"An Integrative Approach to Prioritizing and Restoring Aquatic Habitat Connectivity in a National Park Setting: the Case of Kejimkujik"

By

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ABSTRACT

"An Integrative Approach to Prioritizing and Restoring Aquatic Habitat Connectivity in a National Park Setting: the Case of Kejimkujik"

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Abstract: In recent years, the degree of connectivity between and amongst aquatic ecosystems has been subject to increased anthropogenic alteration and disturbance, causing restricted access to suitable habitat and in some cases leading to complete biotic isolation. This phenomenon, known as aquatic habitat fragmentation is often caused by improperly functioning structures such as road culverts, bridges, and dams. Regrettably, infrastructure development, management, and land use decisions continue in the absence of adequate information on hydrologic connectivity, likely because a standardized and well-defined protocol for assessing aquatic connectivity does not currently exist. Although scoring and ranking methods have been used to assess and restore integrity at a single barrier structure, the cumulative effects of multiple barriers are rarely considered and are poorly understood because methods are not available to measure their effects. Attempting to help fill this void,this thesis applied a Parks Canada optimization model developed by Cote et al., (2009) called the Dendritic Connectivity Index (DCI). This model helped to assess the connectivity status of the aquatic ecosystem at Kejimkujik National Park through the identification of barriers restricting fish movement and fragmenting the landscape. This connectivity information was then applied to help develop a of a prioritization scheme that maximized ecosystem benefit by assessing the cumulative impact of multiple barriers, therefore helping park management make better informed decisions.

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Chapter 1

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Water of suitable quality and quantity is essential to all life. It shapes and beautifies the landscape, controls climate, determines the nature of the surrounding environment, and provides a wide range of interconnected habitat. However, in our rapidly developing world, the degree of connectivity between and amongst aquatic ecosystems has been subject to increased anthropogenic alteration/disturbance, causing restricted access to suitable habitat and in some cases leading to complete biotic isolation (Fagan, 2002; Eikass & McIntosh, 2006; Freeman *et al*., 2007; Parks Canada, A, 2010). This phenomenon, known as aquatic habitat fragmentation, is often caused by improperly functioning structures such as road culverts, bridges, and dams.

Although the topic of aquatic connectivity has received increased attention over the past decade (Fullerton *et al*., 2010), many gaps in the literature exist as noted in Fausch *et al*., (2002). For example, although many studies have successfully identified barriers to aquatic organism movement (Forest Practices Board, 2009; Poplar-Jeffers *et al*., 2009; Argent & Kimmel, 2010; Parks Canada, B, 2010) and attempted to restore function of a single structure, very few have prioritized and addressed restoration initiatives at a watershed scale attempting to maximize ecosystem benefit (Kemp & O'Hanley, 2010). This thesis will aim towards the development and implementation of an integrative approach to prioritizing and restoring aquatic habitat connectivity in Kejimkujik National Park and National Historic Site of Canada using brook trout (*Salvelinus fontinalis*) as the indicator species.

1.2 Aquatic Connectivity and Fragmentation

"The concept of connectivity underlies many core questions in ecology because it defines linkages among ecosystem elements in space and time" (Fullerton *et al*., 2010; p. 2216). Connectivity is a critical component of freshwater ecosystem health that affects population size (Preston, 1962), productivity (Dryden & Stein, 1975; Baker & Votapka, 1990; Stanford *et al*., 1996), species composition (Sheldon, 1987, Sheldon, 1988), extinction risk (Dunham *et al*., 1997; Fagan *et al*., 2002; Morita & Yamamoto, 2002), genetic stability (Morita & Yamamoto, 2002), morphological characteristics (Reznick, 1982; Crossin *et al*., 2004), life history (Dingle, 1996) and the ability of biota to recover from disturbance (Stanford *et al*., 1996). Regrettably, infrastructure development, management, and land use decisions are often made in the absence of adequate information on hydrologic connectivity, leading to fragmentation of important aquatic habitats (Pringle, 2003; Eikass & McIntosh, 2006; Cote, 2009).

Habitat fragmentation is understood to be a process during which “a large expanse of habitat is transformed into a number of smaller patches of smaller total area, isolated from each other by a matrix of habitats unlike the original” (Wilcove *et al*., 1986; p. 238). This phenomenon becomes problematic for many species, including brook trout and other fish species that require high levels of connectivity to move throughout a watershed to access feeding grounds, suitable water quality, spawning areas, and summer refuge areas at different times in their lifecycle (Corbett *et al*., 2007; Brunt, 2011). The identification of structures responsible for causing aquatic habitat fragmentation (referred to as aquatic barriers) will be further discussed in Section 1.5.

Although decades of research have highlighted the critical importance of habitat connectivity in ecology and conservation within terrestrial ecosystems, little of this work has touched upon aquatic ecosystems (Cote *et al*., 2009; Fullerton et al., 2010). This is surprising, considering the fact that landscape and riverine ecology share many attributes (Benda *et al*., 2004) including the concept of connectivity (Wiens, 2002, Cote *et al*., 2009). This is likely due to the fact that it is a difficult concept to explore given the high spatial and temporal complexities of riverine systems (Fullerton *et al*., 2010).

The literature indicates that at present, there is an absence of a clear, well-defined protocol for determining the overall connectivity status of a riverine system (Kemp & O’Hanley, 2010). Moreover, it becomes apparent that in many studies, including that of

Poplar-Jeffers *et al*. (2009), the identification of dispersal barriers (section 1.5) is not a 'clear cut' or well-defined process. Finally, the prioritization of restoration initiatives often deals with site-specific barrier remediation, completely overlooking the spatial and temporal complexities of the aquatic system and the life cycle stages of the species in question (Kemp & O'Hanley, 2010).

Recognizing that Kejimkujik National Park and National Historic Site of Canada has identified freshwater development and aquatic fragmentation as significant threats to ecological integrity (Parks Canada, B, 2010), this thesis will aid in developing/fine-tuning an approach to assess the aquatic connectivity status of the Park through the identification of fish passage barriers responsible for fragmenting the landscape. Furthermore, it will aid in the development of a prioritization scheme that maximizes ecosystem benefit by assessing the cumulative impact of multiple barriers.

1.3 Brook Trout (*Salvelinus fontinalis*) Habitat Requirements

Brook trout (*Salvelinus fontinalis*) are native to eastern North America (Menendez, 1976; Raleigh, 1982). Their extensive distribution throughout the Atlantic Provinces makes them one of the most preferred fish for anglers. The abundance and distribution of brook trout throughout eastern North America is strongly influenced by both quality of aquatic habitat and state or provincial management practices (Minns, 2001; Armstrong *et al*., 2003). Due to the species wide ranging movement throughout a watershed, and the array of specific habitat requirements outlined below, brook trout are often used as an environmental indicator providing insight into the overall health of an aquatic ecosystem. Throughout this thesis brook trout will be used as the indicator species to determine the aquatic connectivity status of Kejimkujik, and the success of restoration efforts within this National Park.

Habitat is understood to be the range of physical and chemical factors affecting an animal (Armstrong et al., 2003). According to Armstrong *et al*. (2003), “these factors are those considered to be acting in the immediate vicinity of the animal” (p.144). In reality, factors may result from processes that impinge across a broad range of scales and therefore when considering habitat management and/or restoration, water quality, water quantity and physical structure of the riverine environment must be taken into account. The literature suggests that management and/or restoration practices to resolve problems in just one of these areas will often be ineffective due to the interrelated and complex nature of aquatic systems (Naiman *et al.*, 1992; National Research Council, 1992; Armstrong *et al.*, 2003).

According to Raleigh, (1982), optimal brook trout habitat is characterized by clear, cold spring-fed water; a suitable dissolved oxygen content and pH range; a silt free rocky substrate in riffle-run areas; an approximate 1-1 pool-riffle ratio with areas of slow, deep water; well vegetated stream banks; abundant in-stream cover; and relatively stable water flow, temperature regimes, and stream banks. Spawning typically occurs in streams with temperatures ranging from 4.5-10 ^{o}C; however, it is not uncommon for spawning to occur in gravels surrounding cold groundwater upwelling in lakes and ponds (Raleigh, 1982).

