000000
448903	5013345	rock	1	1	0	0	0	0	0	0	0	-25.54630088810
449429	5013682	rock	1	1	1	1	0	0	0	0	0	-23.69440078740
449668	5018030	rock	1	1	1	0	0	0	0	0	0	-23.24069976810
450286	5018471	rock	1	1	1	0	0	0	0	0	1	-21.00110054020
448910	5013334	rock	1	1	0	0	0	0	0	0	0	-26.14809989930
449668	5018034	rock	1	1	1	0	0	0	0	0	0	-22.05559921260
449255	5013744	rock	1	1	1	0	0	0	0	0	1	-25.43519973750
450632	5018008	rock	1	1	1	0	0	0	0	0	1	-24.06259918210
449541	5013987	rock	1	1	1	0	0	0	0	0	1	-24.61109924320
450634	5018006	rock	1	1	1	0	0	0	0	0	1	-22.72879981990
449254	5013739	rock	1	1	1	0	0	0	0	0	1	-24.16670036320
450396	5013617	rock	1	1	0	0	0	0	0	0	1	-26.21389961240
451271	5017471	rock	1	1	1	0	0	0	0	0	0	-23.91670036320
448802	5014014	rock	1	1	1	0	0	0	0	0	1	-24.27779960630
450135	5018074	rock	1	1	1	1	0	0	0	0	0	-22.89290046690
450379	5013598	rock	1	1	0	0	0	0	0	0	1	-24.17210006710
450869	5017386	rock	1	1	1	1	0	0	0	0	0	-21.16720008850
450390	5013612	rock	1	1	0	0	0	0	0	0	1	-24.33699989320
451173	5017447	rock	1	1	1	1	0	0	0	0	1	-21.64399909970
450402	5013602	rock	1	1	0	0	0	0	0	0	1	-24.19910049440
450484	5017624	rock	1	1	1	1	0	0	0	0	1	-21.27799987790
449203	5013730	rock	1	1	1	1	0	0	0	0	1	-25.08329963680
450802	5018465	rock	1	1	0	0	0	0	0	0	0	-23.41830062870
450147	5018081	rock	1	1	1	1	0	0	0	0	0	-22.12969970700
450795	5018461	rock	1	1	0	0	0	0	0	0	0	-23.51429939270
450147	5018077	rock	1	1	1	1	0	0	0	0	0	-23.59149932860
450506	5013489	rock	1	1	0	0	0	0	0	1	1	-22.90320014950
450799	5018457	rock	1	1	0	0	0	0	0	0	0	-24.18079948430
451174	5012787	rock	1	1	0	0	0	0	0	0	0	-24.31660079960
451173	5012784	rock	1	1	0	0	0	0	0	0	0	-24.22579956050
449434	5012881	sandy_clay	0	0	0	0	1	1	1	1	0	-30.91390037540
449426	5012875	silty_sand	0	0	0	0	0	1	1	0	0	-33.58240127560
450770	5018114	rock	0	1	1	0	0	0	0	0	1	-26.02779960630

Table A2.1 Cont'd

Easting	Northing	Description	Sediment Veneer	Driessenid Mussels	Periphyton	Pit Karren	Clay	Silt	Sand	Gravel	Boulder Cobble	Backscatter (Db)
450770	5018122	rock	0	1	1	0	0	0	0	0	1	-24.70689964290
448953	5012765	silty_sand	0	0	0	0	0	1	1	0	0	-29.92320060730
450772	5018128	rock	0	1	1	0	0	0	0	0	1	-24.28610038760
449425	5012881	silty_sand	0	0	0	0	0	1	1	0	0	-38.31480026250
450474	5018264	rock	0	1	1	1	0	0	0	0	0	-28.38890075680
452022	5018276	silty_sand	0	1	0	0	0	1	1	0	0	-32.66249847410
449009	5013002	gravelly_sand	0	1	0	0	0	1	1	1	0	-33.15739822390
449327	5012933	silty_sand	0	0	0	0	0	1	1	0	0	-33.90739822390
450468	5018268	rock	0	1	1	1	0	0	0	0	0	-24.80559921260
448875	5012769	silty_sand	0	0	0	0	0	1	1	0	0	-29.98430061340
449002	5013000	gravelly_sand	0	1	0	0	0	1	1	1	0	-30.43519973750
452426	5018185	sandy_clay	0	1	0	0	1	1	1	1	0	-25.86109924320
449004	5013005	gravelly_sand	0	1	0	0	1	1	1	1	0	-30.27779960630
452435	5017710	sandy_clay	0	1	0	0	1	1	1	0	0	-27.11109924320
450714	5017965	rock	0	1	1	1	0	0	0	0	0	-26.78000068660
448990	5012976	silty_sand	0	1	1	0	0	1	1	0	0	-32.49069976810
450714	5017968	rock	0	1	1	1	0	0	0	0	0	-27.21089935300
451275	5017542	gravelly_sand	0	1	0	0	0	1	1	1	0	-29.22220039370
450708	5013529	sandy_clay	0	1	0	0	1	0	1	1	0	-25.43980026250
451397	5012921	sandy_clay	0	0	0	0	1	1	0	0	0	-30.91670036320
448978	5012981	silty_sand	0	1	1	0	0	1	1	0	0	-30.42589950560
452620	5018131	sandy_clay	0	1	0	0	1	1	1	0	0	-25.67589950560
449322	5012928	silty_sand	0	0	0	0	0	1	1	0	0	-34.06480026250
450460	5018273	rock	0	1	1	1	0	0	0	0	0	-25.66530036930
451215	5012973	gravelly_sand	0	1	0	0	1	1	1	1	0	-32.91669845580
448982	5012989	silty_sand	0	1	1	0	0	1	1	0	0	-33.40739822390
451505	5017862	silty_sand	0	0	0	0	0	1	1	0	0	-35.63890075680
449318	5012935	silty_sand	0	0	0	0	0	1	1	0	0	-35.99069976810
450705	5017963	rock	0	1	1	1	0	0	0	0	0	-24.77420043950
450924	5012928	gravelly_sand	0	1	0	0	0	0	1	1	1	-27.29070091250
451051	5013473	silty_sand	0	0	0	0	0	1	1	0	0	-32.25000000000
451251	5017550	gravelly_sand	0	1	0	0	0	1	1	1	0	-28.29630088810
450708	5013836	gravelly_sand	0	1	0	0	0	1	1	1	0	-31.61109924320
451269	5017565	gravelly_sand	0	1	0	0	0	1	1	1	0	-28.97690010070
450426	5013680	silty_sand	0	1	0	0	0	1	1	1	0	-27.85370063780
451265	5017568	gravelly_sand	0	1	1	0	0	0	1	1	0	-28.37960052490
451498	5018119	silty_sand	0	0	0	0	0	1	1	0	0	-35.76309967040
450387	5013637	sandy_clay	0	1	0	0	0	1	1	1	0	-27.35560035710
451701	5012890	sandy_clay	0	0	0	0	1	1	1	1	0	-26.47220039370
451155	5014010	silty_sand	0	0	0	0	0	1	1	0	0	-34.27780151370
452230	5017576	sandy_clay	0	1	0	0	1	1	1	1	0	-26.42130088810
451084	5013821	silty_sand	0	0	0	0	0	1	1	0	0	-33.02780151370
451856	5017639	silty_sand	0	1	0	0	0	1	1	1	0	-32.39580154420
451170	5014015	silty_sand	0	0	0	0	0	1	1	0	0	-35.00000000000
452284	5017443	sandy_clay	0	1	0	0	1	1	1	1	0	-26.75930023190
451724	5017926	silty_sand	0	0	0	0	0	1	1	0	0	-33.20140075680
450186	5018291	rock	0	1	1	1	0	0	0	0	0	-23.49510002140
451537	5013886	silty_sand	0	0	0	0	0	1	1	0	0	-33.36109924320
451406	5013960	silty_sand	0	0	0	0	0	1	1	0	0	-35.35189819340
451835	5018203	silty_sand	0	0	0	0	0	1	1	0	0	-33.66109848020
451836	5013833	silty_sand	0	0	0	0	0	1	1	0	0	-32.53699874880
451514	5013789	silty_sand	0	0	0	0	0	1	1	0	0	-33.62500000000
451650	5014156	silty_sand	0	0	0	0	0	1	1	0	0	-32.45830154420
449053	5012877	silty_sand	0	0	0	0	0	1	1	0	0	-30.67659950260
449047	5012876	silty_sand	0	0	0	0	0	1	1	0	0	-29.04920005800
449043	5012876	silty_sand	0	0	0	0	0	1	1	0	0	-29.61750030520
452197	5017901	sandy_clay	0	1	0	0	1	1	1	0	0	-26.25000000000
450187	5018297	rock	0	1	1	1	0	0	0	0	0	-24.05839920040
451499	5013471	silty_sand	0	0	0	0	0	1	1	0	0	-34.31940078740
450183	5018297	rock	0	1	1	1	0	0	0	0	0	-25.01280021670
451637	5018112	silty_sand	0	0	0	0	0	1	1	0	0	-33.99069976810

Appendix 3. Supplement to Chapter 4: Related coastal wetland data and additional analysis.

Table A3.1 Coastal wetland site descriptions.

Site Code	Site Name	UTM (Zone 17T)		Type	Potential Stranding	Vegetation Density			Fish Habitat	Human Impact
		East	North			Submergent	Emergent	Floating		
CN	Cove Island North	440191	5018069	Island	Yes	High	Low	Low	High	None
BP	Boat Passage	443876	5015425	Island	No	High	Moderate	Low	High	None
RUW	Russel Island West	444813	5012619	Island	Yes	High	High	Low	Moderate	None
RUE	Russel Island East	445873	5012700	Island	Yes	Low	Low	-	Low	None
HBE	Hay Bay East	446379	5009958	Mainland	No	High	Moderate	High	High	High
HBW	Hay Bay West	444952	5009163	Mainland	No	High	High	Moderate	High	Moderate
HBS	Hay Bay South	445556	5009243	Mainland	Yes	High	Moderate	Moderate	High	Moderate
BT	Big Tub Harbour	446532	5011503	Mainland	No	Low	Low	-	Low	High

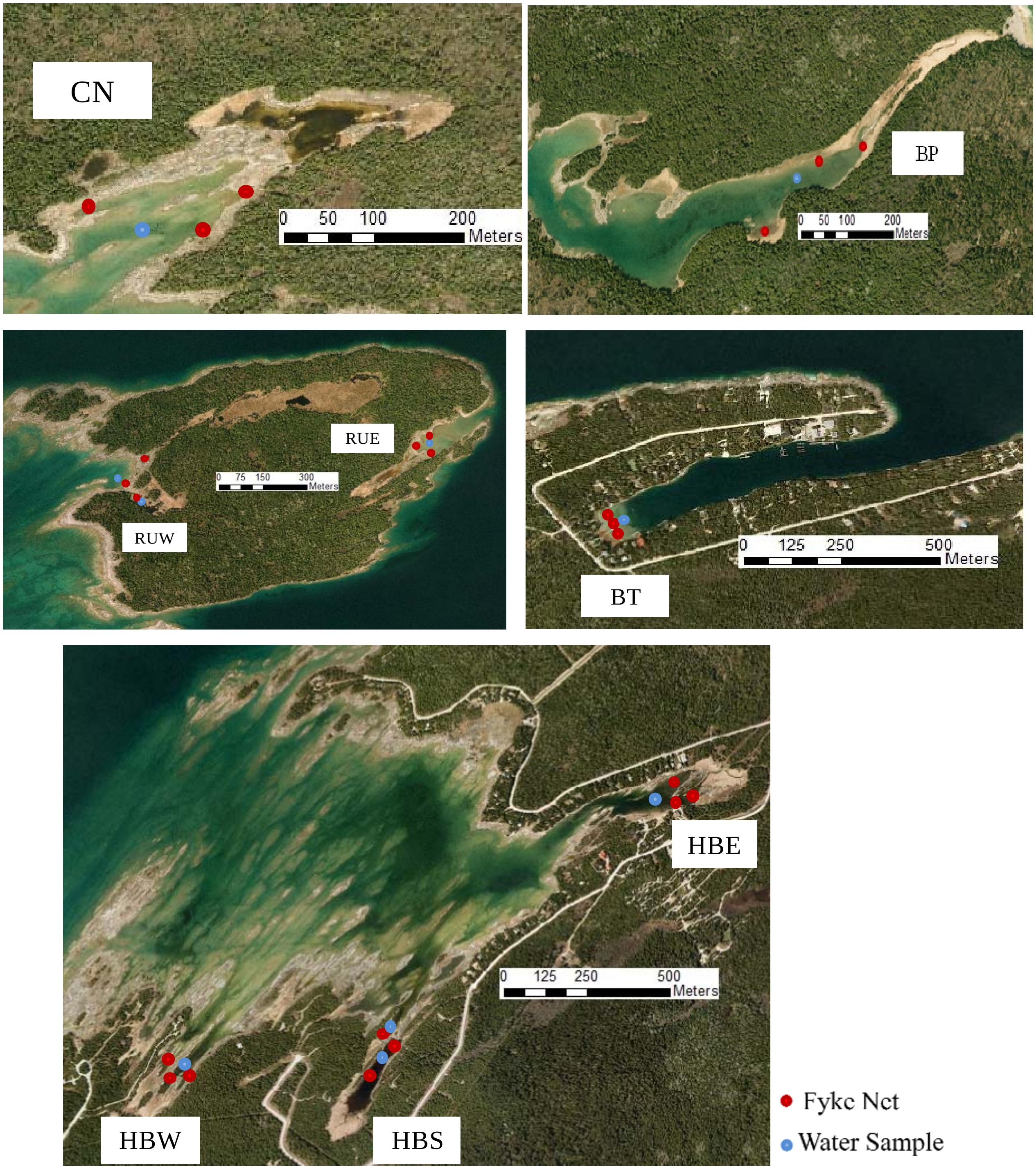


Figure A3.1 Coastal wetland fish (fyke net) and water sample sites. Site codes on Table A3.1.

Table A3.2 Coastal wetland fish site-year sample abundance. Site codes on Table A3.1.

	lake trout	rockbass	brown bullhead	bowfin	freshwater drum	longnose sucker	white sucker	mottled sculpin	spotfin shiner	lake chub	brook stickleback	northern pike	iowa darter	johnny darter	banded killifish	threespine stickleback	longnose gar	pumpkinseed	bluegill	common shiner	smallmouth bass	largemouth bass	round goby	golden shiner	emerald shiner	blackchin shiner	blacknose shiner	spottail shiner	mimic shiner	yellow perch	northern redbelly dace	finescale dace	bluntnose minnow	fathead minnow	ninespine stickleback	longnose dace	creek chub	central mudminnow
CN2005	0	71	0	0	1	0	0	0	0	0	0	0	0	25	0	0	0	2	0	0	3	0	0	0	0	0	0	0	0	17	0	0	34	0	1	0	0	0
CN2006	0	222	0	0	0	0	1	0	0	0	0	0	4	3	1	0	0	60	0	67	7	0	0	0	3	0	0	0	0	243	0	0	472	0	1	0	0	0
CN2007	0	116	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	127	0	0	20	0	3	0	0	2	0	19	0	70	0	0	68	0	0	0	0	0
CN2008	0	63	0	0	0	0	0	0	0	0	0	2	3	4	0	0	0	58	5	3	22	0	0	0	0	2	0	0	0	2	0	0	274	0	0	0	0	0
CN2009	0	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	7	4	0	9	0	0	0	0	1	0	0	0	0	46	0	1	0	0	0
CN2010	0	225	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	6	0	60	14	0	3	0	0	18	0	0	14	10	0	0	401	0	0	0	0	0
CN2011	0	58	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31	3	13	13	0	3	0	0	18	3	0	13	3	0	0	254	0	0	0	0	0
CN2012	0	71	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	53	0	0	79	0	7	0	0	0	8	0	0	2	0	0	1132	0	0	0	0	0
BP2005	0	89	0	0	0	0	0	0	0	0	0	0	7	9	3	0	0	0	0	7	0	0	0	0	0	0	0	54	65	18	0	0	69	0	6	0	1	0
BP2006	0	51	0	0	0	0	0	0	0	0	0	0	0	12	1	0	0	2	0	230	1	0	4	0	3	0	0	535	0	11	0	0	208	0	3	0	0	0
BP2007	0	53	0	0	0	0	0	1	0	0	0	0	0	3	1	0	0	5	0	53	4	0	6	0	15	0	8	3	67	4	0	0	195	0	2	0	0	0
BP2008	0	43	1	0	0	0	0	0	0	0	2	0	1	1	8	0	1	1	1	90	0	0	32	0	0	0	0	19	0	24	0	0	90	0	1	0	0	0
BP2009	0	38	0	0	0	0	0	0	0	0	0	0	1	1	13	0	0	0	0	18	0	0	2	0	7	26	0	79	710	7	0	0	762	4	0	0	0	0
BP2010	0	88	0	0	0	0	1	0	0	0	0	0	0	0	10	0	0	0	0	12	3	0	10	0	5	251	0	54	435	89	0	0	547	1	0	0	1	0
BP2011	0	40	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	1	2	19	1	0	12	0	15	23	0	9	295	1	0	0	383	0	0	0	0	0
BP2012	0	89	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	5	0	28	3	0	9	0	0	0	2	9	62	31	0	0	251	0	0	0	0	0
RUW2005	0	75	0	0	0	2	21	0	0	0	0	0	0	0	0	0	0	34	0	0	2	0	1	0	0	0	0	0	0	0	0	0	16	0	8	0	0	0
RUW2006	0	72	0	0	0	0	2	0	0	0	11	0	6	3	0	0	0	249	0	7	0	0	0	2	37	35	0	5	0	0	0	0	213	139	1	0	0	0
RUW2007	0	150	0	0	0	0	7	0	0	0	43	0	1	0	8	0	0	279	0	2	1	0	1	0	0	4	0	3	0	0	11	17	18	4	0	1	0	0
RUW2008	0	75	0	0	0	0	7	0	0	1	4	0	0	0	5	0	0	111	0	0	7	0	0	0	0	11	0	0	0	1	3	0	99	15	0	0	0	0
RUW2009	0	179	0	0	0	0	25	0	0	2	1	0	0	1	0	0	0	1	0	0	3	0	8	0	0	0	0	0	3	1	0	0	18	0	0	0	0	0
RUW2010	0	37	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	0	2	0	0	0	0	0	0	0	0	0	17	0	1	0	0	0
RUW2011	0	93	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	6	0	3	1	0	0	0	0	2	0	0	0	47	0	0	0	0	0
RUW2012	0	252	0	0	0	0	2	0	0	0	5	0	2	0	0	0	0	182	0	43	8	0	2	0	3	0	0	0	0	2	26	25	77	1	0	0	0	0
RUE2005	0	21	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	6	1	0	1	1	0	0	0	0	0	0	0	0	13	0	0	0	0	0
RUE2006	0	28	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	112	40	0	0	0	0
RUE2007	0	4	0	0	0	0	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	16	0	1	0	0	0	0	0	0	0	128	0	0	0	0	0
RUE2008	0	17	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	1	0	0	0	0	0	0	1	0	0	7	0	0	0	0	0
RUE2009	0	5	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	14	0	0	0	0	2	44	0	0	0	31	0	1	0	0	0
RUE2010	0	9	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	14	0	0	5	0	0	4	0	0	0	71	0	0	0	0	0
RUE2011	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	4	0	0	0	0	0	19	0	0	0	24	0	0	0	0	0
RUE2012	0	3	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	7	0	0	0	0	0

Table A3.2 Cont'd

	lake trout	rockbass	brown bullhead	bowfin	freshwater drum	longnose sucker	white sucker	mottled sculpin	spotfin shiner	lake chub	brook stickleback	northern pike	iowa darter	johnny darter	banded killifish	threespine stickleback	longnose gar	pumpkinseed	bluegill	common shiner	smallmouth bass	largemouth bass	round goby	golden shiner	emerald shiner	blackchin shiner	blacknose shiner	spottail shiner	mimic shiner	yellow perch	northern redbelly dace	finescale dace	bluntnose minnow	fathead minnow	ninespine stickleback	longnose dace	creek chub	central mudminnow
HBE2005	0	22	19	1	0	0	1	0	0	0	0	1	0	0	4	0	0	51	0	0	1	0	0	21	0	4	0	0	0	18	1	0	4	0	0	0	0	0
HBE2006	0	5	7	1	0	0	0	0	0	0	0	1	0	0	1	0	1	52	0	3	1	0	0	0	0	0	0	4	0	1	0	0	75	0	0	0	0	0
HBE2007	0	89	18	1	0	0	3	0	0	0	0	4	1	0	9	0	0	104	0	5	3	0	1	2	0	17	4	0	0	2	0	0	23	2	0	0	0	0
HBE2008	0	72	1	0	0	0	0	0	0	0	0	0	6	0	2	0	0	1	0	42	1	0	4	0	0	12	0	0	608	6	0	0	243	5	3	0	0	0
HBE2009	0	66	6	1	0	0	0	0	0	0	0	1	0	0	22	0	0	87	0	66	7	0	1	3	0	18	0	3	53	62	1	0	190	0	0	0	0	0
HBE2010	0	100	16	0	0	0	1	0	0	0	0	0	0	0	19	0	0	80	0	36	2	0	2	15	0	6	0	0	168	5	0	0	132	1	0	0	0	0
HBE2011	0	60	9	0	0	0	1	0	0	0	0	0	0	1	15	0	0	31	1	23	0	0	6	11	0	6	3	6	65	15	3	0	97	0	0	0	0	0
HBE2012	0	60	4	0	0	0	1	0	0	0	0	0	0	0	2	0	0	51	0	12	1	0	15	6	0	21	0	0	28	3	0	0	15	0	0	0	0	0
HBS2005	0	42	34	0	0	0	6	0	0	0	0	2	0	1	0	0	0	68	0	30	0	0	0	38	0	3	0	0	0	30	0	0	53	0	0	0	0	0
HBS2006	0	67	26	0	0	0	1	0	0	0	0	3	1	0	14	0	0	204	0	21	0	0	3	98	4	54	0	0	0	10	1	0	87	0	0	0	0	1
HBS2007	0	62	21	0	0	0	12	0	0	0	0	4	0	0	5	0	0	229	0	63	0	1	0	106	0	37	10	0	0	29	0	0	67	5	0	0	0	0
HBS2008	0	95	14	1	0	0	1	0	0	0	0	1	0	0	5	0	0	110	0	13	6	0	5	41	0	42	3	0	0	3	0	0	82	0	0	0	0	0
HBS2009	0	103	15	0	0	0	6	0	0	0	0	0	0	0	16	0	0	153	0	5	5	0	0	27	0	3	0	0	1	27	0	0	86	0	0	0	0	3
HBS2010	0	25	43	2	0	0	0	0	0	0	7	1	4	0	24	0	0	43	0	12	1	0	0	126	0	173	9	0	1	2	6	0	89	0	1	0	0	12
HBS2011	0	49	46	0	0	0	0	0	0	0	0	0	6	3	6	0	0	136	0	17	0	0	1	29	4	11	1	0	46	37	0	0	327	3	0	0	0	5
HBS2012	0	69	70	0	0	0	0	0	0	0	0	0	0	1	7	0	0	643	0	3	13	0	3	59	0	45	9	0	0	18	0	0	159	1	0	0	0	0
HBW2006	0	97	1	0	0	0	0	0	0	0	0	4	1	0	1	0	0	171	0	1	2	0	11	0	0	1	0	0	0	101	1	0	28	1	0	0	0	0
HBW2007	0	30	15	0	0	0	0	0	0	0	0	7	0	0	3	0	0	86	0	0	0	0	5	0	0	0	0	0	0	38	0	0	2	0	0	0	0	0
HBW2008	0	42	19	0	0	0	0	0	0	0	0	1	0	0	9	0	0	36	0	0	0	0	3	0	0	0	0	0	0	82	0	0	45	0	0	0	0	0
HBW2009	0	82	22	0	0	0	1	0	0	0	0	2	0	0	80	0	0	147	0	0	19	0	0	9	0	31	0	0	3	20	1	0	107	0	0	0	0	0
HBW2010	0	22	7	0	0	0	0	0	0	0	1	0	7	0	62	0	0	84	0	0	0	0	0	34	0	8	0	0	126	6	0	0	418	2	0	0	0	0
HBW2011	0	63	3	0	0	0	0	0	0	0	0	0	0	0	5	0	0	8	0	0	5	0	1	10	0	6	0	0	1	0	0	0	2	0	0	0	0	0
HBW2012	0	120	0	0	0	0	0	0	0	0	0	0	1	0	15	0	0	13	0	3	37	0	12	7	0	8	0	1	16	4	0	0	62	0	0	0	0	0
BT2005	0	17	0	0	0	0	26	0	9	0	0	0	0	1	0	0	0	0	0	0	0	0	52	0	0	0	0	39	0	2	0	0	35	0	0	0	5	0
BT2006	0	6	0	0	0	0	8	0	0	0	6	0	0	0	0	0	0	0	0	3	0	0	1091	0	4	0	0	0	0	0	0	0	12	0	4	0	0	0
BT2007	0	12	0	0	0	0	20	1	0	0	1	0	0	0	0	0	0	0	0	5	0	0	89	0	75	0	0	47	0	54	0	0	12	0	2	0	0	0
BT2008	0	3	0	0	0	0	0	0	0	0	0	0	0	1	1	3	0	0	0	0	0	0	2622	0	0	0	0	0	1	0	0	0	0	0	5	0	0	0
BT2009	0	8	0	0	0	0	4	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2544	0	57	0	0	6	2	1	0	0	1	0	6	0	0	0
BT2010	1	47	0	0	0	0	18	0	0	0	9	0	0	0	1	0	0	0	0	0	0	0	978	0	0	2	0	1	0	1	0	0	1	0	7	0	0	0
BT2011	0	12	0	0	0	0	5	0	0	0	10	0	0	0	0	4	0	0	0	0	0	0	3135	0	0	0	0	0	3	3	0	0	1	0	8	0	0	0
BT2012	0	12	0	0	0	0	1	0	0	0	3	0	0	0	0	2	0	0	0	0	0	0	1002	0	53	0	0	1	3	0	0	0	2	0	6	0	0	0

Table A3.3 Coastal wetland fish assemblage summaries. Site codes on Table A1.1. WFI* = Wetland Fish Index (Seilheimer and Chow-Fraser 2007).