The literature consistently states that temperature, dissolved oxygen (D.O.) content, and pH are among the most important water quality factors limiting brook trout distribution and production (Menendez, 1976; Raleigh, 1982; Armstrong *et al*., 2003). Although many specific variables exist when considering brook trout habitat (some of which will be mentioned briefly), pH, D.O., and temperature alone provide good insight into the overall state and habitat availability of an aquatic system. For example, pH will typically indicate local geological structure (buffering capacity), degree of acid rain, as well as chemical contamination. D.O. is an excellent indicator of organic substance concentration, water velocity, and pool-riffle ratios. Finally, temperature is an excellent indicator of forest cover, ground water input and water depth. Hendry *et al* (2003) suggests the inter-related components of aquatic habitats should be viewed as a continuum and in fact, it will be necessary to share this view in order to properly quantify the importance of these three variables.

Laboratory studies and individual research have proposed a wide range of tolerable pH ranges on both extremes. However, the literature indicates that the optimal pH range for brook trout appears to be 6.5-8.0 with a tolerance range of 4.0-9.5 (with few exceptions) (Daye & Garside, 1975; Raleigh, 1982; Hendry *et al*., 2003).

In terms of tolerance, upper and lower temperature limits for brook trout vary. Raleigh, (1982) indicates that this may be a reflection of local and regional population acclimation differences. The general consensus indicates that the tolerable temperature range for brook trout is 0-24^{o} C with an optimal range for growth and survival of 11-16 ^{o} C (Raleigh, 1982; Hendry *et al*., 2003). It has been suggested however, that populations are more subject to disease where temperatures exceed 20 ^{o} C for prolonged periods of time (Raleigh, 1982, Rutherford, 2007). Therefore, trout will move within the watershed to find optimum temperature conditions rather than tolerate stressful levels (Rutherford, 2007). It has been indicated that the size of summer cold water refuges, in areas of springs or below thermoclines, often become limiting factors on the size of the population (Rutherford, 2007). This idea however, is assuming trout can easily assess these refuge areas without movement restrictions (as will be discussed below).

Dissolved oxygen concentrations also exhibit a wide range of acceptable limits however the direct relationship with temperature explains this variation to some extent. For example, an increase in temperature causes the dissolved oxygen saturation level to decrease (and *vice versa*). At the same time, this increase in temperature (decreasing D.O. saturation) also increases D.O. requirements for the trout (Raleigh, 1982). Due to this relationship, optimum D.O. levels for Brook trout are characterized by specific water temperature and appear to be $\geq$7 mg/l at temperatures < 15 ^{o} C and $\geq$ 9 mg/l at temperatures $\geq$ 15 ^{o} C (Raleigh, 1982).

It is important to note that brook trout can often survive close to the tolerance limits but stress is experienced when values fall outside of the optimum range (Raleigh, 1982; Rutherford, 2007). This stress on the fish will often decrease productivity and alter feeding habits, therefore brook trout are known to move within the system in order to occupy water bodies with the most suitable balance between variables (McCormick *et al*., 1972; Menendez, 1976; Riley, 1992; Abraham, 2006; Hartman & Logan, 2010). Examples of such movement have been well documented through programs including Kejimkujik National Park's fish tagging and creel census studies (Corbett, 2007; Parks Canada, B, 2010). In some instances, as seen with tag number 3669, movement has exceeded 25 km in one season, demonstrating the widespread movement of the species (Brunt, 1989). This ability to move within the system is critically dependent on the connectivity status of the aquatic environment in question (McCleary et al., 2006; Hicks & Sullivan, 2008) therefore highlighting the importance of aquatic connectivity/fragmentation research.

1.4 Brook Trout (*Salvelinus fontinalis*) Swimming Capabilities

As mentioned above, brook trout require a very specific set of habitat requirements, and move within a system to occupy areas with the most suitable balance between variables (McCormick *et al*., 1972; Menendez, 1976; Riley, 1992; Abraham, 2006; Hartman & Logan, 2010). While navigating a system and attempting to satisfy their biological needs, fish must successfully traverse an ever-changing set of migratory obstacles and barriers. During the upstream phase of movement, it is not uncommon for fish to encounter water velocities that come close to or exceed their maximum sustainable swim speeds (Cote *et al*., 2005; Castro-Santos, 2006). Velocity barriers and/or obstacles occur naturally and may include falls, rapids, or stream stretches with high slope ($\geq$ 5%). They may also be anthropogenic in origin and can include culverts, dams and poorly designed/malfunctioning fishways (Castro-Santos, 2006).

In order to properly understand the reasons behind the ability or inability of a fish to overcome movement obstacles and barriers, one must examine the swimming capabilities of the species in question. As outlined by Peake *et al*. (1997), the three general categories of fish swimming behavior include sustained, burst, and prolonged speeds. Sustained swimming occurs at relatively low speeds, allowing individuals to maintain sustained swimming velocities for long periods ($\geq$200 minutes) without becoming fatigued (Beamish, 1978). In this report, sustained swim speed is understood to be < 0.5 m/s for an indefinite period of time. Burst swimming involves a species maintaining relatively high swim speeds for 15-20 seconds after which they become exhausted (Beamish, 1978). Burst speed for brook trout in this report will be 0.93 m/s for 20 seconds. Finally, prolonged swimming is said to cover a spectrum of velocities between sustained and burst (Peake *et al*., 1997). The accepted value for prolonged speed here will be 0.5 m/s for 200 minutes.

It is important to note that the literature suggests a wide range of swimming performances for brook trout, as controlled laboratory conditions do not always mimic conditions in the natural environment (Peake *et al*., 1997; Castro-Santos, 2004; Peake & Farrell 2006). This research has chosen to adopt and accept the values (stated above) commonly agreed upon by all five Atlantic National Parks taking part in the Parks Canada Aquatic Connectivity Restoration Initiative. These values are suggestions from the most recent literature (Peake, 2007), and have been accepted by fish biologists and hydrologists within Parks Canada Agency.

1.5 Identifying Fish Movement Barriers:

Brook trout require a high level of aquatic connectivity in order to satisfy their biological and physical needs. Because infrastructure development decisions continue to be made in the absence of adequate hydrologic information (Eikass & McIntosh, 2006), connectivity and continuity of aquatic systems have been increasingly disrupted (Cote *et al*. 2005) by improperly functioning structures such as bridges, dams and culverts. For the purposes of this thesis, road culverts will be the aquatic barrier in question while bridges and dams will receive little attention due to the scope of the project.

Culverts are the economical method for crossing and redirecting small water bodies when building roads (Forest Practices Board, 2009). According to Peake (2007), culvert designs and installation practices have been developed with little consideration of swimming/ jumping capabilities or the physiology of fish. Moreover, fish behavior and performance information in relation to culvert passage is scarce in the literature (Cote *et al*., 2005). Finally, according to Peake (2007), “little effort has been made to synthesize existing information into a predictive tool for assessing the degree to which particular culvert installations might be impacting ecosystem connectivity”, (p 2). Helping to address and overcome these issues in a way that can be widely applied, is one of the targeted outcomes of this thesis and the Parks Canada Aquatic Connectivity Initiative.

Many reasons exist for the underachievement of road culverts in a modern context. First, many culverts were installed by logging companies decades ago, when virtually no watercourse alteration guidelines existed. Secondly, until recently, culverts were designed to simply facilitate movement of volumes of water according to a 100 year flow event, without considering the requirements of biotic communities. Finally, and although it is understood that the life of a typical galvanized culvert is between 20-40 years, many old culverts have been neglected (due to changes in land ownership etc.) and have degraded over the decades, creating migratory obstacles. Acknowledging these issues and recognizing the relationship between improperly functioning culverts and aquatic ecosystem health, many provincial and federal government agencies have initiated environmental legislation and policies to address the negative impacts that stream crossings have on fish habitat (Forest Practices Board, 2009). This has directly prompted extensive research in culvert (and stream crossing) dynamics, leading to an increased understanding fish passage barriers and aquatic connectivity as a whole.

Many scholars, including Cote *et al.*, (2005), indicate that culverts often create difficult or impassible outlet drops impeding upstream movement for fish. Culverts also channel water flow leading to increased water velocities not necessarily within the swimming capability range of the species in question (Forest Practices Board, 2009; Cote et al., 2005). Responding to the complex relationship between and amongst the variables at play (natural and manmade), the research community has been attempting recently to bridge the gap between disciplines producing models and tools that incorporate physics, hydrodynamics, and ecology. For the purpose of this research, and because very few alternatives exist, Atlantic National Parks have chosen a rule-based simulation tool called FishXing (pronounced "fish crossing") to help predict hydraulic conditions (possibly restricting fish movement) based on measurable culvert characteristics.

FishXing, developed by the USDA Forest Service, "is intended to assist engineers, hydrologists, and fish biologists in the evaluation and design of culverts for fish passage" (FishXing, 2011) and can be downloaded free of charge at http://www.stream.fs.fed.us/fishxing/index.html . Given accurate culvert attributes (measured in field surveys) and watershed specific hydraulic characteristics, it models the complexities of hydraulics and fish performance (for a variety of species) within a given culvert (Peake, 2007; Cote, 2009; FishXing, 2011). The output provides a percentage of flows passable for the species in question, therefore identifying aquatic barriers and predicting the extent of movement restriction. The literature indicates that in many studies, the FishXing model has been successful in identifying culverts that impede fish movement, and has helped to remove or restore many barriers causing aquatic fragmentation (Burford *et al.*, 2009, Cote, 2009). It is important to note that the FishXing model only provides output for single culverts, and does not take into account the dynamics of multiple barriers in dendritic systems. Therefore, as will be discussed in

Section 1.7, the FishXing output will be used to populate a connectivity model that assesses the cumulative impacts of multiple barriers and aids in prioritizing restoration.

1.6 The Importance of Local Ecological Knowledge (LEK)

In recent decades, government agencies have attempted to undertake the majority of environmental monitoring activities, It has become apparent, however, that collective efforts of the government alone are not enough (Vaughan et al., 2001; Savan *et al*., 2003). There is therefore a need for community members and organizations to be involved in environmental monitoring activities. In fact, the United Nations Environmental Programme proclaims that citizen engagement is fundamental to sustainability (Au *et al*., 2000). Sharpe and Conrad (2006) indicate that citizen involvement is on a steady rise in response to the apparent gaps in monitoring activities. They indicate that there is also great potential for the inclusion of Local Ecological Knowledge (LEK) into the environmental management structure (Sharpe & Conrad, 2006).

Community-Based Monitoring (CBM) is extremely important as organizations and interested/concerned individuals attempt to monitor, manage, and/or restore local environments. Whitelaw *et al*., (2003) describe CBM as being “a process where concerned citizens, government agencies, industry, academia, community groups and local institutions collaborate to monitor, track and respond to issues of common community concern" (p. 410). In many cases, community members/groups have taken on the burden of monitoring the local environment (traditionally done by the government) and they have proven to be effective on many levels. Although community level environmental monitoring activities have been the focus of criticism from professional scientists and decision makers in recent years, it has been documented by many that on the whole, monitoring data gathered by community groups and citizen scientists can be comparable to that gathered by professionals (Sharpe & Conrad,2006; Engel & Voshell, 2002; Fore *et al.*, 2001).

A perfect example of community members holding invaluable LEK can be seen at Kejimkujik, where highly motivated volunteers have collaborated with Parks Canada to develop and implement the extremely successful creel census and fish tagging programs. Without this group of dedicated community members, very little regarding the status of brook trout population in the park and greater ecosystem would be known and moreover, future management/restoration practices would not have over three decades of valuable monitoring data to integrate into the decision making process.

Recognizing the incredible amount of LEK specific to brook trout at Kejimkujik, this thesis will attempt to use this knowledge base and incorporate data and recommendations from this dedicated group of citizen scientists into the decision making process regarding the aquatic connectivity project .

1.7 Prioritizing Restoration Initiatives

It is apparent that at present, the scientific community lacks a standardized, clear, and well-defined protocol for prioritizing aquatic barriers. Due to the nature of peer-reviewed literature, aquatic connectivity studies are broken down into very specific topics and published in a number of journals making it extremely difficult for readers to tie together and build on existing research. On the other hand, many organizations including Clean Annapolis River project (CARP), Mersey Tobeatic Research Institute (MTRI) and the Forest Practices Board (FPB) have developed holistic approaches to address connectivity problems however, no information-sharing mechanisms exist for effectively achieving standardization. Therefore, although many valuable advancements, ideas, and procedures have been developed in these studies, the scientific community often overlooks the results, as they are not present in the peer-reviewed literature. This section will provide an overview of the available prioritization tools (both peer-reviewed and unpublished) and highlight the importance of implementing the Parks Canada model developed by Cote *et al*. (2009).

Many, including Kemp and O'Hanley (2010) suggest that the well-planned removal of aquatic barriers is a very effective means of restoration, and one that if done correctly, can maximize ecosystem benefit. Therefore, it is interesting to note that very little attention has been directed toward the development of systematic methods for prioritizing barrier removal actions, considering the enormous effort and resources currently being invested into aquatic restoration (Kemp & O'Hanley, 2010). The literature indicates that at present, two general categories of prioritization methods exist which include scoring-and-ranking techniques and optimization modeling (Kemp & O'Hanley, 2010).

The most common approach to prioritizing barrier removal decisions is the scoring-and-ranking method (Pess *et al*., 1998; Taylor & Love, 2003; Karle, 2005) whereby individual barriers are scored based on a set of assessment criteria. The physical, ecological and economical criteria produce individual scores and barriers are subsequently ranked in descending order (Kemp & O'Hanley, 2010). The basic idea with scoring-and-ranking is to move down the ordered list restoring barriers until the budget is exhausted (Kemp & O'Hanley, 2010). Although this technique is relatively straightforward and requires little to no computational effort, its major pitfall is that restoration decisions are considered independent of each other (Kemp & O'Hanley, 2010). O'Hanley and Tomberlin (2005) suggest that by ignoring the spatial structure of multiple interconnected barriers, highly inefficient outcomes can result and in some cases, produce no net habitat gain. The FishXing simulation tool (Section 1.5) can be used as a scoring-and-ranking method where passibility scores are ordered and restored based on their ranking. Although important criteria is often overlooked by scoring-and-ranking methods, it is important to note that tools, including FishXing, can prove extremely valuable when integrated with optimization models (as will be further discussed below).

The second approach to prioritizing barrier removal decisions, and one which only a few studies have recently investigated, is optimization modeling (Kuby *et al.*, 2005; O'Hanley & Tomberlin, 2005). This more technical approach, considers the underlying spatial network formed by the presence of multiple interconnected barriers (Kemp & O'Hanley, 2010). It appears that most optimization models attempt to maximize the total increase in accessible habitat upstream of a given barrier (O'Hanley & Tomberlin, 2005; Cote et al., 2009), and acknowledge/ incorporate the complexities of multiple barriers in dendritic systems. Some optimization models, including the model developed by Zheng *et al*. (2009), can produce multiple restoration scenarios based on a specific budget. For example, given a budget of $100,000, the model may suggest restoration at sites A, B, and D; however, given a budget of $50,000 the model may suggest B, C, and F, an entirely different set of prioritized barriers. This versatility is inevitably a valuable quality, as ecosystem benefit is maximized given a specified budget. It is important to note that these recently developed optimization models have yet to be deployed on a large scale, and in most cases have only been implemented a few times by their developers. This fact truly highlights the idea that, at present, the research community lacks a well-defined thoroughly tested protocol for prioritizing aquatic barriers.