	Fish Richness	Total Fish Abundance	Exotic Species Richness	Native Species Richness	Exotic Fish Abundance	Native Fish Abundance	% Exotic Species Richness	% Exotic Fish Abundance	WFI (Presence/Absence)*	WFI (Abundance)*	WFI EXadj (Presence/Absence)*	WFI EXadj (Abundance)	Shannon's Diverity Index	Simpson's Diveristy Index
CN2005	8	154	0	8	0	154	0	0	3.15	3.52	3.15	3.52	1.427	0.7
CN2006	12	1084	0	12	0	1084	0	0	3.72	3.88	3.72	3.88	1.459	0.711
CN2007	8	425	1	7	3	422	13	1	3.67	3.57	3.31	3.49	1.649	0.779
CN2008	11	438	0	11	0	438	0	0	3.91	3.93	3.91	3.93	1.226	0.568
CN2009	8	112	1	7	9	103	13	8	3.62	4.12	3.26	3.84	1.354	0.672
CN2010	10	753	1	9	3	750	10	0	4	4.22	3.68	4.21	1.269	0.619
CN2011	11	412	1	10	3	409	9	1	3.17	2.97	2.87	2.87	1.376	0.589
CN2012	8	1353	1	7	7	1346	12.5	0.5	3.45	3.75	3.1	3.68	0.669	0.292
BP2005	11	328	0	11	0	328	0	0	3.91	4.09	3.91	4.09	1.856	0.811
BP2006	12	1061	1	11	4	1057	8	0	3.5	3.82	3.21	3.76	1.319	0.658
BP2007	15	420	1	14	6	414	7	1	3.82	4.13	3.56	4.03	1.693	0.725
BP2008	15	315	1	14	32	283	7	10	3.75	3.97	3.49	3.65	1.839	0.798
BP2009	13	1668	1	13	2	1666	8	0	3.92	4.22	3.64	4.19	1.181	0.659
BP2010	14	1507	1	13	10	1497	7	1	3.79	4.2	3.52	4.12	1.628	0.754
BP2011	13	805	1	12	12	793	8	1	3.83	4.33	3.55	4.23	1.314	0.435
BP2012	11	493	1	10	9	484	9	2	3.8	4.11	3.5	3.97	1.536	0.537
RUW2005	8	159	1	7	1	158	13	1	3.92	3.75	3.57	3.67	1.475	0.551
RUW2006	15	782	0	15	0	782	0	0	3.63	3.75	3.63	3.75	1.761	0.733
RUW2007	16	550	1	15	1	549	6	0	3.83	3.69	3.58	3.64	1.479	0.659
RUW2008	12	339	0	12	0	339	0	0	3.61	3.71	3.61	3.71	1.659	0.754
RUW2009	11	242	1	10	8	234	9	3	3.54	3.77	3.24	3.6	1.003	0.435
RUW2010	7	60	1	6	2	58	14	3	4	4.13	3.62	3.95	1.042	0.537
RUW2011	8	159	1	7	3	156	13	2	4	4.18	3.64	4.04	1.071	0.551
RUW2012	15	671	1	14	2	644	6	0	3.71	3.97	3.46	3.92	1.628	0.733
RUE2005	7	44	1	6	1	43	14	2	3.6	4.14	3.22	3.99	1.329	0.664
RUE2006	8	188	1	7	1	187	13	1	3.56	3.68	3.2	3.6	1.115	0.577
RUE2007	8	153	1	7	16	137	13	10	3.54	3.8	3.18	3.48	0.645	0.288
RUE2008	7	31	1	6	1	30	14	3	3.33	3.71	2.96	3.53	1.351	0.637
RUE2009	8	99	1	7	14	85	13	14	4	4.35	3.65	3.97	1.369	0.681
RUE2010	6	104	1	5	14	90	17	13	4.73	4.48	4.32	4.12	1.058	0.504
RUE2011	5	65	1	4	4	61	20	6	4.29	4.4	3.84	4.16	1.314	0.706
RUE2012	5	17	0	5	0	17	0	0	4.17	4.29	4.17	4.29	1.365	0.706

Table A3.3 Cont'd

	Fish Richness	Total Fish Abundance	Exotic Species Richness	Native Species Richness	Exotic Fish Abundance	Native Fish Abundance	% Exotic Species Richness	% Exotic Fish Abundance	WFI (Presence/Absence)*	WFI (Abundance)*	WFI EXadj (Presence/Absence)*	WFI EXadj (Abundance)	Shannon's Diverity Index	Simpson's Diveristy Index
HBE2005	14	148	0	14	0	148	0	0	3.73	3.55	3.73	3.55	1.909	0.805
HBE2006	13	152	0	13	0	152	0	0	3.78	3.76	3.78	3.76	1.341	0.635
HBE2007	17	288	1	16	1	287	6	0	3.84	3.88	3.6	3.82	1.828	0.758
HBE2008	14	1006	1	13	4	1002	7	0	4.04	4.42	3.77	4.36	1.181	0.569
HBE2009	16	587	1	15	1	586	6	0	3.86	4.07	3.61	4.03	2.021	0.826
HBE2010	14	583	1	13	2	581	7	0	3.8	4.07	3.53	4.01	1.895	0.811
HBE2011	17	353	1	16	6	347	6	2	3.84	4.01	3.6	3.87	2.168	0.843
HBE2012	13	219	1	12	15	204	8	7	3.88	4.13	3.6	3.87	2.031	0.831
HBS2005	12	307	0	12	0	307	0	0	3.6	3.69	3.6	3.69	2.04	0.855
HBS2006	17	595	1	16	3	592	6	1	3.94	3.89	3.69	3.82	1.951	0.809
HBS2007	14	651	0	14	0	651	0	0	3.62	3.78	3.62	3.78	2.013	0.814
HBS2008	15	422	1	14	5	417	7	1	3.78	3.9	3.52	3.8	1.96	0.822
HBS2009	13	450	0	13	0	450	0	0	3.88	3.72	3.88	3.72	1.828	0.785
HBS2010	19	581	0	19	0	581	0	0	3.97	3.99	3.97	3.99	2.074	0.825
HBS2011	17	727	1	16	1	726	6	0	3.85	3.93	3.61	3.93	1.841	0.745
HBS2012	14	1100	1	13	3	1097	7	0	3.64	3.73	3.37	3.68	1.466	0.624
HBW2006	15	421	1	14	11	410	7	3	3.92	3.69	3.66	3.53	1.492	0.719
HBW2007	8	186	1	7	5	181	13	3	3.5	3.4	3.15	3.24	1.514	0.709
HBW2008	8	237	1	7	3	234	13	1	3.5	3.48	3.15	3.37	1.68	0.782
HBW2009	13	524	0	13	0	524	0	0	3.87	3.83	3.87	3.83	1.948	0.823
HBW2010	12	777	0	12	0	777	0	0	3.88	4	3.88	4	1.502	0.663
HBW2011	10	104	1	9	1	103	10	1	4	3.89	3.68	3.79	1.45	0.608
HBW2012	12	292	1	11	12	280	8	4	4.08	4.18	3.79	4	1.85	0.77
BT2005	9	186	1	8	52	134	11	28	3.17	3.35	2.83	2.83	1.812	0.811
BT2006	8	1134	1	7	1091	43	13	96	3.54	3.75	3.18	2.77	0.231	0.074
BT2007	11	318	1	10	89	229	9	28	3.47	3.46	3.17	2.93	1.835	0.808
BT2008	7	2636	2	5	2625	11	29	100	3.79	3.86	3.25	2.86	0.042	0.011
BT2009	10	2630	2	8	2545	85	20	97	3.44	3.51	2.99	2.53	0.185	0.064
BT2010	11	1066	1	10	978	88	9	92	3.71	3.7	3.4	2.74	0.403	0.156
BT2011	9	3181	2	7	3139	42	22	99	3.53	3.66	3.06	2.67	0.103	0.029
BT2012	10	1085	2	8	1004	81	20	93	3.44	3.63	2.99	2.67	0.368	0.145

Table A3.4 Coastal wetland macrophyte presence/year (1 = present; 0 = absent). Site codes on Table A1.1. WMI* = Wetland Macrophyte Index (Croft and Chow-Fraser 2007).

	Carex sp.	*Chara sp.*	*Eleocharis acicularis*	*Eleocharis smallii*	*Eleocharis sp.*	*Elodea canadensis*	*Juncus sp.*	*Myriophyllum spicatum*	*Myriophyllum sibiricum*	*Myrophyllum sp.*	*Najas flexilis*	*Nuphar variegata*	*Phragmites australis*	*Polygonum sp.*	*Potamogeton amplifolius*	*Potamogeton crispus*	*Potamogeton filiformis*	*Potamogeton foliosus*	*Potamogeton natans*	*Potamogeton richardsonii*	*Potamogeton robbinsii*	*Potamogeton zosteriformis*	*Potamogeton sp.*	*Ranunculus species*	*Scirpus acutus*	*Scirpus validus*	*Scirpus sp.*	*Sagittaria species*	*Sparganium sp.*	*Typha sp.*	*Utricularia sp.*	*Vallisneria americana*	WMI*	WMI adj*	% Exotic
CN2005	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	0	1	1	1	1	1	0	0	3.1	2.76	11
CN2006	1	1	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	0	0	1	0	0	2.58	2.25	11
CN2007	1	1	0	1	1	1	1	1	1	1	1	0	0	1	1	0	0	0	0	1	1	0	1	0	0	1	1	1	0	1	0	0	2.93	2.63	9
CN2008	1	1	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	1	1	0	0	1	0	0	2.5	2.17	11
CN2009	1	1	0	1	1	1	1	1	1	1	1	0	0	0	0	1	0	1	0	1	1	0	1	1	0	1	1	0	0	1	0	0	2.61	2.18	18
CN2010	1	1	0	1	1	1	1	1	1	1	1	0	0	1	0	1	0	1	0	1	1	0	1	1	0	1	1	0	0	1	0	0	2.58	2.17	17
CN2011	1	1	0	1	1	1	1	1	1	1	1	0	1	0	0	0	0	1	0	1	1	0	1	0	0	1	1	0	0	1	0	0	2.74	2.42	10
CN2012	1	1	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	1	0	1	1	0	1	0	0	1	1	0	0	1	0	0	2.74	2.42	10
BP2005	1	0	1	1	1	1	1	1	0	1	1	0	0	0	0	0	1	1	0	1	0	0	1	1	0	1	1	1	0	1	0	1	3.04	2.74	9
BP2006	1	1	1	1	1	1	1	1	0	1	1	0	0	0	0	0	1	1	0	1	0	0	1	1	0	1	1	0	0	1	0	1	2.73	2.41	10
BP2007	1	1	1	1	1	1	1	1	1	1	1	0	0	1	0	1	1	1	0	1	0	1	1	1	0	1	1	1	0	1	0	1	2.86	2.49	13
BP2008	1	1	1	1	1	1	1	1	0	1	1	0	0	0	0	0	1	1	0	1	0	0	1	1	0	1	1	1	0	1	0	1	2.89	2.59	9
BP2009	1	1	1	1	1	1	1	1	0	1	1	0	0	0	0	0	1	1	0	1	0	0	1	1	0	1	1	0	0	1	0	1	2.75	2.43	10
BP2010	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	1	1	0	1	0	1	1	1	0	1	1	0	0	1	0	1	2.78	2.49	8
BP2011	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	1	1	0	1	0	1	1	1	0	1	1	0	0	1	0	1	2.78	2.49	8
BP2012	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	1	1	0	1	0	1	1	1	0	1	1	0	0	1	0	1	2.78	2.49	8
RUW2005	1	0	0	1	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	1	0	0	2.78	2.2	33
RUW2006	1	0	0	1	1	1	1	1	1	1	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	1	1	0	1	1	0	0	2.33	1.93	17
RUW2007	1	0	0	1	1	1	1	1	1	1	0	0	0	1	0	0	0	1	1	0	0	0	1	0	0	1	1	0	1	1	0	0	2.38	2	14
RUW2008	1	0	0	1	1	0	1	1	1	1	0	0	0	1	0	0	0	1	1	0	0	0	1	0	0	1	1	0	0	1	0	0	2.44	2.07	14
RUW2009	1	0	0	1	1	0	1	1	1	1	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	1	1	0	0	1	0	0	2.38	1.97	17
RUW2010	1	0	0	1	1	0	1	1	1	1	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	1	1	0	0	1	0	0	2.38	1.97	17
RUW2011	1	0	0	1	1	0	1	1	1	1	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	1	1	0	0	1	0	0	2.38	1.97	17
RUW2012	1	0	0	1	1	0	1	1	1	1	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	1	1	0	0	1	0	0	2.38	1.97	17
RUE2005	1	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	4	4	0
RUE2006	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	3.67	3.67	0
RUE2007	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	3.67	3.67	0
RUE2008	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	3.67	3.67	0
RUE2009	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	3.67	3.67	0
RUE2010	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	3.67	3.67	0
RUE2011	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	3.67	3.67	0
RUE2012	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	3.67	3.67	0

Table A3.4 Cont'd

	Carex sp.	*Chara sp.*	*Eleocharis acicularis*	*Eleocharis smallii*	*Eleocharis sp.*	*Elodea canadensis*	*Juncus sp.*	*Myriophyllum spicatum*	*Myriophyllum sibiricum*	*Myrophyllum sp.*	*Najas flexilis*	*Nuphar variegata*	*Phragmites australis*	*Polygonum sp.*	*Potamogeton amplifolius*	*Potamogeton crispus*	*Potamogeton filiformis*	*Potamogeton foliosus*	*Potamogeton natans*	*Potamogeton richardsonii*	*Potamogeton robbinsii*	*Potamogeton zosteriformis*	*Potamogeton sp.*	*Ranunculus species*	*Scirpus acutus*	*Scirpus validus*	*Scirpus sp.*	*Sagittaria species*	*Sparganium sp.*	*Typha sp.*	*Utricularia sp.*	*Vallisneria americana*	WMI*	WMI adj*	% Exotic
HBE2005	1	1	1	1	1	1	1	1	0	1	1	1	0	0	0	0	0	0	0	1	0	0	1	0	1	1	1	1	1	0	1	1	3.03	2.76	7
HBE2006	1	1	1	1	1	1	1	1	0	1	1	1	0	1	0	0	0	0	0	1	0	0	1	0	1	1	1	1	0	1	0	1	2.93	2.62	10
HBE2007	1	1	0	1	1	1	1	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0	1	0	1	1	1	0	0	1	0	1	2.68	2.36	10
HBE2008	1	1	0	1	1	1	1	1	0	1	0	1	0	0	0	0	0	0	0	1	0	0	1	1	1	1	1	0	0	1	0	1	2.67	2.33	11
HBE2009	1	1	0	1	1	1	1	1	0	1	0	1	0	0	0	0	0	0	0	1	0	0	1	1	1	1	1	0	1	1	1	1	2.63	2.33	9
HBE2010	1	1	0	1	1	1	1	1	0	1	0	1	0	0	0	0	0	0	0	1	0	0	1	1	1	1	1	0	0	1	1	1	2.65	2.35	9
HBE2011	1	1	0	1	1	1	1	1	0	1	0	1	0	0	0	0	0	0	0	1	0	0	1	1	1	1	1	0	0	1	1	1	2.63	2.31	10
HBE2012	1	1	0	1	1	1	1	1	0	1	0	1	0	0	0	0	0	0	0	1	0	0	1	1	1	1	1	0	0	1	1	1	2.63	2.31	10
HBS2005	1	1	0	1	1	1	1	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	1	1	1	1	1	0	1	3.13	2.83	9
HBS2006	1	1	0	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	1	1	0	1	2.91	2.56	13
HBS2007	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	0	0	1	1	1	0	0	1	1	1	1	1	0	1	1	0	1	2.68	2.41	7
HBS2008	1	1	0	1	1	1	1	1	0	1	1	1	0	1	1	0	0	0	1	0	0	0	1	0	1	1	1	1	1	1	0	1	2.82	2.55	8
HBS2009	1	1	0	1	1	1	1	1	1	1	0	1	0	1	1	0	0	0	1	0	0	0	1	0	1	1	1	0	1	1	1	1	2.84	2.56	8
HBS2010	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	0	0	0	1	0	0	0	1	0	1	1	1	0	1	1	1	1	2.65	2.36	8
HBS2011	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	0	0	1	1	1	0	0	1	0	1	1	1	0	1	1	1	1	2.68	2.41	7
HBS2012	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	0	0	1	1	1	0	0	1	0	1	1	1	0	1	1	1	1	2.68	2.41	7
HBW2006	1	1	0	1	1	1	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0	1	1	1	0	1	0	0	1	0	0	2.65	2.3	13
HBW2007	1	1	0	1	1	1	1	1	1	1	1	1	0	1	0	0	0	1	0	1	0	0	1	1	1	0	1	1	0	1	0	1	2.89	2.59	9
HBW2008	1	1	0	1	1	1	1	1	1	1	0	0	1	1	0	0	1	0	0	0	0	0	1	1	1	0	1	1	0	1	0	1	2.89	2.59	9
HBW2009	1	1	0	1	1	1	1	1	1	1	1	0	1	0	0	0	0	1	0	1	0	0	1	1	1	0	1	0	0	1	0	1	2.82	2.5	10
HBW2010	1	1	0	1	1	1	1	1	1	1	1	0	1	0	0	0	0	1	0	1	0	0	1	1	1	0	1	0	0	1	0	1	2.82	2.5	10
HBW2011	1	1	0	1	1	1	1	1	1	1	1	0	1	0	0	0	0	1	1	0	0	0	1	0	1	0	1	0	0	1	0	1	2.84	2.49	13
HBW2012	1	1	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	1	1	0	0	0	1	0	1	0	1	0	0	1	0	1	2.84	2.49	13
BT2005	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1.8	1.8	0
BT2006	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1.8	1.8	0
BT2007	0	1	0	0	0	1	1	0	1	1	0	0	0	0	0	0	1	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	2.62	2.62	0
BT2008	1	1	0	0	0	1	1	1	1	1	0	0	0	0	0	0	1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	2.36	2.02	11
BT2009	1	1	0	0	1	1	1	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	1	1	0	0	0	0	0	2.5	2.5	0
BT2010	1	1	0	0	1	1	1	0	1	1	0	0	1	0	0	0	1	0	0	1	0	0	1	0	0	1	1	0	0	1	0	0	2.46	2.46	0
BT2011	1	1	0	0	1	1	1	1	0	1	0	0	0	0	0	0	1	0	0	1	1	1	1	0	0	1	1	0	0	1	0	0	2.53	2.18	13
BT2012	1	1	0	0	1	1	1	1	0	1	0	0	0	0	0	0	1	0	0	1	1	1	1	0	0	1	1	0	0	1	0	0	2.53	2.18	13

Table A3.5 Coastal wetland water quality and other characteristics. Site codes on Table A1.1. WQI = Water Quality Index 6 (turbidity, conductivity, temperature, pH, total phosphorus, and total nitrogen) and 7 (WQI_6 and Chlorophyll a)(Chow-Fraser 2006)). Stranding part of wetland from Lake Huron, complete (no water flow) or incomplete (water flow <5cm), 1 = yes and 0 = no. Relative shoreline development: 2= heavy human development, 1= light development, 0= no development. Location UTM NAD 83, Zone 17T.

SITE_name	Temperature (C)	Total Nitrogen (mg/l)	Total Phosphorus (mg/l)	Conductivity	Chlorophyll a	pH	Turbidity (NTU)	WQI_6*	WQI_7*	Complete Stranding	Incomplete Stranding	Shoreline Development**	Lake Level (m ASL)	UTM Easting	UTM Northing
CN2005	20.12	0.01	0.00312	138	0.23	8.4	0.69	3.6	3.87	1	0	0	176.2	440279	5018058
CN2006	22.06	1.03	0.01	206	0.23	8.63	1	2.23	2.56	1	0	0	176.1	440279	5018058
CN2007	19.01	0.5	0.0044	213	0.3	8.32	1.88	2.41	2.65	1	0	0	176.1	440279	5018058
CN2008	19.8	0.44	0.0176	207	0.2	8.73	1.92	1.94	2.38	1	0	0	176.2	440279	5018058
CN2009	15.8	0.4	0.0122	202	0.7	8.46	0.65	2.79	2.92	0	1	0	176.4	440279	5018058
CN2010	20.42	0.447	0.004	198	0.5	8.38	0.53	3	3.1	1	0	0	176.2	440279	5018058
CN2011	21.3	0.446	0.0048	208	2.9	8.46	1.2	2.51	2.42	0	1	0	176.2	440279	5018058
CN2012	23	0.464	0.0075	207	0.4	8.72	1.25	2.25	2.51	1	0	0	176	440279	5018058
BP2005	17.75	0.4	0.00555	140	1.07	8.46	1.63	2.63	2.68	0	0	0	176.2	444021	5015521
BP2006	22.18	0.41	0.03	207	1.8	8.68	1	1.65	1.74	0	0	0	176.1	444021	5015521
BP2007	18.61	0.48	0.0105	215	1.9	8.26	5.31	1.73	1.84	0	0	0	176.1	444021	5015521
BP2008	21.3	0.39	0.0061	211	0.5	8.86	4	1.8	2.06	0	0	0	176.2	444021	5015521
BP2009	17.7	0.42	0.0246	212	3.1	8.36	5.9	1.5	1.61	0	0	0	176.4	444021	5015521
BP2010	21.72	0.373	0.0078	206	0.1	8.2	1.65	2.31	2.78	0	0	0	176.2	444021	5015521
BP2011	21	0.309	0.0083	208	1.6	8.5	1.34	2.36	2.42	0	0	0	176.2	444021	5015521
BP2012	24	1.18	0.0075	205	0.5	8.92	1.8	1.88	2.11	0	0	0	176	444021	5015521
RUW2005	12.07	0.01	0.0189	134	0.12	7.77	1.76	3.24	3.74	0	1	0	176.2	444829	5012509
RUW2006	20.83	0.72	0.015	221	1.2	8.62	2.2	2.18	2.35	0	1	0	176.1	444829	5012509
RUW2007	19.23	0.61	0.0066	227.5	1.25	8.7	1.94	2.6	2.64	0	1	0	176.1	444829	5012509
RUW2008	21.55	0.48	0.03185	225.5	0.6	8.95	3.22	1.72	2.06	0	1	0	176.2	444829	5012509
RUW2009	16.63	0.41	0.0177	241.5	2.35	8.48	1.24	2.7	2.74	0	1	0	176.4	444829	5012509
RUW2010	20.87	0.471	0.0086	234.5	0.6	8.6	0.66	2.63	2.86	0	1	0	176.2	444829	5012509
RUW2011	20.35	0.433	0.00835	221.5	0.7	8.33	1.07	2.51	2.66	0	1	0	176.2	444829	5012509
RUW2012	20.48	0.844	0.01815	237	0.85	8.86	2.07	1.8	2.02	1	0	0	176	444829	5012509
RUE2005	18.8	0.01	0.00979	141	0.48	8.47	1.33	3.02	3.31	1	0	0	176.2	445837	5012674
RUE2006	20.27	0.61	0.01	207	0.386	8.53	1	2.38	1.82	1	0	0	176.1	445837	5012674
RUE2007	18.56	0.46	0.0032	212	0.5	8.25	0.86	2.91	3	1	0	0	176.1	445837	5012674
RUE2008	19.31	0.46	0.0178	207	0.1	8.54	0.45	2.67	3.13	1	0	0	176.2	445837	5012674
RUE2009	13.81	0.403	0.0115	197	0.3	8.44	0.58	2.97	3.19	0	1	0	176.4	445837	5012674
RUE2010	18.4	0.414	0.003	204	0.8	8.6	0.5	3.11	3.1	1	0	0	176.2	445837	5012674
RUE2011	19.44	0.454	0.0038	213	0.6	8.34	1.06	2.71	2.81	1	0	0	176.2	445837	5012674
RUE2012	19.26	0.45	0.0054	208	0.3	8.75	2.13	2.21	2.48	1	0	0	176	445837	5012674

Table A3.5 Cont'd

SITE_name	Temperature (C)	Total Nitrogen (mg/l)	Total Phosphorus (mg/l)	Conductivity	Chlorophyll a	pH	Turbidity (NTU)	WQI_6*	WQI_7*	Complete Stranding	Incomplete Stranding	Shoreline Development**	Lake Level (m ASL)	UTM Easting	UTM Northing
HBE2005	22.8	0.01	0.01222	181	2.32	8.72	2.71	2.65	2.79	0	0	2	176.2	446399	5009966
HBE2006	25.11	0.47	0.02	217	3.584	8.71	4	1.37	0.99	0	0	2	176.1	446399	5009966
HBE2007	23.64	0.41	0.0065	215	2.2	9.01	1.13	2.25	2.25	0	0	2	176.1	446399	5009966
HBE2008	22.3	0.34	0.0306	269	1.1	9.01	0.83	1.97	2.19	0	0	2	176.2	446399	5009966
HBE2009	20.1	0.48	0.0549	233	7	8.02	1.8	1.78	1.8	0	0	2	176.4	446399	5009966
HBE2010	23	0.67	0.0196	253	5.3	8.62	1.6	1.78	1.76	0	0	2	176.2	446399	5009966
HBE2011	21.8	0.459	0.0141	264	3.9	8.56	1	2.17	2.14	0	0	2	176.2	446399	5009966
HBE2012	24.47	0.491	0.0162	230	2.6	8.71	2.1	1.71	1.81	0	0	2	176	446399	5009966
HBS2005	22.95	0.2	0.01769	145	1.16	8.54	2.04	2.1	2.31	0	1	1	176.2	445486	5009124
HBS2006	26.06	0.54	0.03	220	2.18	9.01	2.3	1.46	1.08	0	1	1	176.1	445486	5009124
HBS2007	20.98	0.66	0.00915	236	1.5	8.92	1.06	2.25	2.32	1	0	1	176.1	445486	5009124
HBS2008	21.84	0.6	0.0111	300	0.8	8.73	0.95	2.15	2.32	0	1	1	176.2	445486	5009124
HBS2009	20.25	0.6	0.016	281	2.75	7.99	1.09	2.24	2.26	0	1	1	176.4	445486	5009124
HBS2010	23.15	0.522	0.0202	333.5	7.15	8.43	1.325	1.86	1.81	0	1	1	176.2	445486	5009124
HBS2011	21.4	0.571	0.0109	299.5	2	8.16	1	2.28	2.32	0	1	1	176.2	445486	5009124
HBS2012	23.1	0.673	0.0172	226	0.6	8.7	1.59	1.85	2.21	1	0	1	176	445486	5009124
HBW2006	25.21	0.56	0.03	195	1.2	8.8	4	1.23	1.56	0	0	1	176.1	444875	5009082
HBW2007	21.07	0.34	0.0079	208	1.1	8.87	1.06	2.38	2.48	0	0	1	176.1	444875	5009082
HBW2008	21.5	0.4	0.0101	209	0.6	9.13	1.18	2.17	2.39	0	0	1	176.2	444875	5009082
HBW2009	21.6	0.5	0.0319	213	12.9	8.45	1.39	1.91	1.79	0	0	1	176.4	444875	5009082
HBW2010	22.8	0.378	0.008	210	2.1	8.61	1.03	2.38	2.39	0	0	1	176.2	444875	5009082
HBW2011	22.3	0.408	0.0108	219	2.5	8.7	1	2.28	2.29	0	0	1	176.2	444875	5009082
HBW2012	23.4	0.558	0.0146	206	1.5	9	2.09	1.74	1.89	0	0	1	176	444875	5009082
BT2005	16.06	0.64	0.00504	204.8	0.18	8.48	0.64	2.93	3.17	0	0	2	176.2	446531	5011494
BT2006	17.64	1.31	0.01	205	0.3	8.73	1	2.34	2.59	0	0	2	176.1	446531	5011494
BT2007	16.24	0.47	0.0032	213	0.3	8.26	0.14	3.85	3.89	0	0	2	176.1	446531	5011494
BT2008	17.6	0.48	0.0035	207	0.1	8.51	0.8	2.9	3.22	0	0	2	176.2	446531	5011494
BT2009	13.3	0.42	0.0057	197	0.1	8.3	0.84	3.04	3.37	0	0	2	176.4	446531	5011494
BT2010	15.5	0.5	0.0028	202	0.1	8.58	0.41	3.35	3.59	0	0	2	176.2	446531	5011494
BT2011	18.5	0.468	0.0058	212	0.88	8.29	0.88	2.73	2.83	0	0	2	176.2	446531	5011494
BT2012	21	0.415	0.0112	206	0.3	8.59	0.35	2.84	3.1	0	0	2	176	446531	5011494

Table A3.6 Scientific name of fishes.

Code	Comnmon Name	Scientific Name
LT	lake trout	*Salvelinus namaycush*
RB	rock bass	*Ambloplites rupestris*
BRB	brown bullhead	*Ameiurus nebulosus*
BOW	bowfin	*Amia calva*
FD	freshwater drum	*Aplodinotus grunniens*
LNS	longnose sucker	*Catostomus catostomus*
WS	white sucker	*Catostomus commersoni*
MSC	mottled sculpin	*Cottus bairdi*
SSH	spotfin shiner	*Cyprinella spilopterus*
LC	lake chub	*Couesius plumbeus*
BRS	brook stickleback	*Culaea inconstans*
CC	common carp	*Cyprinus carpio*
NP	northern pike	*Esox lucius*
RD	rainbow darter	*Etheostoma caeruleum*
ID	iowa darter	*Etheostoma exile*
JD	johnny darter	*Etheostoma nigrum*
BK	banded killifish	*Fundulus diaphanus*
TSP	threespine stickleback	*Gasterosteus aculeatus*
LNG	longnose gar	*Lepisoteus osseus*
PSD	pumpkinseed	*Lepomis gibbonus*
BG	bluegill	*Lepomis macrochirus*
CSH	common shiner	*Luxilus cornutus*
SMB	smallmouth bass	*Micropterus dolomieu*
LMB	largemouth bass	*Micropterus salmoides*
RG	round goby	*Neogobius melanostomus*
GSH	golden shiner	*Notemigonus crysoleucas*
ESH	emerald shiner	*Notropis atherinoides*
BLC	blackchin shiner	*Notropis heterondon*
BLN	blacknose shiner	*Notropis heterolepis*
STSH	spottail shiner	*Notropis hudsonius*
MSH	mimic shiner	*Notropis volucellus*
YP	yellow perch	*Perca flavescens*
NRD	northern redbelly dace	*Phoxinus eos*
FSD	finescale dace	*Phoxinus neogaeus*
BTN	bluntnose minnow	*Pimephales notatus*
FTH	fathead minnow	*Pimephales promelas*
NSP	ninespine stickleback	*Pungitius pungitius*
LND	longnose dace	*Rhinichthys cataractae*
CRC	creek chub	*Semotilus atromaculatus*
CMM	central mudminnow	*Umbra limi*

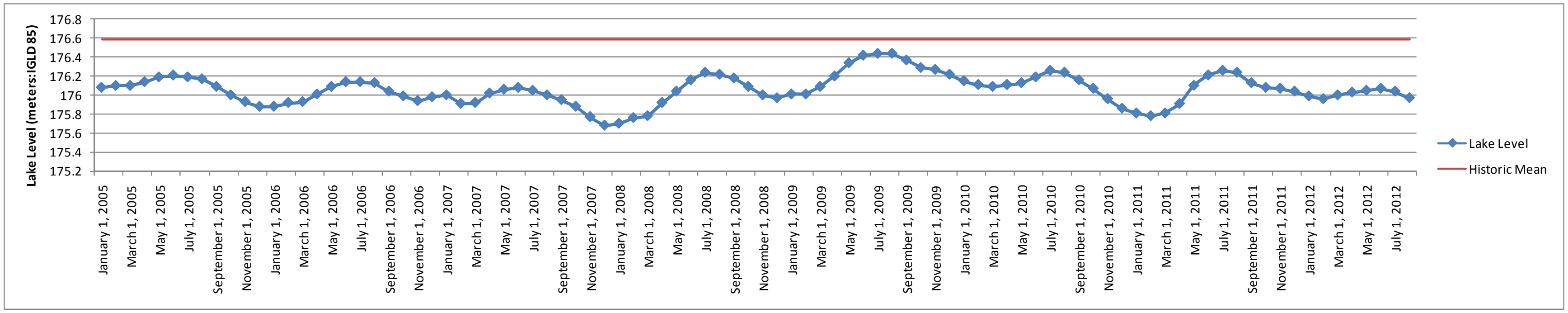


Figure A3.2 Lake level fluctuations for 2005-2012. Data source: www.glerl.noaa.gov.

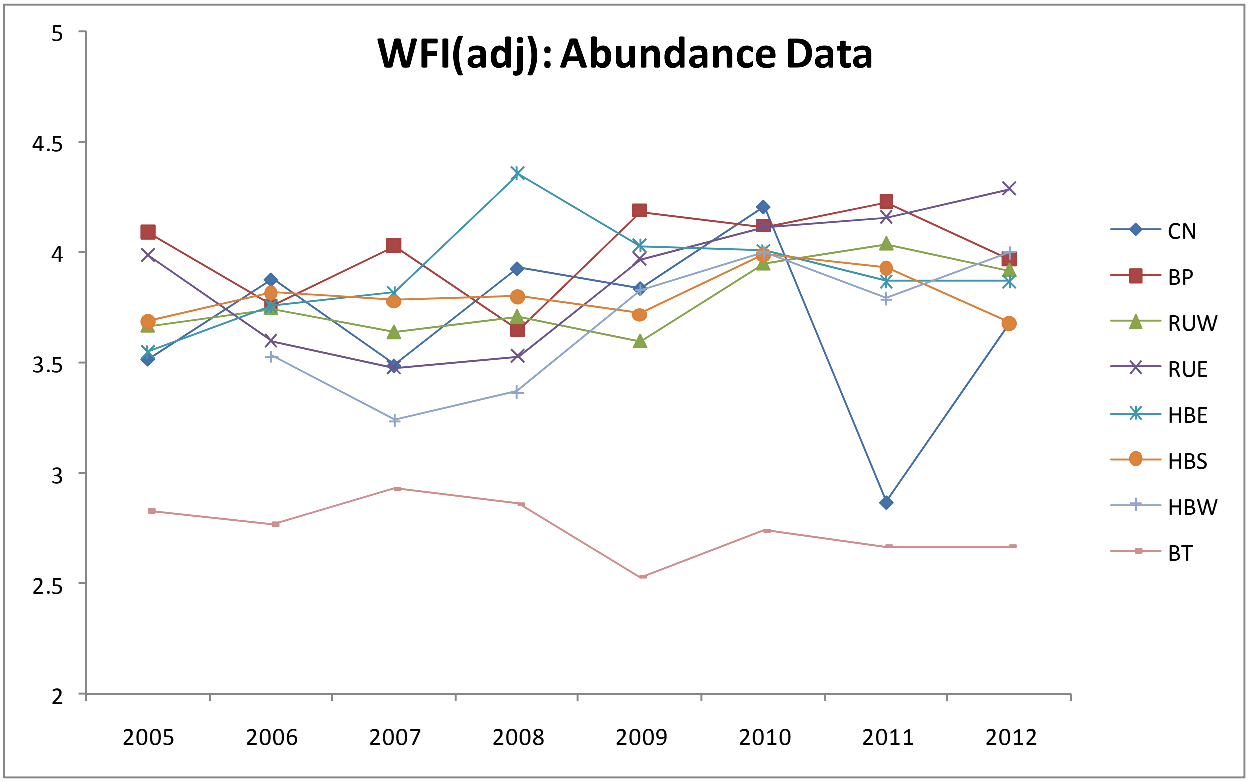


Figure A3.3 Wetland Fish Index (WFIadj) values for abundance data based on Seilheimer and Chow-Fraser (2007). Higher values indicative of higher wetland quality. Sites codes on Table A3.1.

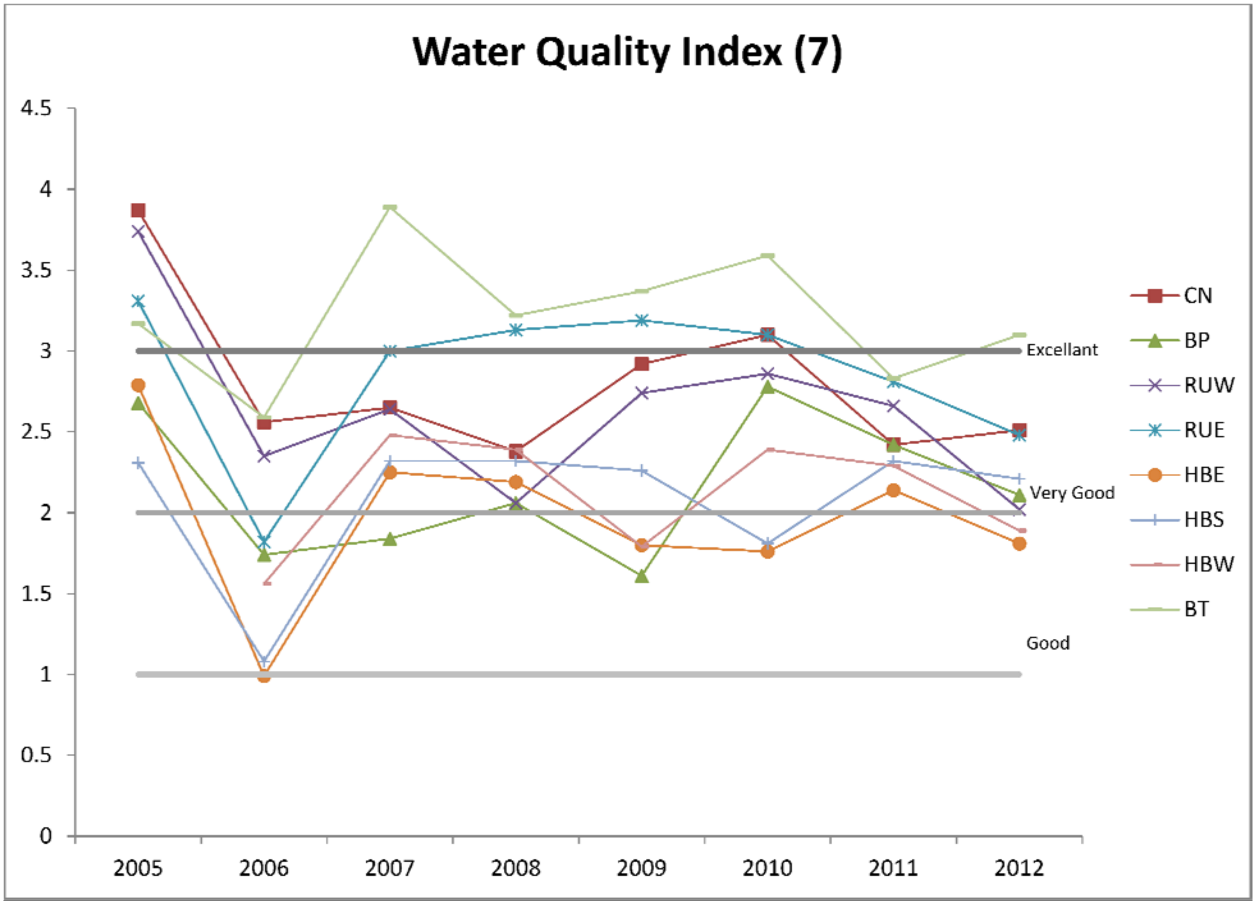


Figure A3.4 Water Quality Index (7 parameter) based on Chow-Fraser (2006). Parameters include: turbidity, conductivity, temperature, pH, total phosphorus, total nitrogen, and chlorophyll *a*. Sites codes on Table A3.1. The low values in 2006 are attributed to precision of contracted laboratory, since 2007 all samples have gone to the National Laboratory for Environmental Testing (Burlington, Ontario).

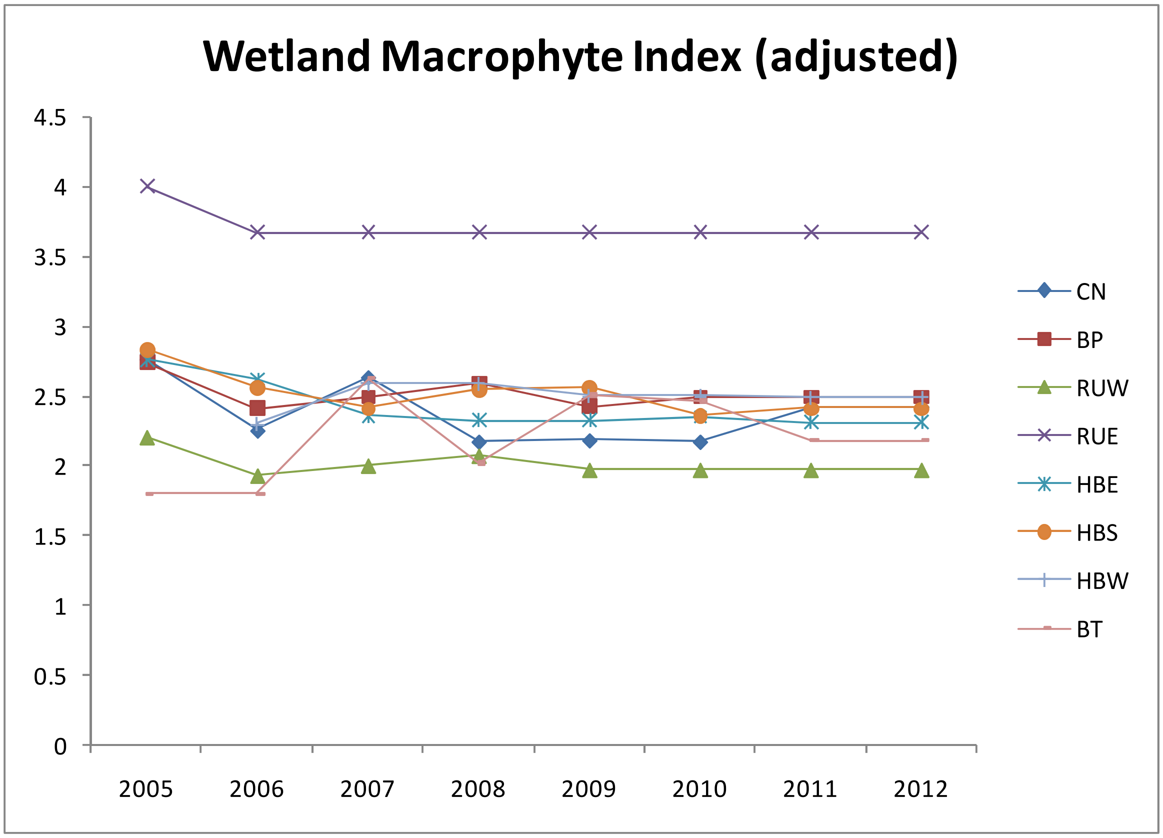


Figure A3.5 Wetland Macrophyte Index (adjusted) based on Croft and Chow-Fraser (2007). The prolonged period of low water levels since 2002 may account for the increasing stability and lack of variability.