This thesis will adopt and apply a Parks Canada optimization model developed by Cote *et al*., (2009) called the Dendritic Connectivity Index (DCI). This index of freshwater ecosystem connectivity was developed to quantify the structural connectivity of watersheds and asses the cumulative impacts of barriers to connectivity (Cote *et al*., 2009). The model also serves as a tool to assist in the prioritization of restoration efforts through GIS analysis. The goal will be to test the prioritization model against other techniques, hoping to illustrate the increased ecosystem benefit provided by such an approach. It is noteworthy that results from scoring-and-ranking methods (including barrier permeability scores produced by the FishXing tool) can be used to populate more complex optimization models, as will be demonstrated in this research.

By implementing and evaluating the DCI, this thesis will explore the effectiveness of this newly developed prioritization model in a National Park setting and provide recommendations for future use. It is hoped that this research will highlight an approach that can be easily adopted by others, therefore moving towards standardization. Furthermore, as this optimization model will be implemented at several other Atlantic National Parks, a significant amount of information will exist regarding the effectiveness of the approach, helping to eliminate some of the uncertainties associated with a newly developed model.

1.8 Restoring Aquatic Connectivity

Although the literature describes two types of prioritization methods for evaluating and prioritizing multiple barrier scenarios, it becomes apparent that very little peer reviewed literature exists regarding the documentation of restoration work and the associated methods used for evaluating success (biotic and abiotic). In other words, many studies discuss the development of techniques/models designed to help decision makers make better-informed decisions, but do not go on to actually restore problematic barriers and evaluate the quality of work and fish movement success. This will be a key component of this thesis. Following the application of the DCI, restoration work will occur, the quality of this work will be evaluated/documented, and several methods will be applied to measure success.

1.9 Measuring Success

Aquatic connectivity studies in the literature rarely reach the point of actually restoring the barriers that have been prioritized, and therefore do not typically investigate ways of measuring success. For the purpose of this research, restoration will be termed successful if the following are observed: (1) each structure in question is 100 percent passable following restoration, (2) brook trout have passed the restored barrier in an upstream motion, (3) water quality parameters do not, at any time, cross stress thresholds for brook trout, and (4) the DCI shows that ecosystem benefit is maximized given the available budget.

Fortunately, the literature includes many methods, protocols, and suggestions regarding ways to identify fish movement. A few of the most common include direct human observation and video filming (Bowen *et al*., 2006), mark and recapture methods

(Kemp & O'Hanley, 2010) and Passive Integrated Transponder (PIT) tags (Aarestrup et al., 2003). Some authors, including Kemp and O'Hanley (2010), highlight that it is not always financially or logistically feasible to employ these types of techniques over an entire watershed or catchment area. Kejimkujik however, is fortunate enough to be able to incorporate their fish tagging program (mark and recapture method) into the Aquatic Connectivity project therefore helping to overcome this financial and logistical burden. Integrating the existing fish-tagging program (undertaken primarily by citizen scientists) into success measurements will prove beneficial on many levels. First, it will encourage citizen science and those possessing valuable LEK to become increasingly involved in management practices, as their hard work will be recognized on a different level. Secondly, it will help develop an approach to overcome the financial and logistical barriers mentioned above, by using existing programs instead of "reinventing the wheel" therefore maximizing resources.

An abundance of literature also exists regarding water quality suitability index models (Raleigh, 1982; Rutherford, 2007) water quality thresholds and accepted in-stream values (Canadian Council of Ministers of the Environment, 2012). These widely accepted guidelines will be used throughout this project as a means of measuring the quality/success of the restoration work on a site specific scale.

As highlighted in section 1.7, the DCI will be the model used to measure the overall success of the aquatic connectivity project (Parks Canada, A, 2010; Parks Canada, B, 2010). This measurement, essentially a standardized all inclusive indicator within

Atlantic National Parks, will be used to report on the connectivity status of the Park in its Annual Report as well as the State of Park report (Parks Canada, A, 2010).

1.10 Summary and Thesis Objectives

It is increasingly apparent that in recent years anthropogenic alteration/disturbance has fragmented many aquatic systems causing restricted access to suitable habitat for many species. Regrettably, infrastructure development, management, and land use decisions continue to be made in the absence of adequate information on hydrologic connectivity, in large part because a standardized and well-defined protocol for assessing aquatic connectivity does not currently exist. Moreover, the literature rarely includes Local Ecological Knowledge (LEK) into integrated resource management practices. Attempting to fill this void, this thesis will adopt and apply a Parks Canada optimization model developed by Cote *et al.*, (2009) called the Dendritic Connectivity Index. This model will help assess the connectivity status of aquatic ecosystems through the identification of fish passage barriers responsible for fragmenting the landscape. Furthermore, it will aid in the development of a prioritization scheme that maximizes ecosystem benefit by assessing the cumulative impact of multiple barriers and integrating valuable LEK, therefore helping decision makers make better informed decisions. Finally, this thesis will document the restoration work, report on the quality of this work, and provide information on biotic achievement following restoration of the identified barriers.

Chapter 2

STUDY AREA

2.1 Description of Study Area

Established in 1969 and located in central south-west Nova Scotia, Kejimkujik National Park and National Historic Site of Canada (Kejimkujik) represents the Atlantic Coastal Uplands Natural Region of Canada covering an area of approximately 381 km^2 (Figure 2.1) (Parks Canada, 2003). Recognizing its status as a Mi'kmaq cultural landscape, Kejimkujik received additional designation as a National Historic Site in 1994 (Parks Canada, 2003).

The south and western boundaries of Kejimkujik fall adjacent to the Tobeatic Wilderness Area (990 km^2) creating a significant contiguous protected area (Figure 2.2) that is home to an impressive collection of flora and fauna (Parks Canada, 2003; Mersey Tobeatic Research Institute and Parks Canada, 2010). Moreover, the greater Kejimkujik/Tobeatic ecosystem is encompassed within the Southwest Nova Biosphere Reserve (Figure 2.2), a UNESCO demonstration area for innovative approaches to conservation and sustainable development (Parks Canada, A, 2010).

Comprised of 46 lakes and more than 30 streams and rivers, including a major portion of the headwaters of the Mersey River (Figure 2.3), the park's aquatic ecosystem consists of shallow, acidic, warm water lakes, still waters and meandering streams, featuring significant seasonal water level changes (Parks Canada, A, 2010).

The greater Kejimkujik ecosystem has long been known to have some of the province's best hunting and fishing with evidence dating as far back as the arrival of the aboriginal peoples, at least 4,000 years ago (Parker, 2004; Parks Canada, A, 2010). In fact, the areas reputation of lucrative hunting and fishing has inspired many artists and writers, including Mike Parker author of "Guides of the North Woods" (2004), "Woodchips & Beans" (1992) and "Where Moose and Trout Abound" (1995), all of which recall poetic tales passed through the generations. Today, 12 species of freshwater fish navigate the waters of Kejimkujik and big game continue to frequent the landscape making this National Park and National Historic site a popular destination for outdoor enthusiasts (Brunt, 2011).