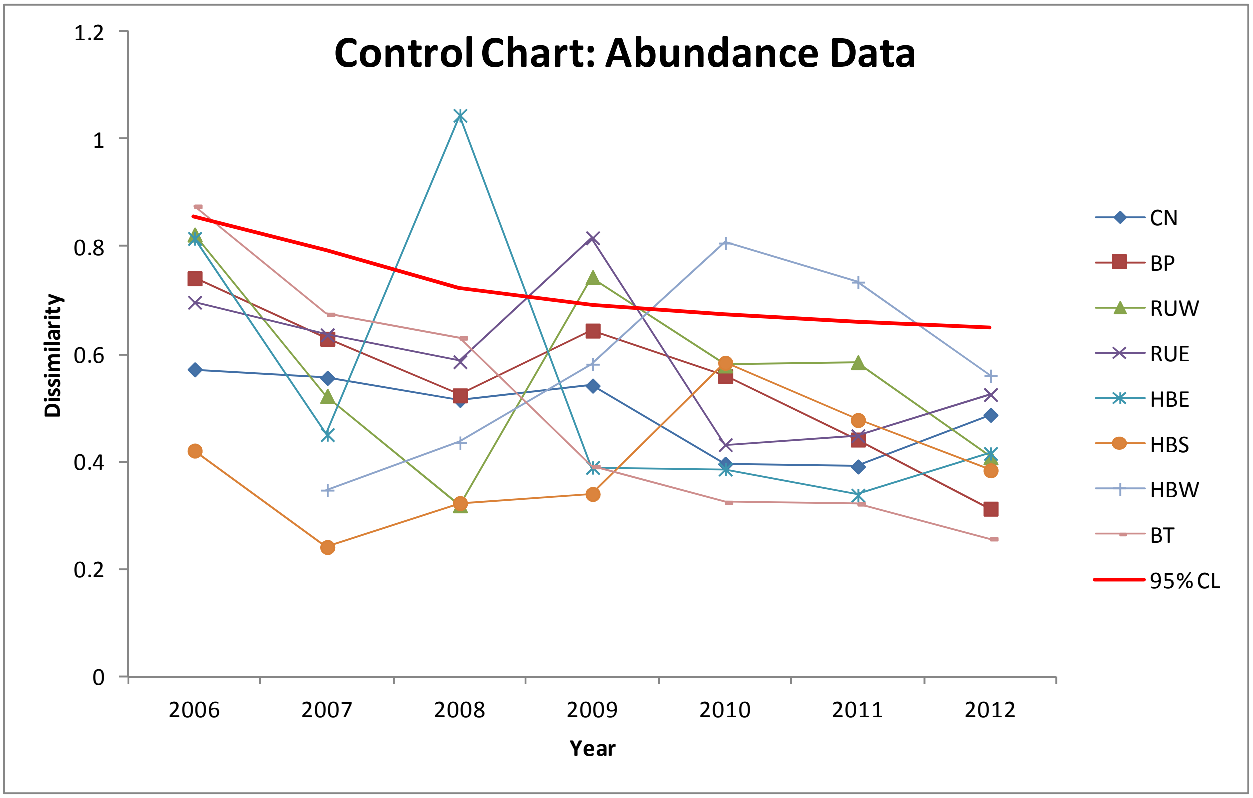


Figure A3.6 Control chart of fish abundance data at each wetland with 95% confidence limit of deviation. Sites codes on Table A3.1.

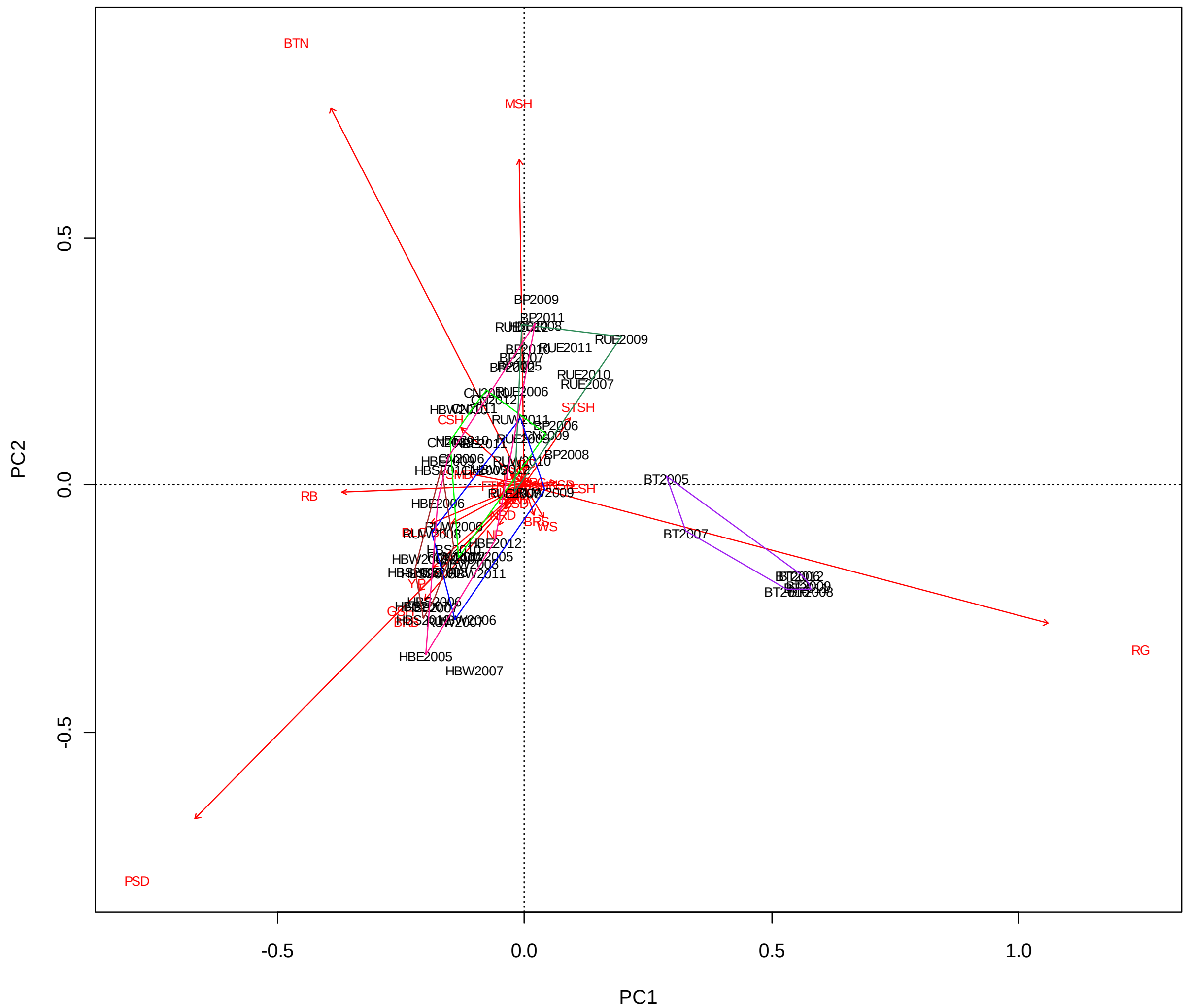


Figure A3.7 Principal Component Analysis (PCA) of fish abundance data in each wetland/year. Site codes on Table A3.1 and fish species codes on Table A3.6.

RUE 2006, pond stranded as rock sill barrier prevents hydrological connection to Lake Huron.

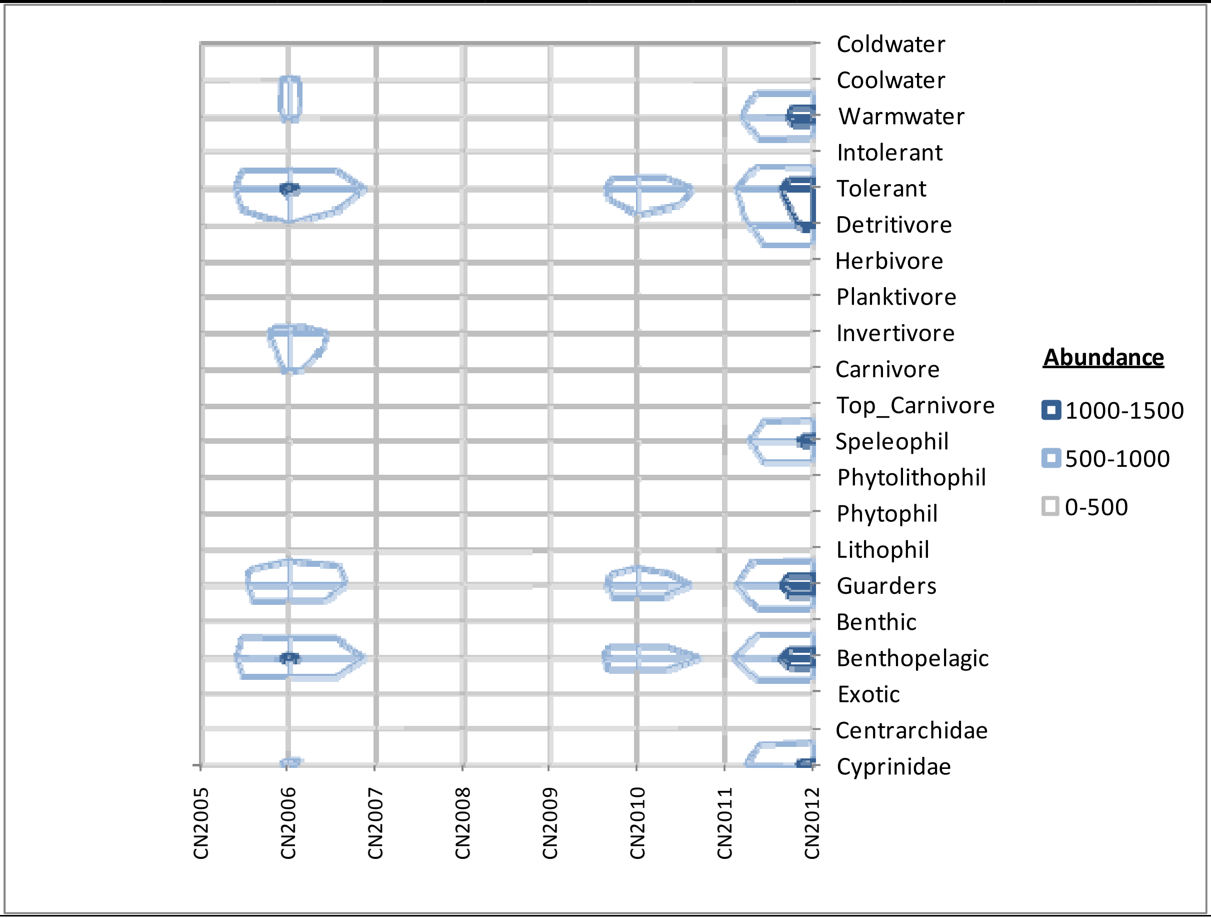
RUE 2007, pond evaporated.

Figure A3.8 Stranding effect at RUE due to low lake levels

Figure A3.9 Retrieving fyke nets from HBW. 2011 field crew: Alexandra Eaves, Cavan Harpur and Scott Parker (left to right on lower image).

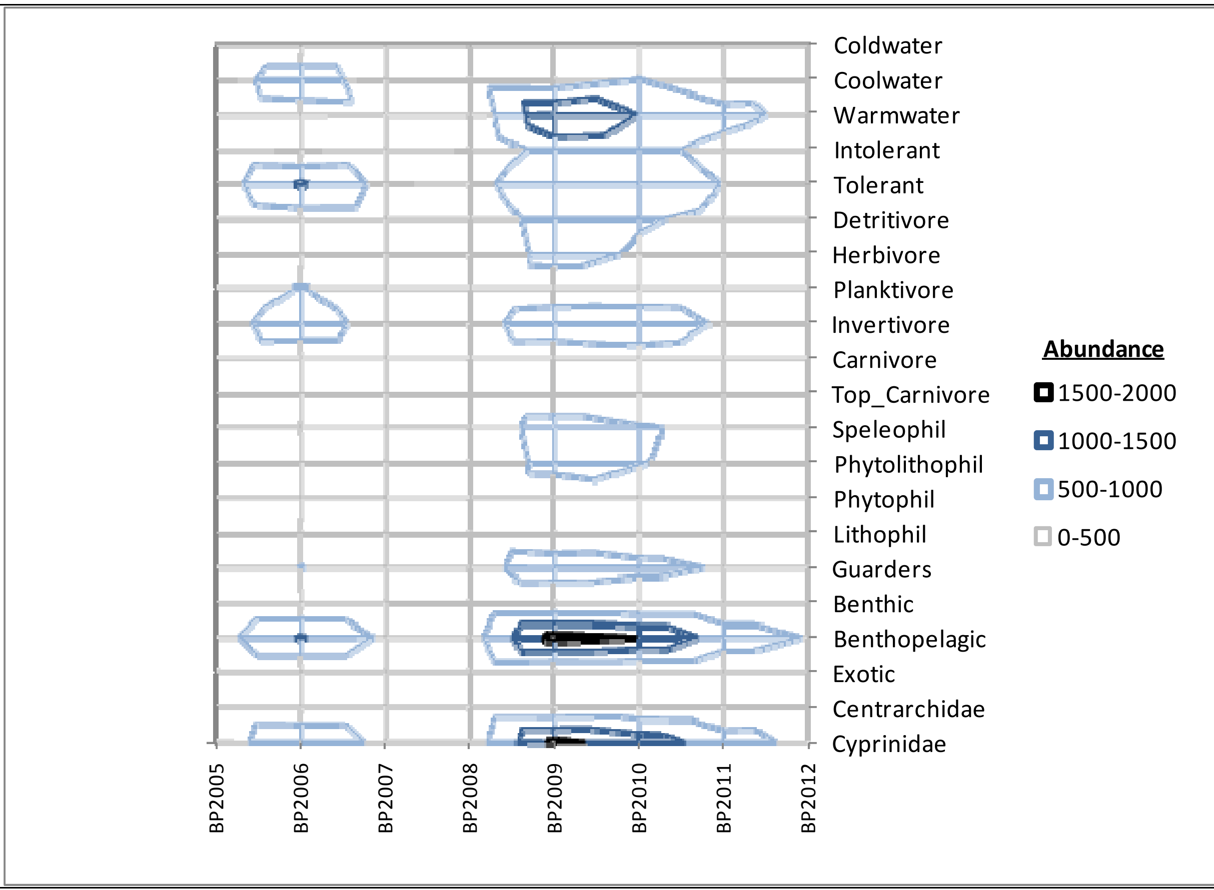
Table A3.7 Fish assemblage traits using abundance data from the coastal wetland survey.

	CN2005	CN2006	CN2007	CN2008	CN2009	CN2010	CN2011	CN2012	Summary		sd
Cyprinidae	34	542	89	279	54	493	301	1140	366.5	±	366.9
Centrarchidae	76	289	263	148	48	245	105	203	172.1	±	91.0
Exotic	0	0	3	0	9	3	3	7	3.1	±	3.4
Benthopelagic	128	1076	422	431	103	748	409	1345	582.8	±	442.0
Benthic	26	8	3	7	9	5	3	8	8.6	±	7.4
Guarders	136	832	334	429	111	709	375	1343	533.6	±	411.9
Lithophil	98	357	246	136	60	296	108	131	179.0	±	106.8
Phytophil	0	5	2	7	0	18	21	8	7.6	±	7.9
Phytolithophil	17	247	70	5	0	24	16	2	47.6	±	83.6
Speleophil	59	475	68	278	46	401	254	1133	339.3	±	358.8
Top_Carnivore	3	7	20	24	4	14	13	80	20.6	±	25.1
Carnivore	94	532	333	147	48	255	105	206	215.0	±	158.3
Invertivore	119	608	357	162	65	352	158	221	255.3	±	176.6
Planktivore	1	5	19	0	2	0	0	0	3.4	±	6.5
Herbivore	0	0	0	0	0	14	16	9	4.9	±	7.0
Detritivore	34	473	68	274	46	403	254	1132	335.5	±	361.5
Tolerant	153	1079	423	433	111	721	378	1345	580.4	±	438.1
Intolerant	1	5	2	5	1	32	34	8	11.0	±	13.8
Warmwater	39	539	215	359	51	435	314	1265	402.1	±	389.9
Coolwater	115	545	210	79	61	318	98	88	189.3	±	167.4
Coldwater	0	0	0	0	0	0	0	0	0.0	±	0.0



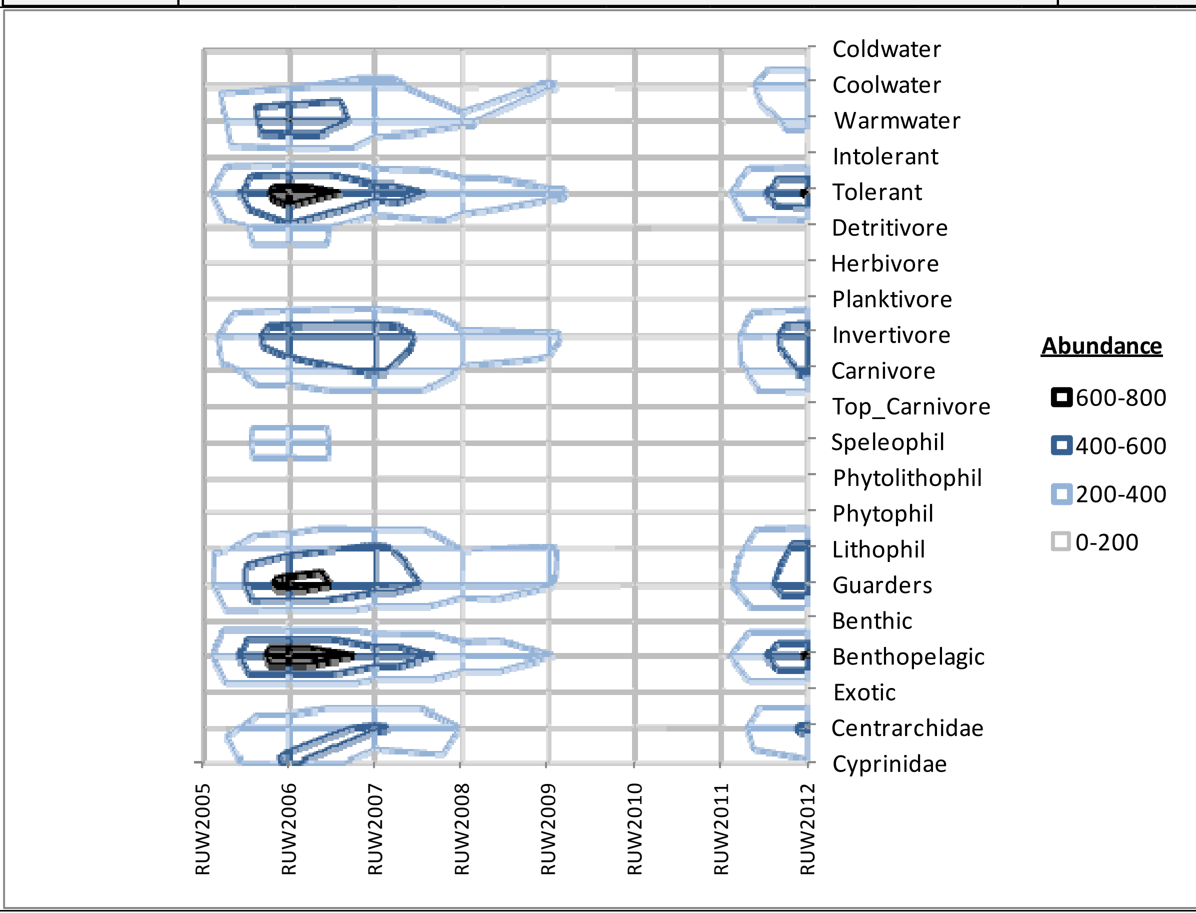
Cove Island North

	BP2005	BP2006	BP2007	BP2008	BP2009	BP2010	BP2011	BP2012	Summary		sd
Cyprinidae	196	976	341	199	1606	1306	744	352	715.0	±	537.1
Centrarchidae	89	54	62	45	38	91	44	97	65.0	±	23.8
Exotic	0	4	6	32	2	10	12	9	9.4	±	10.0
Benthopelagic	312	1045	410	280	1664	1496	793	484	810.5	±	541.2
Benthic	16	16	10	35	4	11	12	9	14.1	±	9.3
Guarders	180	511	322	262	825	661	458	385	450.5	±	213.1
Lithophil	113	299	120	169	60	112	74	131	134.8	±	74.3
Phytophil	10	1	9	10	40	261	27	6	45.5	±	88.0
Phytolithophil	90	11	71	25	718	524	296	93	228.5	±	262.6
Speleophil	78	220	199	92	767	548	383	251	317.3	±	237.7
Top_Carnivore	0	1	4	2	0	3	1	3	1.8	±	1.5
Carnivore	108	65	66	70	45	181	43	128	88.3	±	47.6
Invertivore	253	847	208	223	899	955	407	242	504.3	±	334.8
Planktivore	63	542	21	30	99	69	28	13	108.1	±	177.7
Herbivore	65	0	75	1	710	435	295	64	205.6	±	255.2
Detritivore	69	208	195	90	766	549	383	251	313.9	±	240.2
Tolerant	250	1058	343	311	931	821	487	429	578.8	±	311.4
Intolerant	78	3	77	4	737	686	318	64	245.9	±	304.1
Warmwater	134	211	271	94	1476	986	682	321	521.9	±	490.6
Coolwater	194	850	148	221	192	521	123	172	302.6	±	253.9
Coldwater	0	0	1	0	0	0	0	0	0.1	±	0.4