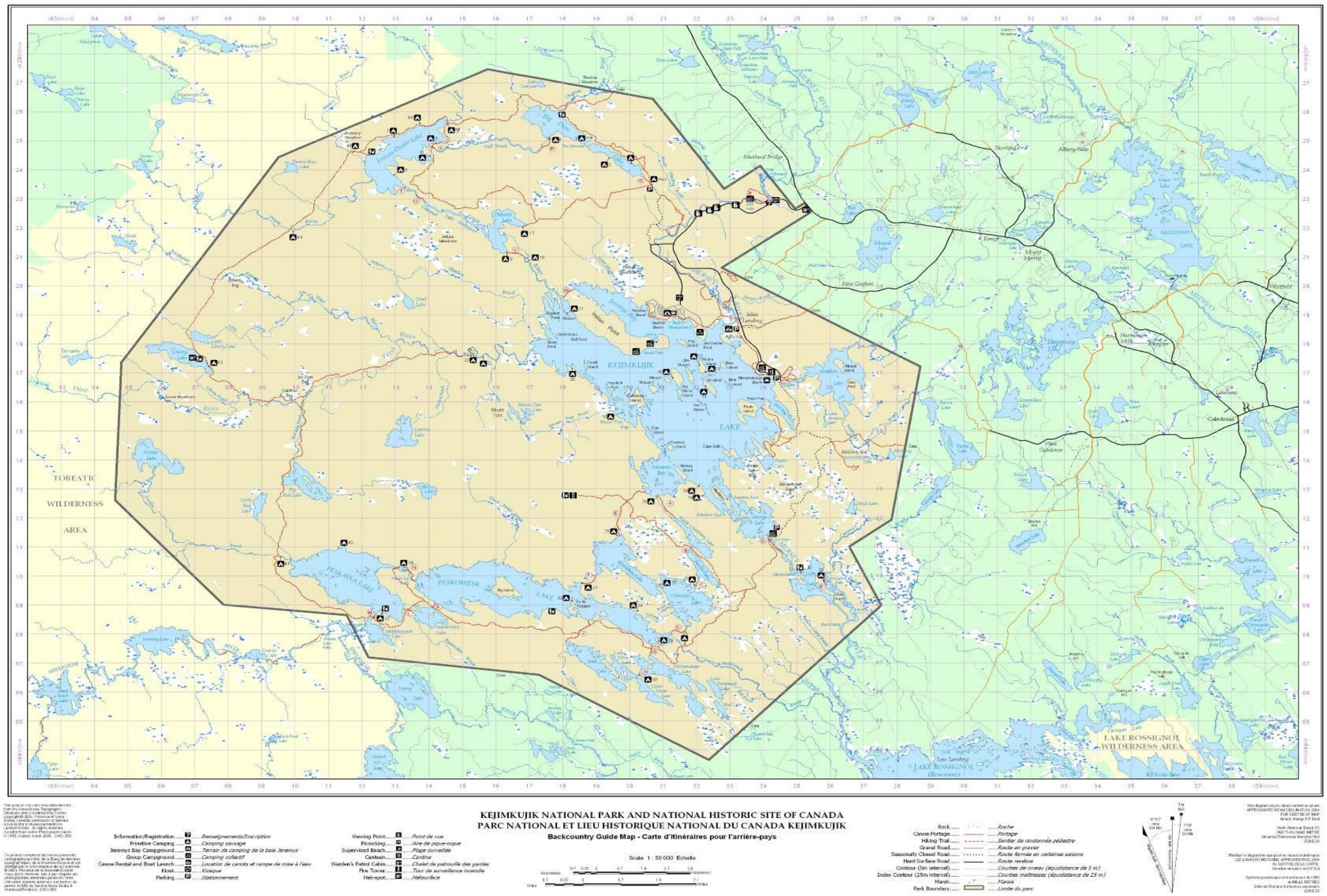


Figure 2.1. Kejimkujik National Park and National Historic Site (Kejimkujik 2011)

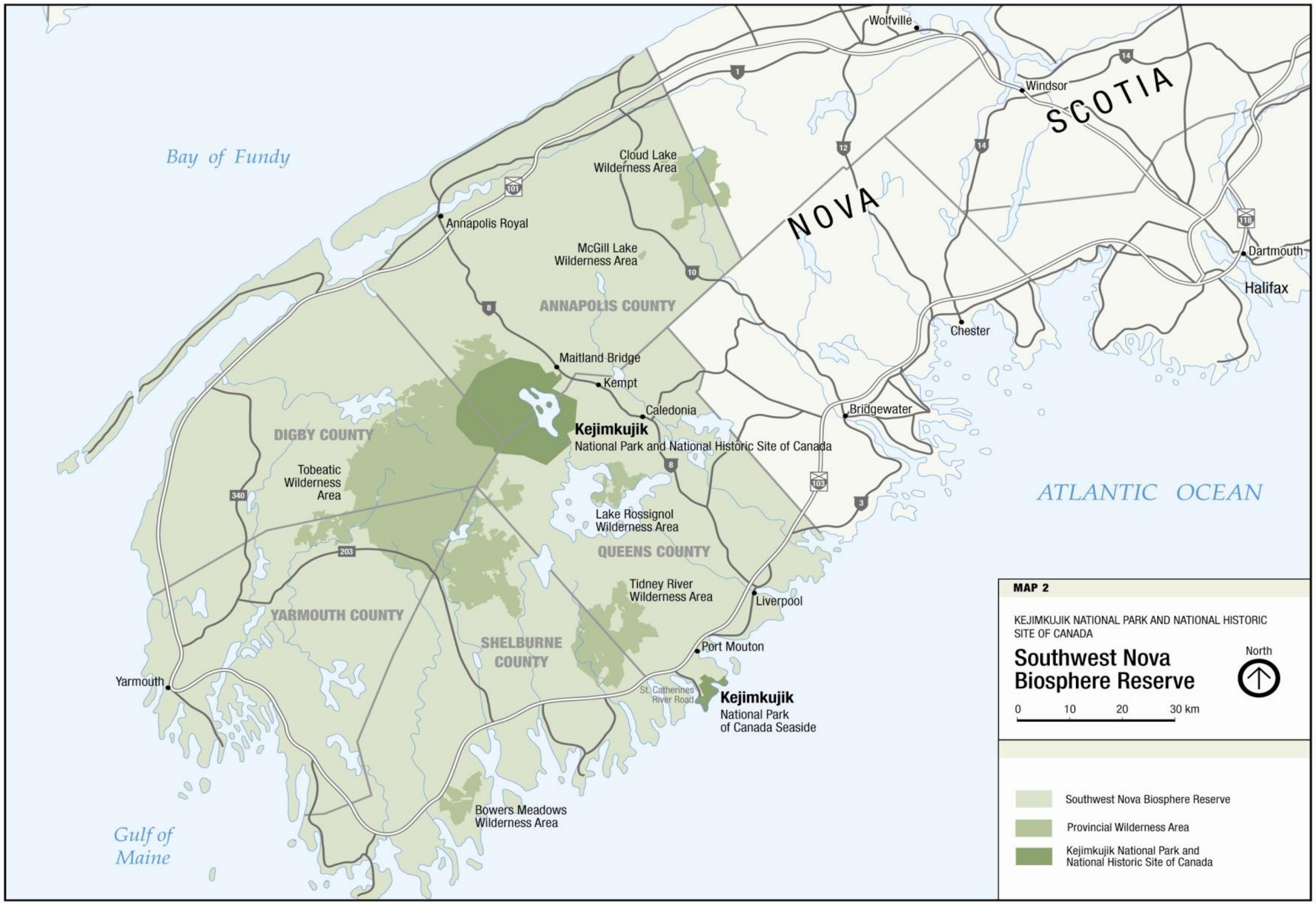


Figure 2.2. Southwest Nova Biosphere Reserve (Management Plan, 2010)