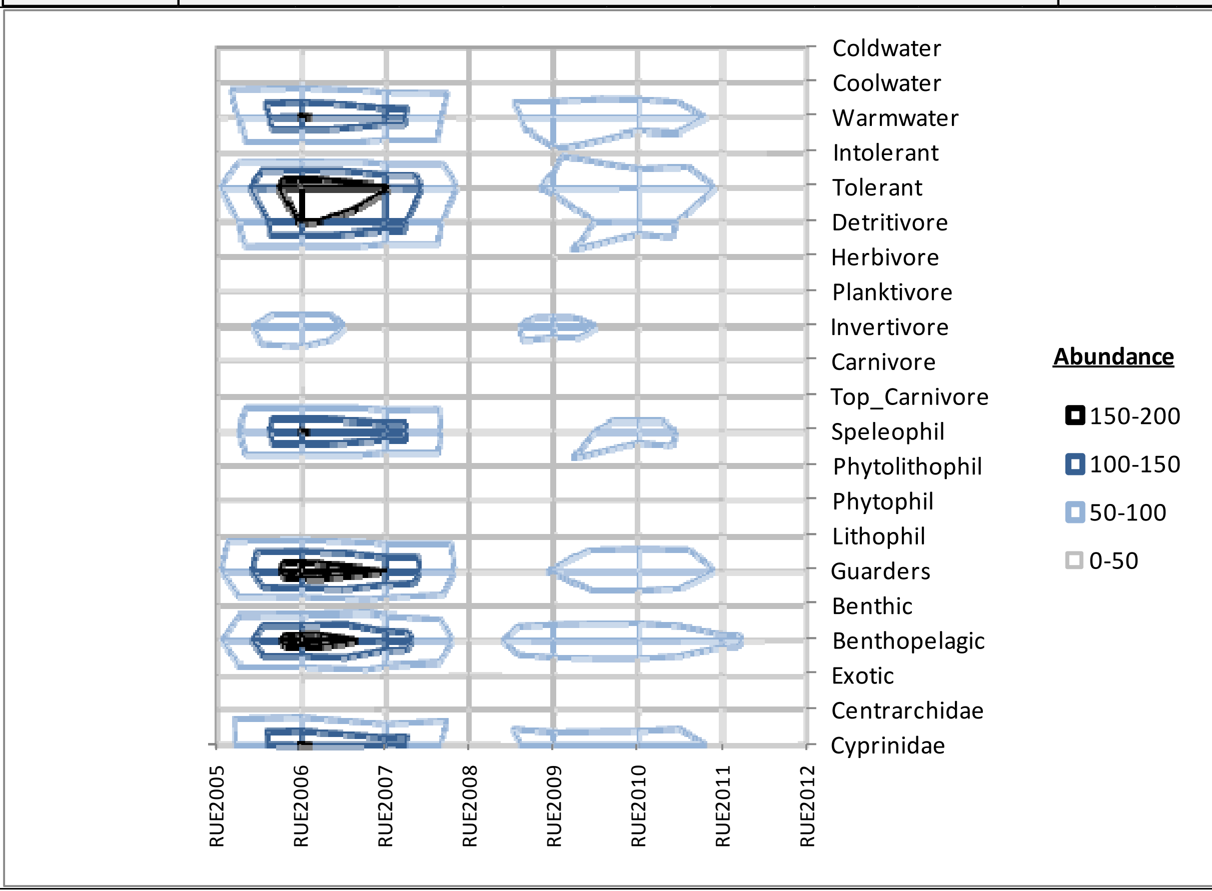
Boat Passage

	RUW2005	RUW2006	RUW2007	RUW2008	RUW2009	RUW2010	RUW2011	RUW2012	Summary		sd
Cyprinidae	16	438	60	129	23	18	54	175	114.1	±	142.7
Centrarchidae	111	321	430	193	183	38	99	442	227.1	±	153.5
Exotic	1	0	1	0	8	2	3	2	2.1	±	2.6
Benthopelagic	135	771	540	332	208	57	153	624	352.5	±	261.8
Benthic	24	11	10	7	34	3	3	6	12.3	±	11.1
Guarders	136	695	498	311	211	59	151	570	328.9	±	232.0
Lithophil	133	339	441	194	216	42	100	483	243.5	±	161.3
Phytophil	0	43	24	19	0	1	1	28	14.5	±	16.4
Phytolithophil	0	6	18	1	4	1	2	29	7.6	±	10.4
Speleophil	16	355	22	114	19	17	47	78	83.5	±	115.2
Top_Carnivore	2	0	1	7	3	0	6	8	3.4	±	3.2
Carnivore	111	321	430	194	184	38	99	444	227.6	±	153.8
Invertivore	135	531	532	240	224	42	109	550	295.4	±	210.2
Planktivore	8	54	82	13	3	1	2	59	27.8	±	32.1
Herbivore	0	2	0	0	3	0	3	0	1.0	±	1.4
Detritivore	37	354	29	121	43	17	47	80	91.0	±	111.3
Tolerant	151	729	502	324	238	58	154	623	347.4	±	244.3
Intolerant	8	53	48	15	4	2	2	7	17.4	±	20.9
Warmwater	52	603	302	232	25	18	56	268	194.5	±	201.6
Coolwater	105	179	248	106	215	42	98	362	169.4	±	103.5
Coldwater	2	0	0	1	2	0	2	0	0.9	±	1.0



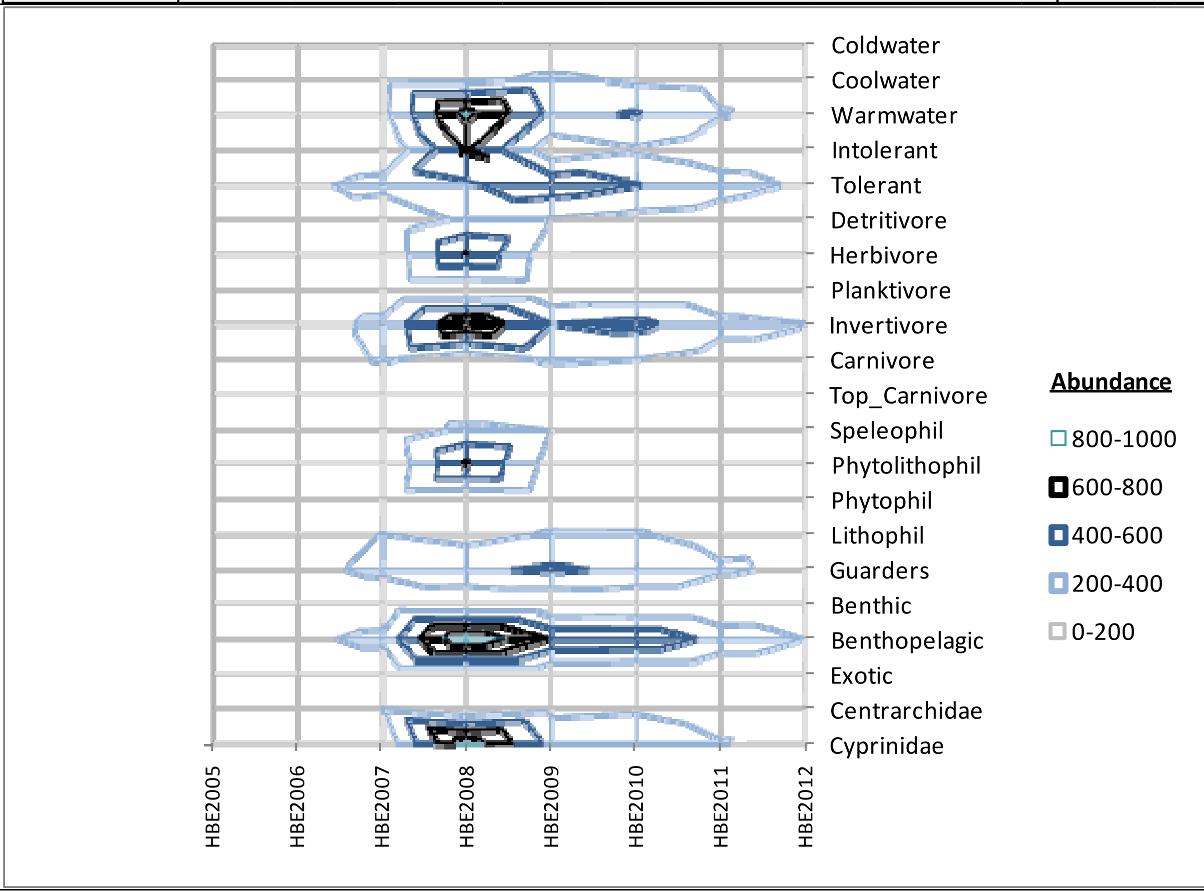
Russel Island West

	RUE2005	RUE2006	RUE2007	RUE2008	RUE2009	RUE2010	RUE2011	RUE2012	Summary		sd
Cyprinidae	20	153	129	7	78	80	43	13	65.4	±	54.5
Centrarchidae	22	29	4	20	6	9	18	3	13.9	±	9.6
Exotic	1	1	16	1	14	14	4	0	6.4	±	7.0
Benthopelagic	42	182	134	28	85	89	61	16	79.6	±	56.1
Benthic	2	6	19	3	14	15	4	1	8.0	±	6.9
Guarders	42	183	150	28	52	94	46	10	75.6	±	61.6
Lithophil	29	35	22	21	20	24	21	5	22.1	±	8.6
Phytophil	1	0	1	0	0	6	0	0	1.0	±	2.1
Phytolithophil	0	0	0	1	44	5	19	5	9.3	±	15.4
Speleophil	13	152	130	7	31	71	24	7	54.4	±	57.6
Top_Carnivore	1	1	0	2	1	0	1	0	0.8	±	0.7
Carnivore	22	29	4	21	6	9	18	3	14.0	±	9.7
Invertivore	31	76	24	24	67	33	41	10	38.3	±	22.5
Planktivore	0	0	2	0	4	0	0	1	0.9	±	1.5
Herbivore	1	0	0	0	44	4	19	5	9.1	±	15.5
Detritivore	14	156	129	9	31	71	24	8	55.3	±	57.9
Tolerant	44	187	153	31	54	94	46	12	77.6	±	62.2
Intolerant	0	1	0	0	45	10	19	5	10.0	±	15.6
Warmwater	15	153	128	10	76	75	44	12	64.1	±	54.4
Coolwater	29	35	24	21	22	29	21	4	23.1	±	9.2
Coldwater	0	0	1	0	1	0	0	1	0.4	±	0.5



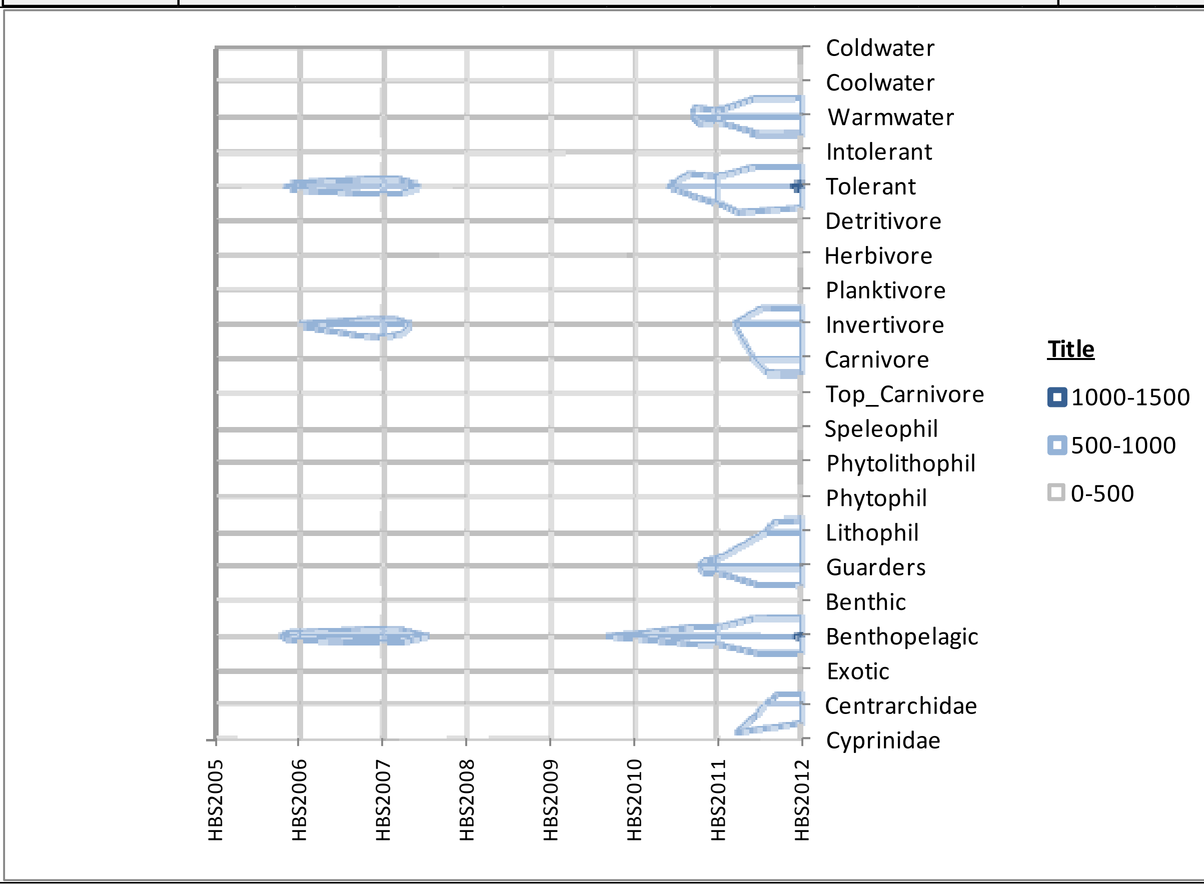
Russel Island East

	HBE2005	HBE2006	HBE2007	HBE2008	HBE2009	HBE2010	HBE2011	HBE2012	Summary		sd
Cyprinidae	30	82	53	910	334	358	214	82	257.9	±	292.5
Centrarchidae	74	58	196	74	160	182	92	112	118.5	±	53.6
Exotic	0	0	1	4	1	2	6	15	3.6	±	5.0
Benthopelagic	128	145	265	995	580	564	336	199	401.5	±	296.4
Benthic	20	7	23	11	7	19	17	20	15.5	±	6.3
Guarders	98	144	246	372	424	369	228	158	254.9	±	121.0
Lithophil	74	60	203	125	220	219	123	139	145.4	±	62.8
Phytophil	32	4	38	20	46	40	38	29	30.9	±	13.4
Phytolithophil	18	1	3	620	115	173	80	31	130.1	±	206.9
Speleophil	23	82	43	249	196	149	107	19	108.5	±	84.0
Top_Carnivore	22	11	26	2	15	18	9	5	13.5	±	8.3
Carnivore	113	69	221	81	230	203	115	119	143.9	±	64.2
Invertivore	142	74	260	760	395	451	256	204	317.8	±	217.0
Planktivore	5	5	9	5	26	19	24	2	11.9	±	9.6
Herbivore	40	7	24	609	62	199	88	38	133.4	±	201.2
Detritivore	5	75	28	248	190	134	98	16	99.3	±	87.1
Tolerant	144	152	266	377	516	409	279	170	289.1	±	135.4
Intolerant	4	0	22	629	71	174	74	49	127.9	±	209.9
Warmwater	97	137	153	859	347	414	214	105	290.8	±	256.9
Coolwater	51	15	135	147	240	169	139	114	126.3	±	69.3
Coldwater	0	0	0	0	0	0	0	0	0.0	±	0.0



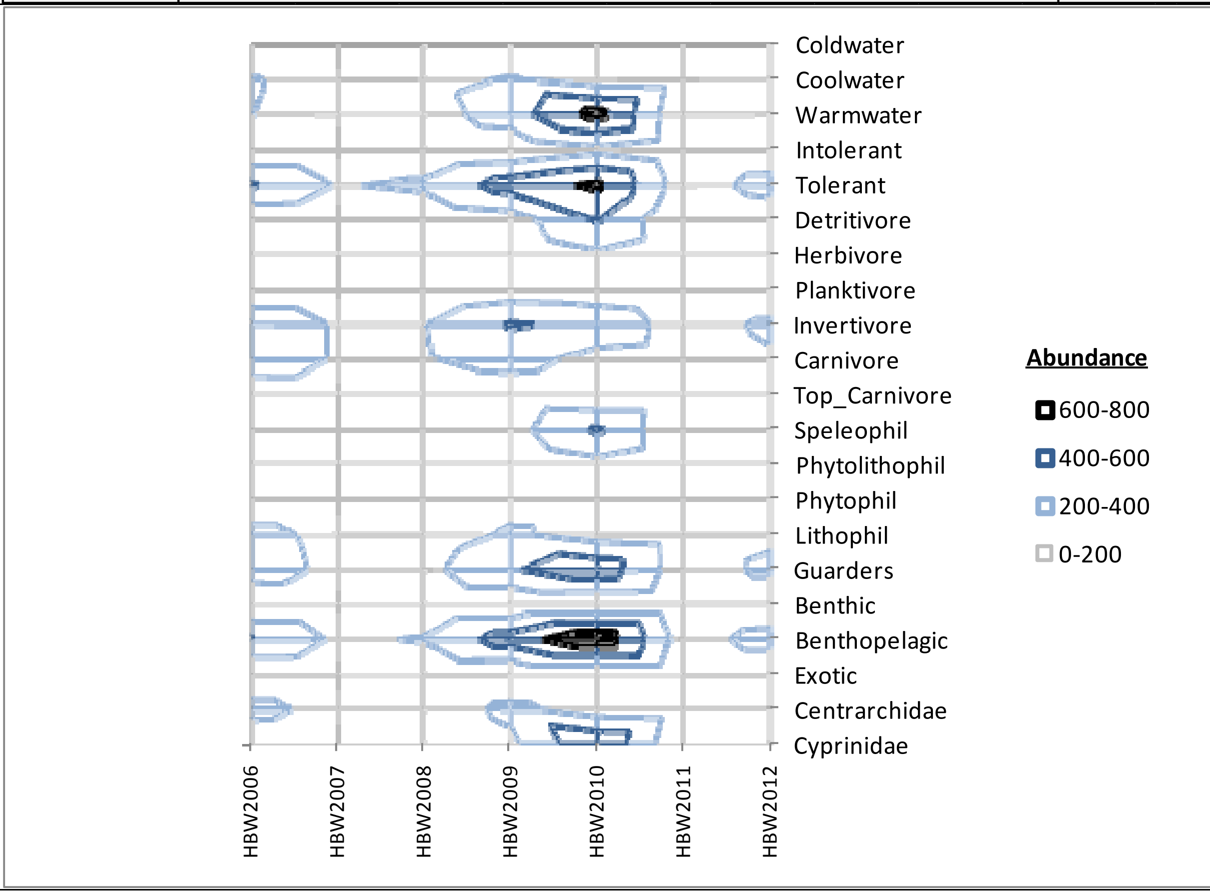
Hay Bay East

	HBS2005	HBS2006	HBS2007	HBS2008	HBS2009	HBS2010	HBS2011	HBS2012	Summary		sd
Cyprinidae	124	265	288	181	122	416	438	276	263.8	±	120.0
Centrarchidae	110	271	292	211	261	69	185	725	265.5	±	201.5
Exotic	0	3	0	5	0	0	1	3	1.5	±	1.9
Benthopelagic	266	564	618	402	429	534	671	1026	563.8	±	227.4
Benthic	41	32	33	20	24	59	61	74	43.0	±	19.5
Guarders	228	408	448	326	367	223	582	962	443.0	±	240.2
Lithophil	147	297	366	224	267	84	212	719	289.5	±	194.1
Phytophil	43	172	163	93	49	357	58	120	131.9	±	103.6
Phytolithophil	30	11	29	3	28	7	89	18	26.9	±	27.2
Speleophil	88	113	93	96	101	132	379	231	154.1	±	102.1
Top_Carnivore	36	29	26	22	20	47	46	83	38.6	±	20.6
Carnivore	176	310	346	230	303	117	268	813	320.4	±	212.8
Invertivore	252	501	580	338	364	488	396	941	482.5	±	212.3
Planktivore	0	19	5	5	16	38	10	7	12.5	±	12.0
Herbivore	72	124	137	58	43	179	122	138	109.1	±	46.7
Detritivore	59	88	84	83	92	89	330	160	123.1	±	88.5
Tolerant	304	540	604	377	446	386	663	1046	545.8	±	236.0
Intolerant	3	55	47	45	4	195	64	54	58.4	±	59.8
Warmwater	193	415	429	254	287	305	587	945	426.9	±	243.0
Coolwater	114	180	222	168	163	276	140	155	177.3	±	50.6
Coldwater	0	0	0	0	0	0	0	0	0.0	±	0.0



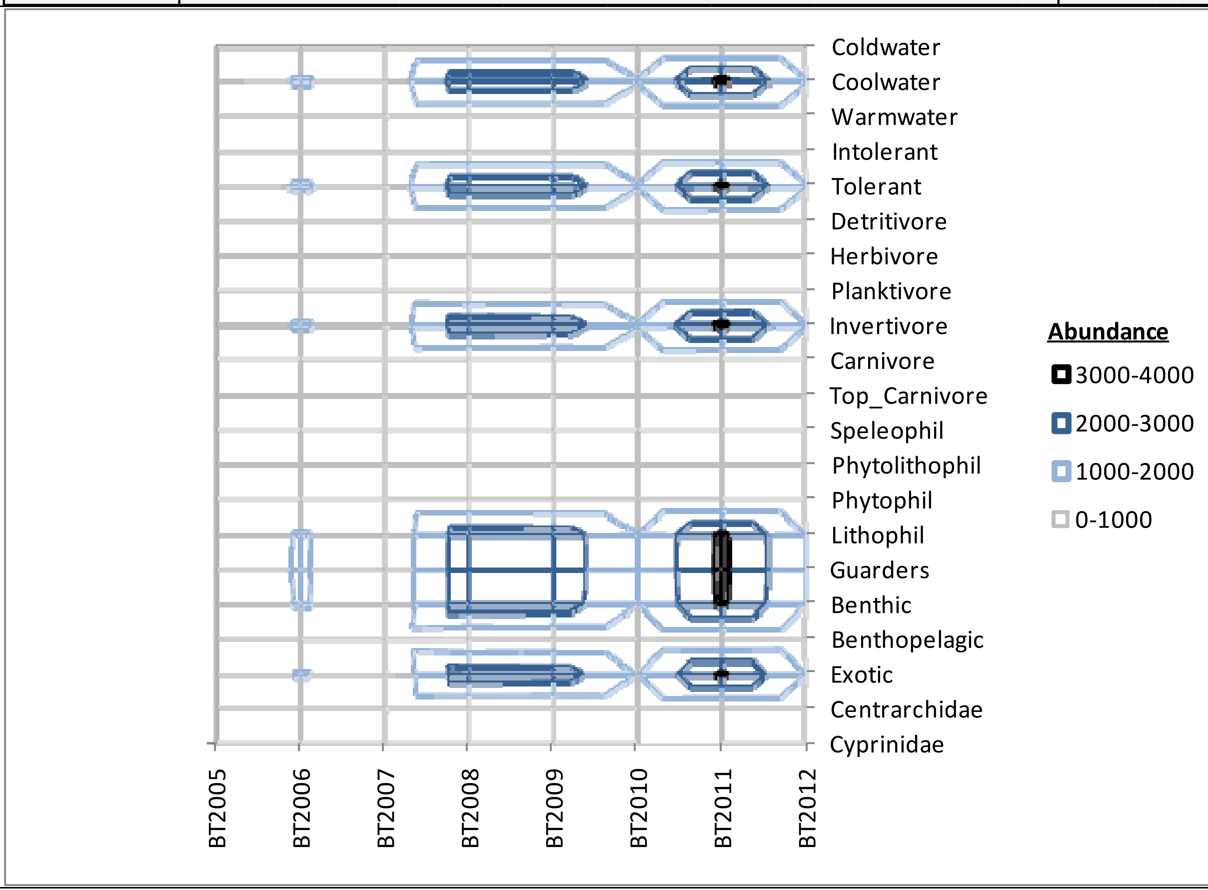
Hay Bay South

	HBW2006	HBW2007	HBW2008	HBW2009	HBW2010	HBW2011	HBW2012	Summary		sd
Cyprinidae	32	2	45	151	588	19	97	133.4	±	206.9
Centrarchidae	270	116	78	248	106	76	170	152.0	±	79.7
Exotic	11	5	3	0	0	1	12	4.6	±	5.1
Benthopelagic	408	166	215	501	763	100	286	348.4	±	229.3
Benthic	13	20	22	23	14	4	13	15.6	±	6.7
Guarders	312	138	145	377	534	82	247	262.1	±	158.8
Lithophil	281	121	81	230	113	72	149	149.6	±	78.1
Phytophil	8	10	10	123	111	21	31	44.9	±	50.1
Phytolithophil	102	38	82	23	139	1	21	58.0	±	50.5
Speleophil	30	17	64	129	427	5	62	104.9	±	147.9
Top_Carnivore	7	22	20	43	7	8	37	20.6	±	14.7
Carnivore	376	176	180	292	119	79	174	199.4	±	101.9
Invertivore	389	177	191	415	359	102	237	267.1	±	120.6
Planktivore	2	3	9	81	63	5	16	25.6	±	32.5
Herbivore	1	15	19	34	167	14	23	39.0	±	57.3
Detritivore	29	2	45	108	420	2	62	95.4	±	147.8
Tolerant	419	186	237	490	635	97	274	334.0	±	188.5
Intolerant	2	0	0	34	142	7	25	30.0	±	51.2
Warmwater	203	103	100	307	671	29	135	221.1	±	217.2
Coolwater	218	83	137	217	106	75	164	142.9	±	59.4
Coldwater	0	0	0	0	0	0	0	0.0	±	0.0



Hay Bay West

	BT2005	BT2006	BT2007	BT2008	BT2009	BT2010	BT2011	BT2012		Summary		sd
Cyprinidae	88	19	139	1	66	4	4	59		47.5	±	49.6
Centrarchidae	17	6	12	3	8	47	12	12		14.6	±	13.8
Exotic	52	1091	89	2625	2545	978	3139	1004		1440.4	±	1182.5
Benthopelagic	107	35	208	13	82	70	41	82		79.8	±	60.1
Benthic	79	1099	110	2623	2548	996	3140	1003		1449.8	±	1173.6
Guarders	105	1122	122	2634	2560	1042	3170	1027		1472.8	±	1171.9
Lithophil	101	1108	126	2626	2556	1044	3152	1015		1466.0	±	1167.7
Phytophil	0	0	0	1	0	3	0	0		0.5	±	1.1
Phytolithophil	11	0	54	1	3	1	6	3		9.9	±	18.2
Speleophil	36	12	13	1	1	1	1	2		8.4	±	12.3
Top_Carnivore	0	0	0	0	0	1	0	0		0.1	±	0.4
Carnivore	24	6	66	3	9	49	15	12		23.0	±	22.7
Invertivore	151	1114	229	2631	2566	1058	3172	1024		1493.1	±	1147.5
Planktivore	39	14	125	6	69	18	18	63		44.0	±	40.1
Herbivore	0	0	0	1	2	0	3	3		1.1	±	1.4
Detritivore	70	20	32	0	5	19	6	3		19.4	±	23.2
Tolerant	186	1124	315	2627	2621	1047	3156	1071		1518.4	±	1129.3
Intolerant	0	10	3	9	9	19	25	14		11.1	±	8.1
Warmwater	44	12	12	1	3	1	4	5		10.3	±	14.3
Coolwater	142	1122	305	2635	2627	1064	3177	1080		1519.0	±	1143.3
Coldwater	0	0	1	0	0	1	0	0		0.3	±	0.5



Big Tub Harbour

Trait Legend

Cyprinidae	Taxonomic family
Centrarchidae	Taxonomic family
Exotic	Non-native species
Benthopelagic	Habitat
Benthic	Habitat
Guarders	Nest guarder
Lithophil	Eggs in or on gravel or rocks
Phytophil	Eggs in or on vegetation
Phytolithophil	Eggs on plants or logs, gravel and rocks
Speleophil	Eggs in hoes, cavities or burrows
Top_Carnivore	Dominant carnivore
Carnivore	Feeds on fish (piscivore) and/or other vertebrates
Invertivore	Feeds on invertebrates including insects, molluscs and crustaceans
Planktivore	Feeds by filtering plankton from the water column
Herbivore	Feeds on green plant biomass made by photosynthesis
Detritivore	Species that consumes detritus
Tolerant	Moderate to high tolerance to turbidity
Intolerant	Low tolerance to turbidity
Warmwater	Prefers water temperatures > 25°C
Coolwater	Prefers water temperatures between 19 and 25°C
Coldwater	Prefers water temperatures < 19°C

References

Abell, R., Allan, J.D., and Lehner, B. (2007). Unlocking the potential of protected areas for freshwaters. *Biological Conservation, 134*(1), 48-63.

Allison, H.E. and Hobbs, R.J. (2004). Resilience, adaptive capacity, and the "Lock-in trap" of the Western Australian agricultural region. *Ecology and Society, 9*(1(3)). http://www.ecologyandsociety.org/vol9/iss1/art3/

Andersen, T., Carstensen, J., Hernandez-Garcia, E., and Duarte, C.M. (2009). Ecological thresholds and regime shifts: approaches to identification. *Trends in Ecology & Evolution, 24*(1), 49-57. doi: 10.1016/j.tree.2008.07.014

Anderson, M.J. (2008). *ControlChart: a FORTRAN computer program for calculating control charts for multivariate response data through time, based on a chosen resemblance measure*. Department of Statistics, University of Auckland, New Zealand.

Anderson, M.J. and Thompson, A.A. (2004). Multivariate control charts for ecological and environmental monitoring. *Ecological Applications, 14(6),* 1921-1935.

Angel, J.R. and Kunkel, K.E. (2010). The response of Great Lakes water levels to future climate scenarios with an emphasis on Lake Michigan-Huron. *Journal of Great Lakes Research, 36 (Supplement 2),* 51-58.

Ardron, J.A., Possingham, H.P., and Klein, C.J. (Eds.). (2010). *Marxan Good Practices Handbook, Version 2*. Victoria, BC: Pacific Marine Analysis and Research Association.

Argyris, C. and Schon, D.A. (1978). *Organizational Learning: A Theory of Action Perspectives*: Addison-Wesley Series on Organization Development.

Assel, R.A. (2003). *An Electronic Atlas of Great Lakes Ice Cover. NOAA Great Lakes Ice Atlas*. National Oceanic and Atmospheric Administration (NOAA), Great Lakes Environmenrtal Reserach Laboratory, Ann Arbor, Michigan. Ann Arbor, Michigan. http://www.glerl.noaa.gov/data/ice/atlas/

Bails, J., Beeton, A., Bulkley, J., DePhilip, M., Gannon, J., Murray, M., Regier, H., and Scavia, D. (2005). *Prescription for Great Lakes Ecosystem Protection and Restoration Avoiding the Tipping Point of Irreversible Changes*. Prepared with support from the Wege Foundation and the Joyce Foundation.

Ball, I.R., Possingham, H.P., and Watts, M. (2009). Marxan and relatives: Software for spatial conservation prioritisation. In A. Moilanen, K.A. Wilson and H.P. Possingham (Eds.), *Spatial Conservation Prioritisation: Quantitative Methods and Computational Tools* (pp. 185-195). Oxford, UK: Oxford University Press.

Barbiero, R.P., Lesht, B.M., and Warren, G.J. (2011). Evidence for bottom-up control of recent shifts in the pelagic food web of Lake Huron. *Journal of Great Lakes Research, 37*(1), 78-85. doi: 10.1016/j.jglr.2010.11.013

Barbiero, R.P., Lesht, B.M., and Warren, G.J. (2012). Convergence of trophic state and the lower food web in Lakes Huron, Michigan and Superior. *Journal of Great Lakes Research, 38*(2), 368-380. doi: 10.1016/j.jglr.2012.03.009

Barmuta, L.A., Linke, S., and Turak, E. (2011). Bridging the gap between 'planning' and 'doing' for biodiversity conservation in freshwaters. *Freshwater Biology, 56*(1), 180-195. doi: 10.1111/j.1365-2427.2010.02514.x

Baron, J.S., Gunderson, L., Allen, C.D., Fleishman, E., McKenzie, D., Meyerson, L.A., Oropeza, J., and Stephenson, N. (2009). Options for national parks and reserves for adapting to climate change. *Environmental management, 44*(6), 1033-1042. doi: 10.1007/s00267-009-9296-6

Beak Consultants Ltd. (1990). *Aquatic Resources Information Needs Study - Fathom Five National Marine Parks (FFNMP)*. Canadian Parks Service.

Beak Consultants Ltd. (1994). *Fathom Five National Marine Park Boundary Analysis Study*. Prepared by Kathy Fisher and Karl Schiefer, Beak Consultants Limited, Brampton, Ontario. Brampton, Ontario

Bennett, E.B. (1988). On the physical limnology of Georgian Bay. *Hydrobiologia*, *163*, 21-34.

Berkes, F., Colding, J., and Folke, C. (Eds.). (2003). *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change*. New York: Cambridge University Press.

Biggs, R., Carpenter, S.R., and Brock, W.A. (2009). Turning back from the brink: Detecting an impending regime shift in time to avert it. *Proceedings of the National Academy of Sciences of the United States of America, 106*(3), 826-831. doi: 10.1073/pnas.0811729106

Blasco, S.M. (2001). Geological history of Fathom Five National Marine Park over the past 15,000 years. In S. Parker and M. Munawar (Eds.), *Ecology, Culture and Conservation of a Protected Area: Fathom Five National Marine Park, Canada* (pp. 45-62). Leiden, The Netherlands: Backhuys Publishers.

Bouvier, L.D., Cottenie, K., and Doka, S.E. (2009). Aquatic connectivity and fish metacommunities in wetlands of the lower Great Lakes. *Canadian Journal of Fisheries and Aquatic Sciences, 66*(6), 933-948. doi: 10.1139/f09-050

Brand, F.S. and Jax, K. (2007). Focusing the meaning(s) of resilience: Resilience as a descriptive concept and a boundary object. *Ecology and Society, 12*(1(23)). http://www.ecologyandsociety.org/vol12/iss1/art23/

Breen, M.J. and Ruetz, C.R. (2006). Gear bias in fyke netting: evaluating soak time, fish density, and predators. *North American Journal of Fisheries Management, 26*(1), 32-41. doi: 10.1577/m05-013.1

Briggs, S. (2003). Command and control in natural resource management: Revisiting Holling and Meffe. *Ecological Management & Restoration, 4(3),* 161-162.

Burton, T.M., Brazner, J.C., Ciborowski, J.J.H., Grabas, G.P., Hummer, J., Schneider, J., and Uzarski, D.G. (Eds.). (2008). *Great Lakes Coastal Wetlands Monitoring Plan*: Great Lakes Commission.

Canada. (1985a). Fisheries Act, c. F-14. *Canada Gazette*. http://laws-lois.justice.gc.ca/eng/acts/F-14/

Canada. (1985b). Navigable Waters Protection Act, c. N-22. *Canada Gazette*. http://laws-lois.justice.gc.ca/eng/acts/N-22/

Canada. (1991). Federal Real Property and Federal Immovables Act, c. 50. *Canada Gazette*. http://laws-lois.justice.gc.ca/eng/acts/F-8.4/

Canada. (2000). Canada National Parks Act, c. 32. *Canada Gazette*. http://laws-lois.justice.gc.ca/eng/acts/N-14.01/

Canada. (2001). Canada Shipping Act, c. 26. *Canada Gazette*. http://laws-lois.justice.gc.ca/eng/acts/C-10.15/

Canada. (2002). Canada National Marine Conservation Areas Act, c. 18. *Canada Gazette*. http://laws-lois.justice.gc.ca/eng/acts/C-7.3/index.html

Canada. (2009). Vessel Operation Restriction Regulations (SOR/2008-120). *Canada Gazette*. http://laws-lois.justice.gc.ca/eng/regulations/SOR-2008-120/

Canada. (2011). *National Framework for Canada's Network of Marine Protected Areas*. Fisheries and Oceans Canada, Ottawa. Ottawa
Canada. (2012a) Canada's Action Plan on Open Government. Ottawa.
Canada and Ontario. (1987). *Agreement for the Establishment of a National Park and a National Marine Park in the Township of St. Edmunds, Province of Ontario*. Tobermory, Ontario.
Canada and EPA. (1995). *The Great Lakes: An Environmental Atlas and Resource Book* (3rd ed.): Government of Canada and United States Environmental Protection Agency (EPA).
Canada, P. (2012b). *Visitor Attendance Statistics for Fathom Five, 2012*. Fathom Five National Marine Park, Tobermory, Ontario. Tobermory, Ontario
Carpenter, G., Gillison, A.N., and Winter, J. (1993). DOMAIN: a flexible modelling procedure for mapping potential distributions of plants and animals. *Biodiversity and Conservation, 2* 667-680.
Carpenter, S., Walker, B., Anderies, J.M., and Abel, N. (2001). From metaphor to measurement: Resilience of what to what? *Ecosystems, 4*(8), 765-781. doi: 10.1007/s10021-001-0045-9
Carpenter, S.R. and Brock, W.A. (2006). Rising variance: a leading indicator of ecological transition. *Ecology Letters, 9*(3), 308-315. doi: 10.1111/j.1461-0248.2005.00877.x
Carpenter, S.R. and Brock, W.A. (2008). Adaptive capacity and traps. *Ecology and Society, 13*(2(40)). http://www.ecologyandsociety.org/vol13/iss2/art40/
Carpenter, S.R. and Gunderson, L.H. (2001). Coping with collapse: Ecological and social dynamics in ecosystem management. *BioScience, 51*(6), 451-457.
CCSP. (2008). *Preliminary review of adaptation options for climate-sensitive ecosystems and resources. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research.*, Washington, DC, USA. Washington, DC, USA. http://www.epa.gov/ncea/
Chapin III, F.S., Carpenter, S.R., Kofinas, G.P., Folke, C., Abel, N., Clark, W.C., Olsson, P., Smith, D.M.S., Walker, B., Young, O.R., Berkes, F., Biggs, R., Grove, J.M., Naylor, R.L., Pinkerton, E., Steffen, W., and Swanson, F.J. (2010). Ecosystem stewardship: sustainability strategies for a rapidly changing planet. *Trends in Ecology and Evolution, 25*(4), 241-249. doi: 10.1016/j.tree.2009.10.008
Chapin III, F.S., Folke, C., and Kofinas, G.P. (2009). A framework for understanding change. In F.S. Chapin III, G.P. Kofinas and C. Folke (Eds.), *Principles of Ecosystem Stewardship: Resilience-Based Natural Resources Management in a Changing World* (pp. 3-28). New York: Springer.
Chisholm, R.A. and Filotas, E. (2009). Critical slowing down as an indicator of transitions in two-species models. *Journal of Theoretical Biology, 257*(1), 142-149. doi: 10.1016/j.jtbi.2008.11.008
Chow-Fraser, P. (2006). Development of the Water Quality Index (WQI) to assess effects of basin-wide land-use alteration on coastal marshes of the Laurentian Great Lakes. In T.P. Simon and P.M. Stewart (Eds.), *Coastal Wetlands of the Laurentian Great Lakes: Health, Habitat and Indicators* (pp. 137-185). Bloomington, IN: Author House.
Chow-Fraser, P. and Albert, D. (1999). *Identification of Eco-Reaches of Great Lakes Coastal Wetlands that have high biodiversity values*. Discussion paper for SOLEC '98. Env Canada-USEPA Pub.
CHS. (2011). Historical water level data Retrieved November 15, 2011, from Fisheries and Oceans Canada, Canadian Hydrographic Service (CHS) http://www.waterlevels.gc.ca

Cole, D.N., Yung, L., Zavaleta, E.S., Aplet, G.H., Chapin III, F.S., Graber, D.M., Higgs, E.S., Hobbs, R.J., Landres, P.B., Millar, C.I., Parsons, D.J., Randall, J.M., Stephenson, N.L., Tonnessen, K.A., White, P.S., and Woodley, S. (2008). Naturalness and beyond: protected area stewardship in an era of global environmental change. *The George Wright Forum, 25 (1),* 36-56.

Coleman, M.A., Chambers, J., Knott, N.A., Malcolm, H.A., Harasti, D., Jordan, A., and Kelaher, B.P. (2011). Connectivity within and among a Network of Temperate Marine Reserves. *PLoS ONE, 6*(5). doi: 10.1371/journal.pone.0020168

Contamin, R. and Ellison, A.M. (2009). Indicators of regime shifts in ecological systems: What do we need to know and when do we need to know it? *Ecological Applications, 19*(3), 799-816.

Costanza, R., Fisher, B., Ali, S., Beer, C., Bond, L., Boumans, R., Danigelis, N.L., Dickinson, J., Elliott, C., Farley, J., Gayer, D.E., Glenn, L.M., Hudspeth, T., Mahoney, D., McCahill, L., McIntosh, B., Reed, B., Rizvi, S.A.T., Rizzo, D.M., Simpatico, T., and Snapp, R. (2007). Quality of life: An approach integrating opportunities, human needs, and subjective well-being. *Ecological Economics, 61*(2-3), 267-276. doi: 10.1016/j.ecolecon.2006.02.023

Courtney, R. and Shaw, J. (2000). Environmental marine geoscience 2. Multibeam bathymetry and backscatter imaging of the Canadian continental shelf. *Geoscience Canada, 27*(1), 31-42.

CPAWS. (2012). *State of Canada's Parks. Parks under threat*. Canadian Parks and Wilderness Society.

Crawford, S.S. (2001). Salmonine introductons to the Laurentian Great Lakes: an historical review and evaluation of ecological effects. *Canadian Special Publication of Fisheries and Aquatic Sciences 132,* 205.

Croft, M.V. and Chow-Fraser, P. (2007). Use and Development of the Wetland Macrophyte Index to Detect Water Quality Impairment in Fish Habitat of Great Lakes Coastal Marshes. *Journal of Great Lakes Research, 33*(Journal Article), 172-197.

Cruce, T. and Yurkovich, E. (2011). *Adapting to Climate Change: A Planning Guide for State Coastal Managers - A Great Lakes Supplement*. NOAA Office of Ocean and Coastal Resource Management., Silver Spring, MD. Silver Spring, MD

Cuhel, R.L. and Aguilar, C. (2013). Ecosystem transformations of the Laurentian Great Lake Michigan by nonindigenous biological invaders. *Annual review of marine science, 5*. doi: 10.1146/annurev-marine-120710-100952

Cumming, G.S. and Collier, J. (2005). Change and identity in complex systems. *Ecology and Society, 10*(1(29)). http://www.ecologyandsociety.org/vol10/iss1/art29/

Cumming, G.S., Cumming, D.H.M., and Redman, C.L. (2006). Scale mismatches in social-ecological systems: Causes, consequences, and solutions. *Ecology and Society, 11*(1(14)). http://www.ecologyandsociety.org/vol11/iss1/art14/

Cvetkovic, M. and Chow-Fraser, P. (2011). Use of ecological indicators to assess the quality of Great Lakes coastal wetlands. *Ecological Indicators, 11*(6), 1609-1622. doi: 10.1016/j.ecolind.2011.04.005

Cvetkovic, M., Kostuk, K., and Chow-Fraser, P. (2012). Gear-Type Influences on Fish Catch and a Wetland Fish Index in Georgian Bay Wetlands. *North American Journal of Fisheries Management, 32*(2), 313-324. doi: 10.1080/02755947.2012.678560

Dakos, V., Carpenter, S.R., Brock, W.A., Ellison, A.M., Guttal, V., Ives, A.R., Kefi, S., Livina, V., Seekell, D.A., van Nes, E.H., and Scheffer, M. (2012). Methods for detecting early warnings of critical transitions in time series illustrated using simulated ecological data. *PloS one, 7*(7), e41010.

Dakos, V., Kefi, S., Rietkerk, M., van Nes, E.H., and Scheffer, M. (2011). Slowing Down in Spatially Patterned Ecosystems at the Brink of Collapse. *American Naturalist, 177*(6), E153-E166. doi: 10.1086/659945

Dakos, V., van Nes, E.H., Donangelo, R., Fort, H., and Scheffer, M. (2010). Spatial correlation as leading indicator of catastrophic shifts. *Theoretical Ecology, 3*(3), 163-174. doi: 10.1007/s12080-009-0060-6

Davis, G.E. (2005). Science and society: Marine reserve design for the California Channel Islands. *Conservation Biology, 19*(6), 1745-1751. doi: 10.1111/j.1523-1739.2005.00317.x

Day, B. (2012). *Shores of Heaven, the Birth of Bruce Peninsula National Parks*. Owen Sound: Self-published.

Day, J., Dudley, N., Hockings, M., Holmes, G., Laffoley, D., Stolton, S., and Wells, S. (2012). *Guidelines for applying the IUCN Protected Area Management Categories to Marine Protected Areas*. IUCN, Gland, Switzerland. Gland, Switzerland

Day, J.C. (2002). Zoning - lessons from the Great Barrier Reef Marine Park. *Ocean & Coastal Management 45:139-156*.

DeSellas, A.M., Paterson, A.M., Sweetman, J.N., and Smol, J.P. (2008). Cladocera assemblages from the surface sediments of south-central Ontario (Canada) lakes and their relationships to measured environmental variables. *Hydrobiologia, 600*(1), 15. doi: 10.1007/s10750-007-9180-4

Desjardine, R.L., Gorenflo, T.K., Payne, R.N., and Schrouder, J.D. (1995). *Fish-community objectives for Lake Huron*.

deYoung, B., Barange, M., Beaugrand, G., Harris, R., Perry, R.I., Scheffer, M., and Werner, F. (2008). Regime shifts in marine ecosystems: detection, prediction and management. *Trends in Ecology & Evolution, 23*(7), 402-409. doi: 10.1016/j.tree.2008.03.008

Diaz, R.J., Solan, M., and Valente, R.M. (2004). A review of approaches for classifying benthic habitats and evaluating habitat quality. *Journal of environmental management, 73*(3), 165-181. doi: 10.1016/j.jenvman.2004.06.004

Dobiesz, N.E., McLeish, D.A., Eshenroder, R.L., Bence, J.R., Mohr, L.C., Ebener, M.P., Nalepa, T.F., Woldt, A.P., Johnson, J.E., Argyle, R.L., and Makarewicz, J.C. (2005). Ecology of the Lake Huron fish community, 1970-1999. *Canadian Journal of Fisheries and Aquatic Sciences, 62*(6), 1432-1451. doi: 10.1139/f05-061

Dudley, N. (Ed.). (2008). *Guidelines for Applying Protected Area Management Categories*. Gland, Switzerland: IUCN.

Eakins, R.J. (2012). Ontario Freshwater Fishes Life History Database. Version 4.24. On-line database. (http://www.ontariofishes.ca), accessed 04 December 2012.

Environment Canada. (1994). *Environmental sensitivity atlas for Lake Huron's Canadian shoreline including Georgian Bay*. Environment Canada, Conservation and Protection, Environmental Protection, Ontario Region, Toronto Toronto

EPA and EC. (2008). *Lake Huron Binational Partnership 2008-2010 Action Plan*. U.S. Environmental Protection Agency and Environment Canada.

EPA and EC. (2010). *Lake Huron Biodiversity Conservation Strategy*. U.S. Environmental Protection Agency and Environment Canada. http://conserveonline.org/workspaces/lakehuron.bcs/

Eshenroder, R.L. (1992). Decline of lake trout in Lake Huron. *Transactions of the American Fisheries Society, 121*(4), 548-550.

Eshenroder, R.L. and Burnham-Curtis, M.K. (1999). Species succession and sustainability of the Great Lakes fish community. In W.W. Taylor and C.P. Ferreri (Eds.), *Great Lakes Fisheries Policy and Management, A Binational Perspective* (pp. 145-184). East Lansing, MI.: Michigan State University Press, East Lansing.

Evans, M.A., Fahnenstiel, G., and Scavia, D. (2011). Incidental oligotrophication of North American Great Lakes. *Environmental Science & Technology, 45*(8), 3297-3303. doi: 10.1021/es103892w

Fazey, I., Fazey, J.A., Fischer, J., Sherren, K., Warren, J., Noss, R.F., and Dovers, S.R. (2007). Adaptive capacity and learning to learn as leverage for social-ecological resilience. *Frontiers in Ecology and the Environment, 5*(7), 375-380. doi: 10.1890/1540-9295(2007)5[375:acaltl]2.0.co;2

Fernandes, L., Jon, D., Lewis, A., Slegers, S., Kerrigan, B., Breen, D., Cameron, D., Jago, B., Hall, J., Lowe, D., Innes, J., Tanzer, J., Chadwick, V., Thompson, L., Gorman, K., Simmons, M., Barnett, B., Sampson, K., De'Ath, G., Mapstone, B., Marsh, H., Possingham, H., Ball, I., Ward, T., Dobbs, K., Aumend, J., Slater, D., and Stapleton, K. (2005). Establishing representative no-take areas in the Great Barrier Reef: large-scale implementation of theory on marine protected areas. *Conservation Biology, 19*(6), 1733-1744.