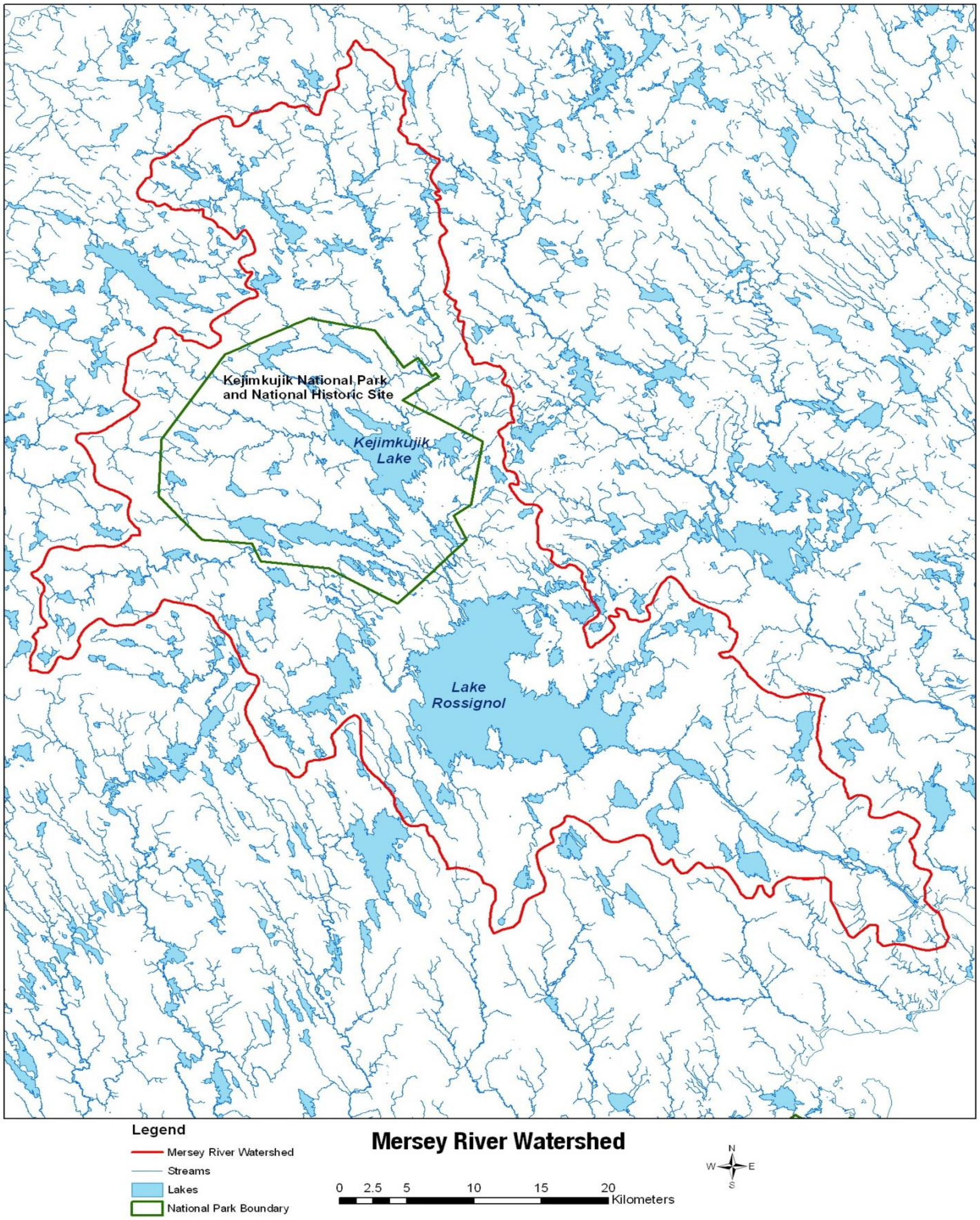


Figure 2.3 Kejimkujik and the Mersey River Watershed (Map by Sally O' Grady)

2.2 Land Use

The use of the Kejimkujik area began approximately 4000 years ago with the arrival of the Mi'kmaq people (Parks Canada, 2003). Early occupation of the landscape included seasonal activity along the lakeshores and rivers, with the Mersey River and associated waterways acting as the transportation link between the Bay of Fundy and the Atlantic coast (Parks Canada, 2003). Spiritual importance given to the area by the Mi'kmaq people can still be seen today on petroglyphs on the shores of Kejimkujik Lake (Parks Canada, 2003; Parks Canada, A, 2010).

Increased European presence in the mid 17th century had a profound impact on all indigenous peoples, including the Mi'kmaq, and also greatly accelerated ecosystem change (Parks Canada, 2003). European settlers established farms, mined for gold and began to log the forests selectively harvesting white pine and red oak. During the 1800s, logging and gold mining shaped the landscape which now comprises the park, and dominated the local economy (Parker, 1992; Parks Canada, A, 2003). The early 1900s were characterized primarily by outdoor recreation use in response to the realization that the area was home to impressive fish and game. Many books, including Albert Bigelow Paines "The Tent Dwellers" chronicle historic hunting and fishing trips in what is today Kejimkujik and the greater ecosystem (Paine, 1908).

Upon establishment of the park in 1969, activities evolved to include wilderness canoeing, hiking, camping swimming, biking, skiing and snowshoeing (Parks Canada, 2003). To support these activities, roads, trails, wilderness campsites and administrative infrastructure were put in place and currently occupy approximately 43 hectares (Parks Canada, 2003). Included in this area are 17.3 km of paved roads, 92.2 km of gravel roads, 92.7 km of hiking trails and 404 campsites (Parks Canada, 2003). Approximate annual visitation is 221, 000 at the entrance gate, with 38, 000 camping nights (Parks Canada, 2003). Kejimkujik also serves as a center for federal scientific research and monitoring with permanent instrument installations aiding over 20 different studies per year (Parks Canada, 2003; Parks Canada, A, 2010).

With significant road and trail infrastructure in place (some dating back before the park was established), aquatic ecosystem fragmentation has been identified as a high priority Ecological Integrity (EI) issue for Kejimkujik in the park management plan , particularly because of the potential impact on fish and fish habitat (Parks Canada, 2003; Parks Canada, A, 2010; Parks Canada, B, 2010). Structures designed to facilitate water movement such as road and trail culverts (of which there are 133) have the potential to fragment the aquatic landscape and therefore restoring problematic structures has been identified as high priority in Kejimkujik and other Atlantic National Parks (Parks Canada, B, 2010).

Today, a series of hydro dams located on the lower Mersey River between the park and the Atlantic Ocean must also be noted as significant land use features largely shaping and influencing Kejimkujik and the greater ecosystem. Aside from altering fluvial geomorphology, the dams act as a barrier and prevent anadromous fish movement by fragmenting the landscape (Parks Canada 2003). Fish requiring movement between fresh and salt water during various stages of their life cycle can no longer do so, forcing landlocked populations to evolve or perish. Although the most significant dams are not located within the parks boundaries, their presence (in the greater ecosystem) has direct influence on species known to frequent the parks waters.

2.3 Geology

Kejimkujik National Park and National Historic Site of Canada is said to typify the visually striking glaciated, rolling drumlin topography of south-western Nova Scotia (Parks Canada, 2003; Stanley, M., 1976). The eastern portion of the park is underlain by the Halifax slate bedrock formation. This formation is comprised of clay and sandy slates overlain by tills with a higher buffering capacity than tills associated with the metamorphosed Goldenville formation in the south-central part of the park, or the granites of the western portion (Stanley, M., 1976; Parks Canada, 2003). Local geology and its direct influence on pH play significant roles in the park’s aquatic and terrestrial ecosystems and can be used to understand variation in water quality across the park.

2.4 Surficial Hydrology

The two major drainage systems receiving water from the park are the Shelburne River and the Upper Mersey River, both of which drain into Lake Rossignol, then into the Mersey River, and eventually into the Atlantic Ocean (Stanley, M., 1976). The Shelburne river system drains a total area of 19 km^2 including just 5 lakes representing 2 percent of the total lake volume in the park (Stanley, M., 1976). The Mersey River system includes the remaining 41 lakes and drains a total area of 362 km^2 (Stanley , M., 1976).

2.5 Water Quality

Several long term EI monitoring programs at Kejimkujik indicate that water quality appears to be good (relative to water quality across Nova Scotia) within the park boundaries and extending into the greater ecosystem (Parks Canada, B, 2010). As experienced throughout much of the province, acid rain is known to negatively affect water quality in the Kejimkujik area and because of the limited buffering capacity of the local geology, pH can often approach unsuitable levels for aquatic organisms. However, it appears that many aquatic organisms including brook trout and other fish species have acclimated and thrive in the present condition.

Measurements of pH vary greatly throughout the park partially attributed to the buffering capacity of the local geology. Unpublished data gathered through the EI monitoring program at Kejimkujik show maximum pH values in the park nearing 6 with minimum values dipping slightly below 4 (Pouliot, D., 2011). Maximum summer water temperature varies greatly, with some areas experiencing temperatures in the mid 20s while others stay relatively cool (14^{o}C) as a result of groundwater input and/or lake stratification (Pouliot, D., 2011). Dissolved oxygen content varies throughout the park (also influenced greatly by temperature) however recent EI monitoring results indicate all but 2 of the 16 lakes monitored had values above 8 mg/l indicating optimal D.O conditions for most aquatic organisms. A very recent study undertaken in 2010/2011 indicates that suspended sediment concentrations are optimal, with natural levels never exceeding 10 parts per million (ppm) (Pouliot, D., 2011).

On the whole, the park's EI monitoring program data indicate a healthy aquatic ecosystem capable of supporting a wide variety of aquatic life.

2.6 Freshwater Fish Species of Kejimkujik

Fishing has played a significant role historically in Kejimkujik, from the traditional food gathering of the Mi'kmaq to the guided fishing trips vividly described in Parkers literary works (Parks Canada, 2011). Kejimkujik's waters presently support 12 species of freshwater fish indicating a healthy and productive aquatic ecosystem (Table 2.1) (Stanley, M., 1976). It is important to note however, that the aggressive and invasive smallmouth bass (*Micropterus dolomieu*) and chain pickerel (*Esox niger*) currently pose a significant threat to the waterways of southwest Nova Scotia, including those encompassed by Kejimkujik. Documented in various lakes and rivers outside the parks boundaries, the presence of these highly invasive species in Kejimkujik has yet to be confirmed by park officials (Brunt, R., 2011; Pouliot, D., 2011).

Table 2.1. Freshwater Fish Species Present at Kejimkujik

Common Name	**Scientific name**
American Eel	*Anguilla rostrata*
Banded Killifish	*Fundulus diaphanous*
Brook Trout	*Salvelinus fontinalis*
Brown Bullhead	*Ameiurus nebulosus*
Brown Trout	*Salmo trutta*
Creek Chub	*Semolitus atromaculatus*
Golden Shiner	*Notemigonus crysoleucas*
Lake Whitefish	*Coregonous clupeaformis*
Nine-spine Stickleback	*Pungitius pungitius*
White Perch	*Morone americana*
White Sucker	*Catostomus commersoni*
Yellow Perch	*Perca flavescens*

The waters of Kejimkujik are known to support a healthy and abundant population of brook trout (*Salvelinus fontinalis)*, a transboundary species highly sensitive to environmental factors including habitat alteration, increased water temperatures, inter-species competition, and over-harvesting (Mersey Tobeatic Research Institute and Parks Canada, 2010; Parks Canada, A, 2011). Because this species is known to act as an excellent environmental indicator of freshwater ecosystem health, and because the species is harvested within the park, several fish monitoring programs exist (Mersey Tobeatic Research Institute and Parks Canada, 2010). The fish tagging program and the creel census (both of which target brook trout) are just two of the recent examples of monitoring the stock. These programs examine species health and abundance, and also provide an opportunity to look at trout growth rate, movement and habitat use (Parks Canada, 2011).

Recognizing that aquatic habitat fragmentation may be an issue within the park boundaries and extending into the greater ecosystem (due to potential barriers described in section 2.2), Kejimkujik has identified the topic as a high priority EI issue and responded by implementing the Aquatic Connectivity Project. In short, the projects intention is to restore fish migration pathways using the transboundary brook trout as the indicator species.

2.7 Fish Management and Protection

In an effort to protect and manage the fish species frequenting the parks waterways, an extensive set of rules and regulations exist for anglers. The fishing season is open from April 1^{st} through August 31^{st} with the exception of Grafton Brook, Rogers Brook, Pebbleloggitch Lake, Beaverskin Lake, Mountain Lake and Cobrielle Lake, all of which are closed indefinitely for further research and monitoring (Parks Canada, 2011).

Anglers wishing to fish within the park's boundaries are required to purchase a National Parks Fishing Permit separate from provincial licenses. The daily catch and maximum possession limit within park boundaries is ten fish, five of which may consist of brook trout (Parks Canada, 2011). In an effort to conserve and protect the stock, Kejimkujik has designated almost half of the park as a "Catch and Release Fishing Zone" (Figure 2.4) where any fish species caught must be returned to the water immediately (Parks Canada, 2011). This specially designated zone is subject to additional rules and regulations including the fly fishing only restriction prohibiting artificial lures or natural baits (Parks Canada, 2011). Moreover, this zone prohibits barbed hooks which are known to cause significant injury or death to fish in specific circumstances.

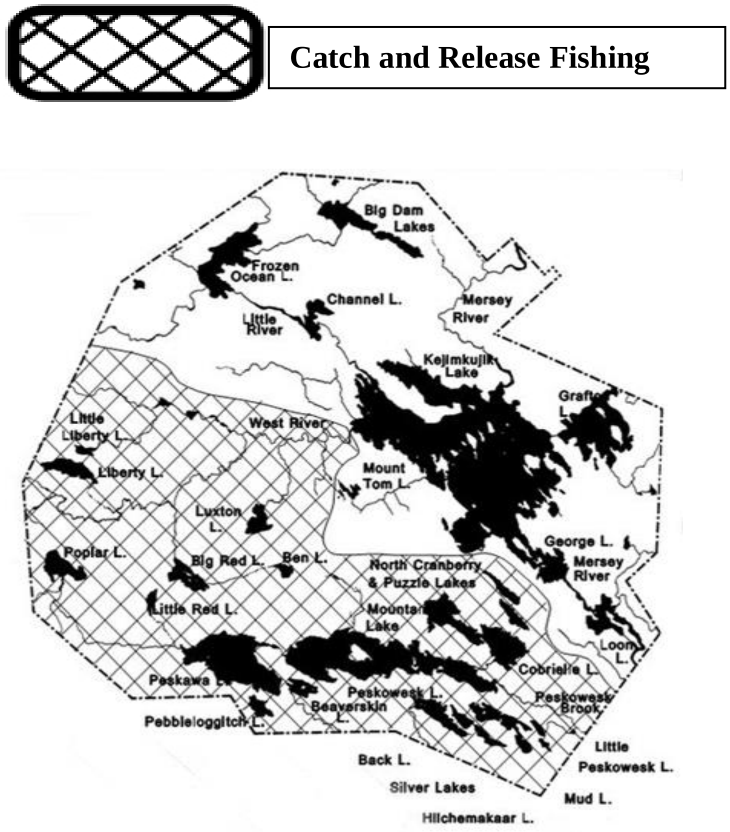


Figure 2.4. Designated Catch and Release Fishing Zone (Parks Canada, 2011)

2.8 Summary

Kejimkujik National Park and National Historic Site of Canada represents a culturally significant landscape and a unique ecosystem home to an array of rare and endangered species. The Tobeatic Wilderness Area paired with the Southwest Nova Biosphere Reserve extend protection into the greater ecosystem greatly benefiting terrestrial and aquatic ecosystems alike.

The parks rich history and appealing physical attributes make it a regional tourist destination for wilderness and outdoor enthusiasts and also a designated central location to transmit the stories and traditions of the Mi' kmaq people dating back over 4000 years.

The Parks aquatic ecosystem appears to exist in a healthy state and currently supports one of the most significant brook trout populations in Nova Scotia. Recognizing this, Kejimkujik has responded by establishing research projects aimed at better understanding the health, relative abundance, condition, growth rate, movement, and habitat use of the species. Furthermore, many fish management and protection strategies exist including rules and regulations that go above and beyond the provinces regulations. One of the most current fish management strategies is the Aquatic Connectivity Project, aimed at restoring migration pathways for fish and specifically Brook trout. This thesis will focus primarily on the development and implementation of the Aquatic Connectivity Project at Kejimkujik National Park and National Historic Site of Canada.

Chapter 3

METHODOLOGY

3.1 Introduction

Recognizing freshwater development and fragmentation as high priority EI issues in the park management plan, the purpose of this research was to measurably restore aquatic ecosystem connectivity in Kejimkujik by rehabilitating and/or replacing priority culverts acting as barriers to fish passage. Freshwater ecosystem integrity would thereby be enhanced in the park by re-opening several key migration pathways for wide-ranging transboundary fish species occupying the parks waters. This chapter details the methods through which fish passage barriers were identified, techniques used to prioritize restoration initiatives, description of restoration works, pre/post monitoring, as well as the methods used to measure success.