Ficke, A.D., Myrick, C.A., and Hansen, L.J. (2007). Potential impacts of global climate change on freshwater fisheries. *Reviews in Fish Biology and Fisheries, 17*(4), 581-613. doi: 10.1007/s11160-007-9059-5

Fitzsimons, J.A. and Robertson, H.A. (2005). Freshwater reserves in Australia: directions and challenges for the development of a comprehensive, adequate and representative system of protected areas *Hydrobiologia, 552*(1), 87-97.

Fluker, S. (2010). Ecological integrity in Canada's National Parks: the false promise of law. *Windsor Review of Legal; and Social Issues, 29*(May).

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., and Holling, C.S. (2004). Regime shifts, resilience, and biodiversity in ecosystem management. *Annual Review of Ecology Evolution and Systematics, 35*(Journal Article), 557-581.

Folke, C., Carpenter, S.R., Walker, B., Scheffer, M., Chapin, T., and Rockström, J. (2010). Resilience thinking: Integrating resilience, adaptability and transformability. *Ecology and Society, 15*(4(20)). http://www.ecologyandsociety.org/vol15/iss4/art20/

Folke, C., Colding, J., and Berkes, F. (2003). Synthesis: Building resilience and adaptive capacity in social-ecological systems. In F. Berkes, J. Colding and C. Folke (Eds.), *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change* (pp. 352-387). Cambridge: Cambridge University Press

Folke, C., Hahn, T., Olsson, P., and Norberg, J. (2005). Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources, 30,* 441-473. doi: 10.1146/annurev.energy.30.050504.144511

Francis, G. (2008). Evolution of contexts for protected areas governance. In K.S. Hanna, D.A. Clark and D.S. Slocombe (Eds.), *Transforming Parks and Protected Areas* (pp. 15-38). New York: Routledge.

Francis, G.R. and Regier, H.A. (1995). Barriers and Bridges to the Restoration of the Great Lakes Basin Ecosystem. In L.H. Gunderson, C.S. Holling and S.S. Light (Eds.), *Barriers and bridges to the renewal of ecosystems and institutions.* New York: Columbia University Press.

Franks Taylor, R., Derosier, A., Dinse, K., Doran, P., Ewert, D., Hall, K., Herbert, M., Khoury, M., Kraus, D., Lapenna, A., Mayne, G., Pearsall, D., Read, J., and Schroeder, B. (2010). *The Sweetwater Sea: An International Biodiversity Conservation Strategy for Lake Huron - Technical Report*. A joint publication of The Nature Conservancy, Environment Canada, Ontario Ministry of Natural Resources Michigan Department of Natural Resources and Environment, Michigan Natural Features Inventory Michigan Sea Grant, and The Nature Conservancy of Canada. http://conserveonline.org/workspaces/lakehuron.bcs/

Game, E.T., Watts, M.E., Wooldridge, S., and Possingham, H.P. (2008). Planning for persistence in marine reserves: A question of catastrophic importance. *Ecological Applications, 18*(3), 670-680. doi: 10.1890/07-1027.1

Geneletti, D. and van Duren, I. (2008). Protected area zoning for conservation and use: A combination of spatial multicriteria and multiobjective evaluation. *Landscape and Urban Planning, 85*(2), 97-110. doi: 10.1016/j.landurbplan.2007.10.004

GLANSIS. (2012). Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS). Retrieved December 5, 2012, from National Oceanic and Atmospheric Administration (NOAA) http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html

GLFC. (1988). *Report of the evaluation of the Great Lakes Fishery Commission's program of sea lamprey barrier dams*.

GLFC. (2007). *A joint strategic plan for management of Great Lakes fisheries*. Great Lakes Fishery Commission, Ann Arbor, MI. Ann Arbor, MI. http://www.glfc.org/fishmgmt/jsp97.pdf

GLFC. (2008). *Strategic vision of the Great Lakes Fishery Commission for the first decade of the new millennium*. Ann Arbor, MI: Great Lakes Fishery Commission.

Goodyear, C.D., Edsall, T.A., Ormsby Dempsey, D.M., Moss, G.D., and Polanski, P.E. (1992). *Atlas of the spawning and nursery areas of Great Lakes fishes. Volume V, Lake Huron*. U.S. Fish and Wildlife Service, Washington. Washington

Graham, J., Amos, B., and Plumptre, T. (2003). *Governance principles for protected areas in the 21st century*. Institute on Governance, Ottawa, Ontario. Ottawa, Ontario

Grantham, H.S., Bode, M., McDonald-Madden, E., Game, E.T., Knight, A.T., and Possingham, H.P. (2010). Effective conservation planning requires learning and adaptation. *Frontiers in Ecology and the Environment*, *8*(8), 431-437. doi: 10.1890/080151

Green, A., Smith, S.E., Lipsett-Moore, G., Groves, C., Peterson, N., Sheppard, S., Lokani, P., Hamilton, R., Almany, J., Aitsi, J., and Bualia, L. (2009). Designing a resilient network of marine protected areas for Kimbe Bay, Papua New Guinea. *Oryx*, *43*(04), 488-498. doi: doi:10.1017/S0030605309990342

Gunderson, L.H., Allen, C.R., and Holling, C.S. (2010). The Evolution of an Idea - the Past, Present, and Future of Ecological Resilience. In L.H. Gunderson, C.S. Holling and C.R.

Allen (Eds.), *Foundations of Ecological Resilience* (pp. 423-444). Washington, DC: Island Press.

Gunderson, L.H. and Holling, C.S. (Eds.). (2002). *Panarchy: Understanding Transformations in Human and Natural Systems*. Washington, DC: Island Press.

Gunderson, L.H., Holling, C.S., and Light, S.S. (1995). Barriers Broken and Bridges Built: A Synthesis. In L.H. Gunderson, C.S. Holling and S.S. Light (Eds.), *Barriers and Bridges to the Renewal of Ecosystem and Institutions* (pp. 399-532). New York: Columbia University Press.

Guttal, V. and Jayaprakash, C. (2009). Spatial variance and spatial skewness: leading indicators of regime shifts in spatial ecological systems. *Theoretical Ecology, 2*(1), 3-12. doi: 10.1007/s12080-008-0033-1

Hager, H.A. and Nudds, T.D. (2001). Parks and protected areas as ecological baselines: establishment of baseline data on species-area relations from islands in Georgian Bay. In S.R. Parker and M. Munawar (Eds.), *Ecology, culture and conservation of a protected area: Fathom Five National Marine Park, Canada.* (pp. 269-280). Leiden, The Netherlands. : Backhuys.

Hall, R.I. and Smol, J.P. (1996). Paleolimnological assessment of long-term water-quality changes in south-central Ontario lakes affected by cottage development and acidification. *Canadian Journal of Fisheries and Aquatic Sciences, 53*(1), 1-17.

Hanrahan, J.L., Kravtsov, S.V., and Roebber, P.J. (2010). Connecting past and present climate variability to the water levels of Lakes Michigan and Huron. *Geophysical Research Letters, 37*. doi: 10.1029/2009gl041707

Hastings, A. and Wysham, D.B. (2010). Regime shifts in ecological systems can occur with no warning. *Ecology Letters, 13*(4), 464-472. doi: 10.1111/j.1461-0248.2010.01439.x

Hecky, R.E., Smith, R.E.H., Barton, D.R., Guildford, S.J., Taylor, W.D., Charlton, M.N., and Howell, T. (2004). The nearshore phosphorus shunt: a consequence of ecosystem engineering by dreissenids in the Laurentian Great Lakes. *Canadian Journal of Fisheries and Aquatic Sciences, 61*(7), 1285-1293. doi: 10.1139/f04-065

Hedges, K.J., Koops, M.A., Mandrak, N.E., and Johannsson, O.E. (2010). Use of aquatic protected areas in the management of large lakes. *Aquatic Ecosystem Health & Management, 13*(2), 135-142. doi: 10.1080/14634981003788912

Hedges, K.J., Koops, M.A., Mandrak, N.E., and Johannsson, O.E. (2011). *Great Lakes Aquatic Protected Areas*. Great Lakes Fishery Commission.

Hittle, J. (2011). *Integrated Planning for Resilient Communities: A Technical Guide to Integrating Hazard, Ecosystem and Land Use Planning*. EBM Tools Network. http://resilient-communities.org/files/Integrated_Planning_for_Resilient_Communities_2-7-11.pdf

Hobbs, R.J., Cole, D.N., Yung, L., Zavaleta, E.S., Aplet, G.H., Chapin, F.S., Landres, P.B., Parsons, D.J., Stephenson, N.L., White, P.S., Graber, D.M., Higgs, E.S., Millar, C.I., Randall, J.M., Tonnessen, K.A., and Woodley, S. (2010). Guiding concepts for park and wilderness stewardship in an era of global environmental change. *Frontiers in Ecology and the Environment, 8(9)*, 483-490. doi: doi:10.1890/090089

Hobbs, R.J., Higgs, E., and Harris, J.A. (2009). Novel ecosystems: implications for conservation and restoration. *Trends in Ecology & Evolution, 24*(11), 599-605. doi: 10.1016/j.tree.2009.05.012

Hockings, M., Stolton, S., Leverington, F., Dudley, N., and Courrau, J. (2006). *Evaluating Effectiveness: A framework for assessing management effectiveness of protected areas. 2nd edition*. IUCN, Gland, Switzerland and Cambridge, UK. Gland, Switzerland and Cambridge, UK

Holling, C.S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics, 4*, 1-23.

Holling, C.S. (1992). Cross-scale morphology, geometry, and dynamics of ecosystems. *Ecological Monographs, 62*(4), 447-502.

Holling, C.S. (1996). Engineering resilience versus ecological resilience. In P.C. Schullze (Ed.), *Engineering within ecological constarints* (pp. 31-44). Washington, D.C., USA: National Academy Press.

Holling, C.S. (Ed.). (1978). *Adaptive Environmental Assessment and Management*. New York: John Wiley & Sons.

Holling, C.S. and Gunderson, L.H. (2002). Resilience and Adaptive Cycles. In L.H. Gunderson and C.S. Holling (Eds.), *Panarchy: Understanding Transformations in Human and Natural Systems* (pp. 25-62). Washington, D.C.: Island Press.

Holling, C.S. and Meffe, G.K. (1996). Command and control and the pathology of natural resource management. *Conservation Biology, 10*(2), 328-337.

Hughes, T.P., Bellwood, D.R., Folke, C., Steneck, R.S., and Wilson, J. (2005). New paradigms for supporting the resilience of marine ecosystems. *Trends in Ecology & Evolution, 20*(7), 380-386. doi: 10.1016/j.tree.2005.03.022

Hughes, T.P., Graham, N.A.J., Jackson, J.B.C., Mumby, P.J., and Steneck, R.S. (2010). Rising to the challenge of sustaining coral reef resilience. *Trends in Ecology & Evolution, 25*(11), 633-642. doi: 10.1016/j.tree.2010.07.011

Humphrey, A.S. (2005). SWOT Analysis for Management Consulting. *SRI Alumni Association Newsletter*.

IJC. (1987). *Great Lakes Water Quality Agreement of 1978*. International Joint Commission (IJC) United States and Canada.

IJC. (2009). *Impacts on Upper Great Lakes Water Levels: St. Clair River*. International Upper Great Lakes Study.

IJC. (2011). *Options for Restoring Lake Michigan-Huron Water Levels: An Exploratory Analysis*. International Upper Great Lakes Study. http://www.iugls.org/

IJC. (2012a). *Great Lakes Water Quality Agreement, 2012*. International Joint Commission (IJC), United States of America and Canada.

IJC. (2012b). *Lake Superior Regulation: Addressing Uncertainty in Upper Great Lakes Water Levels*. International Joint Commission, Upper Great Lakes Study.

IUCN. (2005). *Proceedings of the Vth IUCN World Parks Congress.* Paper presented at the Benefits beyond boundaries : proceedings of the Vth IUCN World Parks Congress, 2003, Durban, South Africa.

IUCN WCPA. (2008). *Establishing Resilient Marine Protected Area Networks - Making It Happen*. International Union for Conservation of Nature (IUCN), World Commission on Protected Areas (WCPA), National Oceanic and Atmospheric Administration (NOAA) and The Nature Conservancy (TNC), Washington, D.C. Washington, D.C. http://cmsdata.iucn.org/downloads/mpanetworksmakingithappen_en.pdf

Jackson, D.A. and Harvey, H.H. (1997). Qualitative and quantitative sampling of lake fish communities. *Canadian Journal of Fisheries and Aquatic Sciences, 54*(12), 2807-2813.

Jude, D.J. and Pappas, J. (1992). Fish utilization of Great Lakes coastal wetlands. *Journal of Great Lakes Research, 18*(4), 651-672.

Kay, J.J. and Boyle, M. (2008). Self-organizing, holarchic, open systems (SOHOs). In D. Waltner-Toews, J.J. Kay and N.-M.E. Lister (Eds.), *The Ecosystem Approach: Complexity, Uncertainty, and Managing for Sustainability* (pp. 51-78). New York: Columbia University Press.

Kay, J.J., Regier, H.A., Boyle, M., and Francis, G. (1999). An ecosystem approach for sustainability: addressing the challenge of complexity. *Futures, 31*(7), 721-742.

Kenchington, R.A. and Day, J.C. (2011). Zoning, a fundamental cornerstone of effective Marine Spatial Planning: lessons learnt from the Great Barrier Reef, Australia. *Journal of Coastal Conservation, 15*(2), 271-278. doi: 10.1007/s11852-011-0147-2

Kerkhoff, A.J. and Enquist, B.J. (2007). The implications of scaling approaches for understanding resilience and reorganization in ecosystems. *BioScience, 57*(6), 489-499. doi: 10.1641/b570606

Kettle, A. (1998). *Flowerpot Island Area Management Plan for Fathom Five National Marine Park*. Parks Canada, Tobermory, Ontario. Tobermory, Ontario

Kingsford, R.T., Biggs, H.C., and Pollard, S.R. (2011). Strategic Adaptive Management in freshwater protected areas and their rivers. *Biological Conservation, 144*(4), 1194-1203. doi: 10.1016/j.biocon.2010.09.022

Kirkpatrick, J.B. (1983). An iterative method for establishing priorities for the selection of nature reserves - an example from Tasmania. *Biological Conservation, 25*(2), 127-134. doi: 10.1016/0006-3207(83)90056-3

Klein, C.J., Steinback, C., Watts, M., Scholz, A.J., and Possingham, H.P. (2009). Spatial marine zoning for fisheries and conservation. *Frontiers in Ecology and the Environment, 8*(7), 349-353. doi: 10.1890/090047

Kor, P.S.G., Cowell, D.W., Karrow, P.F., and Kristjansson, F.J.R. (2012). The Cabot Head Archipelago: evidence of glacial Lake Algonquin on the Northern Bruce Peninsula, Ontario. *Canadian Journal of Earth Sciences, 49*(4), 576-589. doi: 10.1139/e2012-007

Kornis, M.S., Mercado-Silva, N., and Vander Zanden, M.J. (2012). Twenty years of invasion: a review of round goby Neogobius melanostomus biology, spread and ecological implications. *Journal of Fish Biology, 80*(2), 235-285. doi: 10.1111/j.1095-8649.2011.03157.x

Kostylev, V.E., Todd, B.J., Fader, G.B.J., Courtney, R.C., Cameron, G.D.M., and Pickrill, R.A. (2001). Benthic habitat mapping on the Scotian Shelf based on multibeam bathymetry, surficial geology and sea floor photographs. *Marine Ecology-Progress Series, 219*, 121-137.

Kostylev, V.E., Todd, B.J., Longva, O., and Valentine, P.C. (2005). Characterization of benthic habitat on northeastern Georges Bank, Canada. In B.W. Barnes and J.P. Thomas (Eds.), *Benthic Habitats and the Effects of Fishing* (Vol. 41, pp. 141-152). Bethesda: Amer Fisheries Soc.

Krebs, V. and Holley, J. (2006). *Building Smart Communities through Network Weaving*. http://www.orgnet.com/cases.html

Langhammer, P.F., Bakarr, M.I., Bennun, L.A., Brooks, T.M., Clay, R.P., Darwall, W., De Silva, N., Edgar, G.J., Eken, G., Fishpool, L.D.C., Fonseca, G.A.B.d., Foster, M.N., Knox, D.H., Matiku, P., Radford, E.A., Rodrigues, A.S.L., Salaman, P., Sechrest, W., and Tordoff, A.W. (2007). *Identification and Gap Analysis of Key Biodiversity Areas:*

Targets for Comprehensive Protected Area Systems. IUCN, Gland, Switzerland. Gland, Switzerland

Lausche, B. (2011). *Guidelines for Protected Areas Legislation*. International Union for Conservation of Nature and Natural Resources (IUCN), Gland, Switzerland. Gland, Switzerland

Lebel, L., Anderies, J.M., Campbell, B., Folke, C., Hatfield-Dodds, S., Hughes, T.P., and Wilson, J. (2006). Governance and the capacity to manage resilience in regional social-ecological systems. *Ecology and Society, 11*(1(19)). http://www.ecologyandsociety.org/vol11/iss1/art19/

Legendre, P. and Gallagher, E.D. (2001). Ecologically meaningful transformations for ordination of species data. *Oecologia, 129*(2), 271-280.

Legendre, P. and Legendre, L. (1998). *Numerical Ecology* (Vol. Volume 20). Amsterdam: Elsevier Science Ltd.

Lemieux, C.J., Beechey, T.J., and Gray, P.A. (2011). Prospects for Canada's protected areas in an era of rapid climate change. *Land Use Policy 28*, Lem928– 941.

Leslie, J.K. and Timmins, C.A. (2001). Fishes of the shallow littoral zone of Fathom Five National Marine Park. In S. Parker and M. Munawar (Eds.), *Ecology, Culture and Conservation of a Protected Area: Fathom Five National Marine Park* (pp. 167-178). Leiden, The Netherlands: Backhuys Publishers.

Lester, S.E., Halpern, B.S., Grorud-Colvert, K., Lubchenco, J., Ruttenberg, B.I., Gaines, S.D., Airame, S., and Warner, R.R. (2009). Biological effects within no-take marine reserves: a global synthesis. *Marine Ecology-Progress Series, 384*, 33-46. doi: 10.3354/meps08029

Levin, S.A. (1992). The problem of pattern and scale in ecology. *Ecology, 73*(6), 1943-1967.

Levin, S.A. (1999). *Fragile Dominion: Complexity and the Commons*. Reading, MA: Perseus Books.

LHCA. (2007). *Lake Huron-Georgian Bay Watershed. A Canadian Framework for Community Action*. Lake Huron Comunity Action (LHCA); Environment Canada. http://www.lakehuroncommunityaction.ca

Linke, S., Watts, M., Stewart, R., and Possingham, H.P. (2011). Using multivariate analysis to deliver conservation planning products that align with practitioner needs. *Ecography, 34*(2), 203-207. doi: 10.1111/j.1600-0587.2010.06351.x

Liskauskas, A., Johnson, J., McKay, M., Gorenflo, T., Woldt, A., and J., B. (2007). *Environmental Objectives for Lake Huron: A Report of the Environmental Objectives Working Group of the Lake Huron Technical Committee.* Great Lakes Fishery Commission.

Lockwood, M. (2010). Good governance for terrestrial protected areas: A framework, principles and performance outcomes. *Journal of environmental management, 91*(3), 754-766. doi: 10.1016/j.jenvman.2009.10.005

Lötter, M., Lieberknecht, L., Ardron, J.A., Wells, R., Ban, N.C., Nicolson, D.J., and Gerhartz, J.L. (2010). Reserve Design Considerations. In J.A. Ardron, H.P. Possingham and C.J. Klein (Eds.), *Marxan Good Practices Handbook, Version 2* (pp. 39-48). Victoria, BC Pacific Marine Analysis and Research Association.

Madenjian, C.P., Desorcie, T.J., McClain, J.R., Woldt, A.P., Holuszko, J.D., and Bowen II, C.A. (2004). Status of lake trout rehabilitation on Six Fathom Bank and Yankee Reef in Lake Huron. *North American Journal of Fisheries Management, 24*(3), 1003-1016.

Maller, C., Townsend, M., St Leger, L., Henderson-Wilson, C., Pryor, A., Prosser, L., and Moore, M. (2008). *Healthy Parks, Healthy People: The Health Benefits of Contact with Nature in a Park Context*. Deakin University, Melborne, Australia. Melborne, Australia. http://www.healthyparkshealthypeoplecongress.org/images/stories/hphp%20research.pdf

Mandrak, N.E. and Crossman, E.J. (1992). Postglacial dispersal of freshwater fishes into Ontario. *Can. J. Zool, 70*(11), 2247-2259. doi: 10.1139/z92-302

Manning, R.E. (2007). *Parks and Carrying Capacity. Commons without Tragedy*. Washington: Island Press.

McCook, L.J., Ayling, T., Cappo, M., Choat, J.H., Evans, R.D., De Freitas, D.M., Heupel, M., Hughes, T.P., Jones, G.P., Mapstone, B., Marsh, H., Mills, M., Molloy, F.J., Pitcher, C.R., Pressey, R.L., Russ, G.R., Sutton, S., Sweatman, H., Tobin, R., Wachenfeld, D.R., and Williamson, D.H. (2010). Adaptive management of the Great Barrier Reef: A globally significant demonstration of the benefits of networks of marine reserves. *Proceedings of the National Academy of Sciences of the United States of America, 107*(43), 18278-18285. doi: 10.1073/pnas.0909335107

McGinty, N., Power, A.M., and Johnson, M.P. (2012). Trophodynamics and stability of regional scale ecosystems in the Northeast Atlantic. *Ices Journal of Marine Science, 69*(5), 764-775. doi: 10.1093/icesjms/fss025

McLaughlin, C. and Krantzberg, G. (2011). An appraisal of policy implementation deficits in the Great Lakes. *Journal of Great Lakes Research, 37*(2), 390-396. doi: 10.1016/j.jglr.2011.03.014

McLaughlin, C. and Krantzberg, G. (2012). An appraisal of management pathologies in the Great Lakes. *Science of the Total Environment, 416*, 40-47. doi: 10.1016/j.scitotenv.2011.12.015

MEA. (2005). *Living Beyond Our Means: Natural Assets and Human Well-Being*. Millennium Ecosystem Assessment, Washington, D.C. Washington, D.C. http://www.maweb.org/

Mercier, F. and Mondor, C. (1995). *Sea to Sea: Canada's National Marine Conservation System Plan*. Ottawa.

Midwood, J.D. and Chow-Fraser, P. (2012). Changes in aquatic vegetation and fish communities following 5 years of sustained low water levels in coastal marshes of eastern Georgian Bay, Lake Huron. *Global Change Biology, 18*(1), 93-105. doi: 10.1111/j.1365-2486.2011.02558.x

Millerd, F. (2011). The potential impact of climate change on Great Lakes international shipping. *Climatic Change, 104*(3-4), 629-652. doi: 10.1007/s10584-010-9872-z

Mills, E.L., Leach, J.H., Carlton, J.T., and Secor, C.L. (1993). Exotic species in the Great Lakes - A history of biotic crises and anthropogenic introductions. *Journal of Great Lakes Research, 19*(1), 1-54.

Minns, C.K., Kelso, J.R.M., and Randall, R.G. (1996). Detecting the response of fish to habitat alterations in freshwater ecosystems. *Canadian Journal of Fisheries and Aquatic Sciences, 53*, 403-414.

Montgomery, D.C. (2012). *Introduction to Statistical Quality Control. Seventh edition.* New York, New York, USA: John Wiley and Sons.

Morrison, L.W. (2008). The use of control charts to interpret environmental monitoring data. *Natural Areas Journal, 28*, 66-73.

Mortsch, L., Ingram, J., Hebb, A., and Doka, S. (Eds.). (2006). *Great Lakes Coastal Wetlands Communities: Vulnerabilites to Climate Change and Response to Adaptation Strategies*: Environment Canada.

Mumby, P.J., Dahlgren, C.P., Harborne, A.R., Kappel, C.V., Micheli, F., Brumbaugh, D.R., Holmes, K.E., Mendes, J.M., Broad, K., Sanchirico, J.N., Buch, K., Box, S., Stoffle, R.W., and Gill, A.B. (2006). Fishing, trophic cascades, and the process of grazing on coral reefs. *Science, 311*(5757), 98-101. doi: 10.1126/science.1121129

Munawar, M., Munawar, I.F., Dermott, R., Johannssen, O.E., Lynn, D., Munawar, S.F., and Niblock, H. (2003). An Integrated Assessment of the Ecosystem Health of a Protected Area: Fathom Five National Marine Park, Lake Huron. *Aquatic Ecosystem Health & Management, 6*(2), 185 - 204.

Myers, R.A. and Worm, B. (2003). Rapid worldwide depletion of predatory fish communities. *Nature, 423*(6937), 280-283. doi: 10.1038/nature01610

Nadasdy, P. (2007). Adaptive co-management and the gospel of resilience. In D. Armitage, F. Berkes and N. Doubleday (Eds.), *Adaptive Co-Management: Collaboration, Learning, and Multi-Level Governance* (pp. 208-227). Vancouver, BC: UBC Press.

Nalepa, T.F., Fanslow, D.L., Pothoven, S.A., Foley, A.J., and Lang, G.A. (2007). Long-term trends in benthic macroinvertebrate populations in lake huron over the past four decades. *Journal of Great Lakes Research, 33*(2), 421-436. doi: 10.3394/0380-1330(2007)33[421:ltibmp]2.0.co;2

Nalepa, T.F., Pothoven, S.A., and Fanslow, D.L. (2009). Recent changes in benthic macroinvertebrate populations in Lake Huron and impact on the diet of lake whitefish (*Coregonus clupeaformis*). *Aquatic Ecosystem Health & Management, 12*(1), 2 - 10.

NASA. (2011). OceanColor Web. Retrieved June 12, 2011 http://oceancolor.gsfc.nasa.gov/

National Research Council. (2001). *Marine protected areas: tools for sustaining ocean ecosystems*. Washington, D.C.: National Academy Press.

Nel, J.L., Roux, D.J., Abell, R., Ashton, P.J., Cowling, R.M., Higgins, J.V., Thieme, M., and Viers, J.H. (2009). Progress and challenges in freshwater conservation planning. *Aquatic Conservation: Marine and Freshwater Ecosystems, 19*(4), 474-485.

Noss, R.F. (1990). Indicators for Monitoring Biodiversity: A Hierarchical Approach. *Conservation Biology, 4*(4), 355-364.

NPS Advisory Board. (2012). *Revisting Leopold: Resource Stewardship in the National Parks*. The National Park System Advisory Board, Science Comittee, Washington, DC. Washington, DC

OAG. (2005). *Report of the Commissioner of the Environment and Sustainable Development to the House of Commons. Chapter 2, Ecological Integrity in Canada's National Parks*. Office of the Auditor General of Canada, Ottawa, Ontario. Ottawa, Ontario

OAG. (2012). *Report of the Commissioner of the Environment and Sustainable Development. Chapter 3 Marine Protected Areas*. Office of the Auditor General of Canada, Ottawa, Ontario. Ottawa, Ontario. www.oag-bvg.gc.ca

Odum, W.E., Odum, E.P., and Odum, H.T. (1995). Nature's pulsing paradigm. *Estuaries, 18*(4), 547-555.

Olds, A.D., Connolly, R.M., Pitt, K.A., and Maxwell, P.S. (2012). Habitat connectivity improves reserve performance. *Conservation Letters, 5*(1), 56-63. doi: 10.1111/j.1755-263X.2011.00204.x

Olsson, P. (2007). The role of vision in framing adaptive co-management processes: lessons from Kritianstads Vattenrike, southern Sweden. In D. Armitage, F. Berkes and N. Doubleday (Eds.), *Adaptive Co-Management: Collaboration, Learning, and Multi-Level Governance* (pp. 268-285). Vancouver, BC: UBC Press.

Olsson, P., Folke, C., and Hughes, T.P. (2008). Navigating the transition to ecosystem-based management of the Great Barrier Reef, Australia. *Proceedings of the National Academy of Sciences of the United States of America, 105*(28), 9489-9494. doi: 10.1073/pnas.0706905105

Olsson, P., Gunderson, L.H., Carpenter, S.R., Ryan, P., Lebel, L., Folke, C., and Holling, C.S. (2006). Shooting the rapids: Navigating transitions to adaptive governance of social-ecological systems. *Ecology and Society, 11*(1(18)). http://www.ecologyandsociety.org/vol11/iss1/art18/

OMNR. (2010). *Review of Lake Trout Rehabilitation Efforts in Canadian Waters of Lake Huron, 1974 to 2006*. Ontario Ministry of Natural Resources, Upper Great Lakes Managment Unit, Lake Huron Office, Owen Sound, ON. Owen Sound, ON

Ontario. (2006). Provincial Parks and Conservation Reserves Act, 2006, S.O. 2006, Ch. 12. http://www.e-laws.gov.on.ca/

Ontario. (2011). *Ontario Population Projections Update. 2010-1036 Ontario and Its 49 Census Divisions*. Ministry of Finance.

Ontario. (2012). *Ontario's Great Lakes Strategy*. Ontario Ministry of the Environment. Ontario.ca/environment

Ontario Superior Court of Justice. (1994). Statement of Claim. Between Chippewas of Nawash Unceded First Nation and Saugeen First Nation (Plaintiffs) and The Attorney General of Canada and Her Majesty the Queen in Right of Ontario. Court File No. 94-CQ-50872, ammended Court File No. 03-CV-26113-CMI.

Orpin, A.R. and Kostylev, V.E. (2006). Towards a statistically valid method of textural sea floor characterization of benthic habitats. *Marine Geology, 225*(1-4), 209-222. doi: 10.1016/j.margeo.2005.09.002

OSTC. (2011). *Owen Sound Transportation Company, Limited. 2009/2010 Annual Report*. Owen Sound Transportation Company, Owen Sound. Owen Sound

Pandian, P.K., Ruscoe, J.P., Shields, M., Side, J.C., Harris, R.E., Kerr, S.A., and Bullen, C.R. (2009). Seabed habitat mapping techniques: an overview of the performance of various systems. *Mediterranean Marine Science, 10*(2), 29-43.

Parker, S. and Munawar, M. (Eds.). (2001). *Ecology, culture and conservation of a protected area: Fathom Five National Marine Park, Canada*. Leiden: Backhuys.

Parker, S.R. (1998). Boundary analysis of Fathom Five National Marine Park. *Linking Protected Areas with Working Landscapes Conserving Biodiversity. Proceedings of the Third International Conference on Science and Management of Protecetd Areas, 12-16 May 1997*, 198-205.

Parks Canada. (1994). *Guiding Principles and Operational Policies*. Parks Canada, Hull, Quebec. Hull, Quebec

Parks Canada. (1998). *Fathom Five National Marine Park Management Plan*. Ottawa: Parks Canada.

Parks Canada. (2008). *Parks Canada Guide to Management Planning*. Ottawa: Parks Canada.

Parks Canada. (2011). *Fathom Five National Marine Park of Canada: State of the Park Report 2010*. Parks Canada, Gatineau, Quebec. Gatineau, Quebec. http://www.pc.gc.ca/eng/amnc-nmca/on/fathomfive/plan.aspx

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., and Torres, F. (1998). Fishing down marine food webs. *Science, 279*(5352), 860-863.

Peterson, G., Allen, C.R., and Holling, C.S. (1998). Ecological resilience, biodiversity, and scale. *Ecosystems, 1*(1), 6-18.

Peterson, G.D., Cumming, G.S., and Carpenter, S.R. (2003). Scenario planning: a tool for conservation in an uncertain world. *Conservation Biology, 17*(2), 358-366.

Pettersson, M. (1998). Monitoring a freshwater fish population: statistical surveillance of biodiversity. *Environmetrics, 9*(2), 139-150. doi: 10.1002/(SICI)1099-095X(199803/04)9:2<139::AID-ENV291>3.0.CO;2-3

Pimm, S.L. (1984). The complexity and stability of ecosystems. *Nature, 307*(5949), 321-326.

Pittock, J., Hansen, L.J., and Abell, R. (2008). Running dry: freshwater biodiversity, protected areas and climate change. *Biodiversity, 9 (3&4)*, 30-38.

Pomeroy, R.S., Parks, J.E., and Watson, L.M. (2004). *How is your MPA doing? A Guidebook of Natural and Social Indicators for Evaluating Marine Protected Area Management Effectiveness*. IUCN, Gland, Switzerland and Cambridge, UK. Gland, Switzerland and Cambridge, UK

Prato, T. (2006). Adaptive management of national park ecosystems. *The George Wright Forum, 23(1)*, 72-86.

R Development Core Team. (2011). R: A Language and Environment for Statistical Computing. http://www.R-project.org

Reid, D.M., Anderson, D.M., and Henderson, B.A. (2001). Restoration of lake trout in Parry Sound, Lake Huron. *North American Journal of Fisheries Management, 21*(1), 156-169.

Resilience Alliance. (2010). *Assessing Resilience in Social-Ecological Systems: Workbook for Practitioners, Version 2.0*. http://www.resalliance.org/

Ricciardi, A. (2006). Patterns of invasion in the Laurentian Great Lakes in relation to changes in vector activity. *Diversity and Distributions, 12*(4), 425-433. doi: 10.1111/j.1366-9516.2006.00262.x

Riley, S.C., Roseman, E.F., Adams, J.V., O'Brien, T.P., and Farha, S.A. (2010). *Status and Trends of the Lake Huron Offshore Demersal Fish Community, 1976-2009*. Presented at the Great Lakes Fishery Commission Lake Huron Committee Meeting, Windsor, Ontario, 22 March 2010.

Roberts, C.M., Andelman, S., Branch, G., Bustamante, R.H., Castilla, J.C., Dugan, J., Halpern, B.S., Lafferty, K.D., Leslie, H., Lubchenco, J., McArdle, D., Possingham, H.P., Ruckelshaus, M., and Warner, R.R. (2003). Ecological criteria for evaluating candidate sites for marine reserves. *Ecological Applications, 13*(1), S199-S214.

Roseman, E.F., Schaeffer, J.S., and Steen, P.J. (2009). Review of fish diversity in the Lake Huron basin. *Aquatic Ecosystem Health & Management, 12*(1), 11 - 22.

Saunders, D.L., Meeuwig, J.J., and Vincent, A.C.J. (2002). Freshwater Protected Areas: Strategies for Conservation. *Conservation Biology, 16*(1, pp. 30-41), February.

Scheffer, M. (2009). *Critical transitions in nature and society*. Princeton, New Jersey: Princeton University Press.

Scheffer, M., Bascompte, J., Brock, W.A., Brovkin, V., Carpenter, S.R., Dakos, V., Held, H., van Nes, E.H., Rietkerk, M., and Sugihara, G. (2009). Early-warning signals for critical transitions. *Nature*, *461*(7260), 53-59. doi: 10.1038/nature08227

Scheffer, M., Carpenter, S., Foley, J.A., Folke, C., and Walker, B. (2001). Catastrophic shifts in ecosystems. *Nature*, *413*(6856), 591-596.

Scheffer, M. and Carpenter, S.R. (2003). Catastrophic regime shifts in ecosystems: linking theory to observation. *Trends in Ecology & Evolution*, *18*(12), 648-656. doi: 10.1016/j.tree.2003.09.002

Scholz, A., Steinback, C., and Mertens, M. (2006). *Commercial fishing grounds and their relative importance off the Central Coast of California*. Report to the California Marine Life Protection Act Initiative. Ecotrust.

Seilheimer, T.S. and Chow-Fraser, P. (2007). Application of the Wetland Fish Index to Northern Great Lakes Marshes with Emphasis on Georgian Bay Coastal Wetlands. *Journal of Great Lakes Research*, *33*(Journal Article), 154-171.

Sellinger, C.E., Stow, C.A., Lamon, E.C., and Qian, S.S. (2008). Recent water level declines in the Lake Michigan-Huron system. *Environmental Science & Technology, 42*(2), 367-373. doi: 10.1021/es070664+

Sierszen, M.E., Morrice, J.A., Trebitz, A.S., and Hoffman, J.C. (2012). A review of selected ecosystem services provided by coastal wetlands of the Laurentian Great Lakes. *Aquatic Ecosystem Health & Management, 15(1)*, 92-106.

Sloan, N.A. (2004). Northern abalone: using an invertebrate to focus marine conservation ideas and values. *Coastal Management, 32*(2), 129-143. doi: 10.1080/08920750490276128

Slocombe, D.S. (1990). Assessing Transformation and Sustainability in the Great Lakes Basin. *GeoJournal*(21.3), 252-272.

Sly, P.G. and Munawar, M. (1988). Great Lake Manitoulin - Georgian Bay and the North Channel. *Hydrobiologia, 163*, 1-19.

Smith, G.R. and Todd, T.N. (1984). Evolution of species flocks of fishes in north temperate lakes. In A.A. Echelle and I. Kornfield (Eds.), *Evolution of Fish Species Flocks* (pp. 45-68): University of Maine Press, Orono.

Smith, P.G.R., Glooschenko, V., and Hagen, D.A. (1991). Coastal wetlands of three Canadian Great Lakes: inventory, conservation initiatives and patterns of variation. *Canadian Journal of Fisheries and Aquatic Sciences*, *48*(8), 1581-1594. doi: 10.1139/f91-187

SOLEC. (2009). *State of the Great Lakes 2009*. U.S. Environmental Protection Agency and Environment Canada. http://binational.net/solec/intro_e.html

Stabler, C., Parker, S., Vis, C., and Harpur, C. (Eds.). (2011). *Technical Compendium to the State of the Park Report 2010 Fathom Five National Marine Park.* .

Strayer, D.L. and Dudgeon, D. (2010). Freshwater biodiversity conservation: recent progress and future challenges. *Journal of the North American Benthological Society, 29*(1), 344-358. doi: 10.1899/08-171.1

Strecker, A.L., Casselman, J.M., Fortin, M.-J.e., Jackson, D.A., Ridgway, M.S., Abrams, P.A., and Shuter, B.J. (2011). A multi-scale comparison of trait linkages to environmental and spatial variables in fish communities across a large freshwater lake. *Oecologia*. doi: 10.1007/s00442-011-1924-1

Suski, C. and Cooke, S. (2007). Conservation of aquatic resources through the use of freshwater protected areas: opportunities and challenges. *Biodiversity and Conservation, 16*(7), 2015-2029.

ter Braak, C.J.F. (1994). Canonical community ordination. Part I: Basic theory and linear methods. *Ecoscience, 1*(2), 127-140.
Thomas, L. and Middleton, J. (2003). *Guidelines for Management Planning of Protected Areas*. IUCN, Gland, Switzerland and Cambridge, UK. Gland, Switzerland and Cambridge, UK
Thrush, S.F., Hewitt, J.E., Dayton, P.K., Coco, G., Lohrer, A.M., Norkko, A., Norkko, J., and Chiantore, M. (2009). Forecasting the limits of resilience: integrating empirical research with theory. *Proceedings of the Royal Society B-Biological Sciences, 276*(1671), 3209-3217. doi: 10.1098/rspb.2009.0661
Toffler, A. (1970). *Future Shock*: Random House.
Trebitz, A.S. (2006). Characterizing seiche and tide-driven daily water level fluctuations affecting coastal ecosystems of the Great Lakes. *Journal of Great Lakes Research, 32*(1), 102-116.
Trebitz, A.S., Brazner, J.C., Brady, V.J., Axler, R., and Tanner, D.K. (2007). Turbidity tolerances of Great Lakes coastal wetland fishes. *North American Journal of Fisheries Management, 27*(2), 619-633. doi: 10.1577/m05-219.1
Trebitz, A.S. and Taylor, D.L. (2007). Exotic and invasive aquatic plants in great lakes coastal wetlands: Distribution and relation to watershed land use and plant richness and cover. *Journal of Great Lakes Research, 33*(4), 705-721. doi: 10.3394/0380-1330(2007)33[705:eaiapi]2.0.co;2
Turgeon, J. and Bernatchez, L. (2003). Reticulate evolution and phenotypic diversity in North American ciscoes, Coregonus ssp. (Teleostei: Salmonidae): implications for the conservation of an evolutionary legacy. *Conservation Genetics, 4*, 67-81.
UNESCO. (2005). *Towards Knowledge Societies*. United Nations Educational, Scientific and Cultural Organization, Paris. Paris. http://www.unesco.org/publications/
United Nations. (1992). *Convention on Biological Diversity*. Rio de Janeiro. Rio de Janeiro. http://www.cbd.int/
United Nations. (2002, 26 August - 4 September, 2002). *Report of the World Summit on Sustainable Development*, Johannesburg, South Africa.
Upton, S. and Ibrahim, M. (2012). *Resilience in Practice*. Practical Action.
USGS. (2008). Application of Wind Fetch and Wave Models for Habitat Rehabilitation and Enhancement Projects. Retrieved November 15, 2011, from http://www.umesc.usgs.gov/management/dss/wind_fetch_wave_models.html
Vanderploeg, H.A., Liebig, J.R., Nalepa, T.F., Fahnenstiel, G.L., and Pothoven, S.A. (2010). Dreissena and the disappearance of the spring phytoplankton bloom in Lake Michigan. *Journal of Great Lakes Research, 36*, 50-59. doi: 10.1016/j.jglr.2010.04.005
Villa, F., Tunesi, L., and Agardy, T. (2002). Zoning marine protected areas through spatial multiple-criteria analysis: the case of the Asinara Island National Marine Reserve of Italy. *Conservation Biology, 16*(2), 515-526.
Walker, B., Holling, C.S., Carpenter, S.R., and Kinzig, A. (2004). Resilience, adaptability and transformability in social-ecological systems. *Ecology and Society, 9*(2(5)). http://www.ecologyandsociety.org/vol9/iss2/art5/
Walker, B. and Salt, D. (2006). *Resilience Thinking: Sustaining Ecosystems and People in a Changing World*. Washington, DC: Island Press.
Walker, B. and Salt, D. (2012). *Resilience Practice. Building Capacity to Absorb Disturbance and Maintain Function*. Washington, DC: Island Press.

Wang, J., Bai, X.Z., Hu, H.G., Clites, A., Colton, M., and Lofgren, B. (2012). Temporal and spatial variability of Great Lakes ice cover, 1973-2010. *Journal of Climate, 25*(4), 1318-1329. doi: 10.1175/2011jcli4066.1

Wangchuk, S. (2007). Maintaining ecological resilience by linking protected areas through biological corridors in Bhutan. *International Society for Tropical Ecology, 48(2),* 176-187.

Wardekker, J.A., de Jong, A., Knoop, J.M., and van der Sluijs, J.P. (2010). Operationalising a resilience approach to adapting an urban delta to uncertain climate changes. *Technological Forecasting and Social Change, 77*(6), 987-998. doi: 10.1016/j.techfore.2009.11.005

Warner, D.M., Schaeffer, J.S., and O'Brien, T.P. (2009). The Lake Huron pelagic fish community: persistent spatial pattern along biomass and species composition gradients. *Canadian Journal of Fisheries and Aquatic Sciences, 66*(8), 1199-1215. doi: 10.1139/f09-072

Watts, M.E., Ball, I.R., Stewart, R.S., Klein, C.J., Wilson, K., Steinback, C., Lourival, R., Kircher, L., and Possingham, H.P. (2009). Marxan with Zones: Software for optimal conservation based land- and sea-use zoning. *Environmental Modelling & Software, 24*(12), 1513-1521.

Watts, M.E., Klein, C.K., Stewart, R., Ball, I.R., and Possingham, H.P. (2008a). *Marxan with Zones (v1.0.1): Conservation Zoning using Spatially Explicit Annealing*. http://www.uq.edu.au/marxan/docs/Marxan_with_Zones_User_Manual_v101.pdf

Watts, M.E., Steinback, C., and Klein, C. (2008b). *User Guide: Applying Marxan with Zones, North central coast of California marine study*.

Wei, A. and Chow-Fraser, P. (2007). Use of IKONOS Imagery to Map Coastal Wetlands of Georgian Bay. *Fisheries, 32*(4), 167-173.

Wells, M. and Parker, S. (2010). The thermal variability of the waters of Fathom Five National Marine Park, Lake Huron. *Journal of Great Lakes Research, 36(3),* 570-576.

Werhum, L.A. (1994). *The role of interest groups in the creation of Fathom Five National Marine Park and Bruce National Park.* (MA), University of Waterloo, Waterloo, Ontario.

Westley, F. (1995). Governing Design: The Management of Social Systems and Ecosystem Management. In L.H. Gunderson, C.S. Holling and S.S. Light (Eds.), *Barriers and Bridges to the Renewal of Ecosystem and Institutions* (pp. 391-427). New York: Columbia University Press.

Wichert, G.A., Brodribb, K.E., Henson, B.L., and Phair, C. (2005). *Great Lakes Conservation Blueprint for Aquatic Biodiversity: Volume 1*. Nature Conservancy of Canada and Ontario Ministry of Natural Resources.

Wilcox, D.A. and Jerrine Nichols, S. (2008). The effects of water-level fluctuations on vegetation in a Lake Huron wetland. *Wetlands, 28*(2), 487-501.

Wilcox, D.A., Thompson, T.A., Booth, R.K., and Nicholas, J.R. (2007). *Lake-level variability and water availability in the Great Lakes*. Reston, Virginia. Reston, Virginia

Wilkes, D. (2001). An overview of Canada's first national marine park. In S. Parker and M. Munawar (Eds.), *Ecology, Culture and Conservation of a Protected Area: Fathom Five National Marine Park, Canada* (pp. 13-24). Leiden, The Netherlands: Backhuys Publishers.

World Ocean Conference. (2009). *Manado Ocean Declaration.*, World Ocean Conference. May 14, 2009, Manado, Indonesia. Manado, Indonesia. http://www.iucn.org/
Yurick, D. (2010). National Marine Conservation Areas - Extending Parks Canada's Reach into Canada's Oceans and Great Lakes. *The George Wright Forum*, *27(2)*, 170-179.
Zimmerman, M.S. and Krueger, C.C. (2009). An Ecosystem Perspective on Re-establishing Native Deepwater Fishes in the Laurentian Great Lakes. *North American Journal of Fisheries Management*, *29*(5), 1352-1371. doi: 10.1577/m08-194.1
Zolli, A. and Healy, A.M. (2012). *Resilience, Why Things Bounce Back*. New York, NY: Free Press.