In large part, the methodology used in this research follows Cote's (2009) Aquatic Connectivity Monitoring Protocol (Draft) developed at Terra Nova National Park. The protocol is currently being used and refined in several Atlantic National Parks including

Gros Morne, Terra Nova, Cape Breton Highlands, Fundy, and Kejimkujik. A flow chart summarizing the methodology used can be found in Appendix D.

3.2 Stream Crossing Inventory

The initial objective was to identify all stream crossing structures within the parks boundaries, as these were not documented and knowledge of manmade stream crossings at Kejimakujik was limited. This stream crossing inventory took place during the summer of 2008 and 2009 through visual surveys along all park roads and trails in the frontcountry (accessible by road) and backcountry. When a stream crossing was identified, its location was stored in GPS (Garmin GPSMAP 76) and the structure was documented with a series of photographs (Canon Powershot A70). A database was created to house all data providing documentation and groundwork for the future. After a park wide inventory was complete, the database was submitted to the general works sector as well as the parks geomatics specialist, as both have invested interests in the data.

3.3 Preliminary Assessment

Once a better understanding of the number of crossings in the park and the specific location of each structure was established, a preliminary assessment was conducted to determine the purpose and functionality of each crossing. Because the purpose of the project was to identify fish passage barriers and measurably prioritize and restore aquatic connectivity, the preliminary assessment was useful in identifying/classifying (1) structures existing on fish habitat having potential to restrict fish movement and (2) structures designed primarily for drainage purposes. Those structures falling in the latter category were dismissed for the purposes of the Aquatic Connectivity Project allowing researchers to focus efforts on structures where fish are present.

It is important to note that although this project focused primarily on fish passage barriers associated with road/trail culverts, the preliminary assessment took all stream crossings into account including culverts, bridges, dams and natural obstacles. The preliminary assessment criteria is explained in Tables 3.1 and 3.2 below.

Table 3.1 Preliminary Assessment Criteria

Surveyors	name/names of Resource Conservation staff undertaking assessment
Crossing ID	each crossing was assigned a number with the prefix CUL
Date	the date of the preliminary assessment
Time	the time of the preliminary assessment
Stream Name	the name of the water body
Road/Trail Name	the name of the road or trail
Photo Files	the specific photo numbers for each installment
UTM X / UTM Y	detailed UTM zone 20 locations provided by the GPS
Fish Habitat	a yes or no subjective determination answering the question "does the crossing exists on fish habitat?" Determined partially through Habitat Suitability Index Graphs (Appendix) and partially through expert opinion of park staff.
Crossing type	description of the crossing (culvert, bridge, dam, natural, other)
Maintenance Priority	a ranking (low, medium or high) describing the functionality

In addition to the information included in Table 3.1, all structures were ranked to determine maintenance priority (Table 3.2) and this information was turned over to General Works, the division responsible for upkeep of park infastructure.

Table 3.2 Maintenance Priority Ranking

Low	Crossing has no apparent structural damage or impact on fish passage.
Medium	Crossing has minor structural damage and/or exhibits potential to partially obstruct passage (eg slightly embedded, debris in culvert present etc).
High	Crossing requiring immediate attention. Structural damage present (collapsing etc.), and/or acting as a barrier to fish passage.

3.4 Secondary Assessment

Stream crossing structures existing on fish bearing streams were subject to a secondary and more detailed crossing assessment. This secondary assessment was used to determine whether the structure in question was impassible (a complete barrier to fish movement), partially passable (sometimes acting as a barrier to fish movement), or fully passable (never restricting fish movement). All bridges were classified as fully passable for the purposes of this project as (1) bridges do not typically restrict fish movement and (2) bridge replacement costs would far exceed Kejimkujik's Aquatic Connectivity budget. Furthermore, all dams existing in the park were classified as partial barriers to fish movement, and although their obstructive qualities were taken into consideration, resources and expertise were not available to remediate such structures.

Traditionally (based on minimum requirements of the protocol), stream crossing structures requiring a secondary assessment would be assigned subjective values where impassable structures = 0, partially passable structures = 0.5, and fully passable structures = 1. These values would then be used to populate the Dendritic Connectivity Index (DCI) prioritization tool (Section 3.5). This research however, chose to follow the optional (and more detailed) protocol which allows the refinement of the interim passability value designated 0.5 or partially passable. Essentially, the refinement of this value allows researchers to determine what proportion of time (as a percentage) a particular crossing is passable, therefore providing more detailed information to the DCI prioritization tool. It is important to note that for the purposes of the Kejimkujik Aquatic Connectivity Project, all dams and natural obstacles were assigned subjective passability values based on the expertise of resource conservation staff, as standardized methods for determining passability of such structures do not currently exist.

To reach this refined (more descriptive) possibility value (or functionality indicator), the secondary assessment required the collection of additional crossing data (Table 3.3) which was then used to populate hydrological modeling software called "FishXing". Developed by the USDA Forest Service, FishXing "is intended to assist engineers, hydrologists, and fish biologists in the evaluation and design of culverts for fish passage" (FishXing, 2011) and can be downloaded free of charge at http://www.stream.fs.fed.us/fishxing/index.html . Given detailed culvert attributes (Table 3.3) and watershed specific hydraulic characteristics (determined through catchment scaling in this case), it models the complexities of hydraulics and fish performance (for a variety of species) within a given culvert (Peake, 2007; Cote, 2009; FishXing, 2011). The output provides a percentage of flows passable for the species in question, therefore identifying the extent of migration restriction (if any) caused by a specific culvert.

Table 3.3 Required Data and Equipment for Secondary Assessment

Culvert Information	**Necessary Equipment**
Culvert ID	N/A
Location UTM X	Garmin GPS MAP 76
Location UTM X	Garmin GPS MAP 76
Stream/Brook Name	N/A
Crossing Type	FishXing/Aquatic Connectivity Monitoring Protocol
Crossing Name	N/A
Number of Culverts (single/twin)	N/A
Qualitative Passability (0, 0.5, 1)	N/A
Culvert Shape	FishXing/Aquatic Connectivity Monitoring Protocol
Culvert Material	FishXing/Aquatic Connectivity Monitoring Protocol
Water Entry Type	FishXing/Aquatic Connectivity Monitoring Protocol
Presence of Backwater	N/A
Depth Embedded (cm)	Measuring Tape/ Meter stick
Culvert Diameter (cm)	Measuring Tape/ Meter stick
Culvert Length (m)	Measuring Tape
Culvert Bottom Substrate	FishXing/Aquatic Connectivity Monitoring Protocol
Substrate Roughness Coefficient	FishXing/Aquatic Connectivity Monitoring Protocol
Outflow Drop (cm)	Measuring Tape/ Meter stick
Outflow Pool Depth (cm)	Wild Heerbrugg GST 10 Surveyor
Inlet Elevation (m)	Wild Heerbrugg GST 10 Surveyor
Outlet Elevation (m)	Wild Heerbrugg GST 10 Surveyor
Rise (m)	Calculator
Slope (%)	Calculator
Water Level (cm)	Measuring Tape/ Meter stick
Water Depth at Inlet (cm)	Measuring Tape/ Meter stick
Water Depth at Outlet (cm)	Measuring Tape/ Meter stick
High Water Estimate (cm)	Measuring Tape/ Meter stick
Inlet Velocity (m/s)	Swoffer 2100 Flow Meter
Outlet velocity (m/s)	Swoffer 2100 Flow Meter
High Flow/ Low Flow (cf/s)	Parks Canada Streamflow Protocol or ARC GIS Platform

Figure 3.1 illustrates FishXing's input window detailing the required parameters called for by the software. The input window is broken down into 4 categories including: Fish Information, Velocity Reduction Factors, Culvert Information, and Fish Passage Flows.

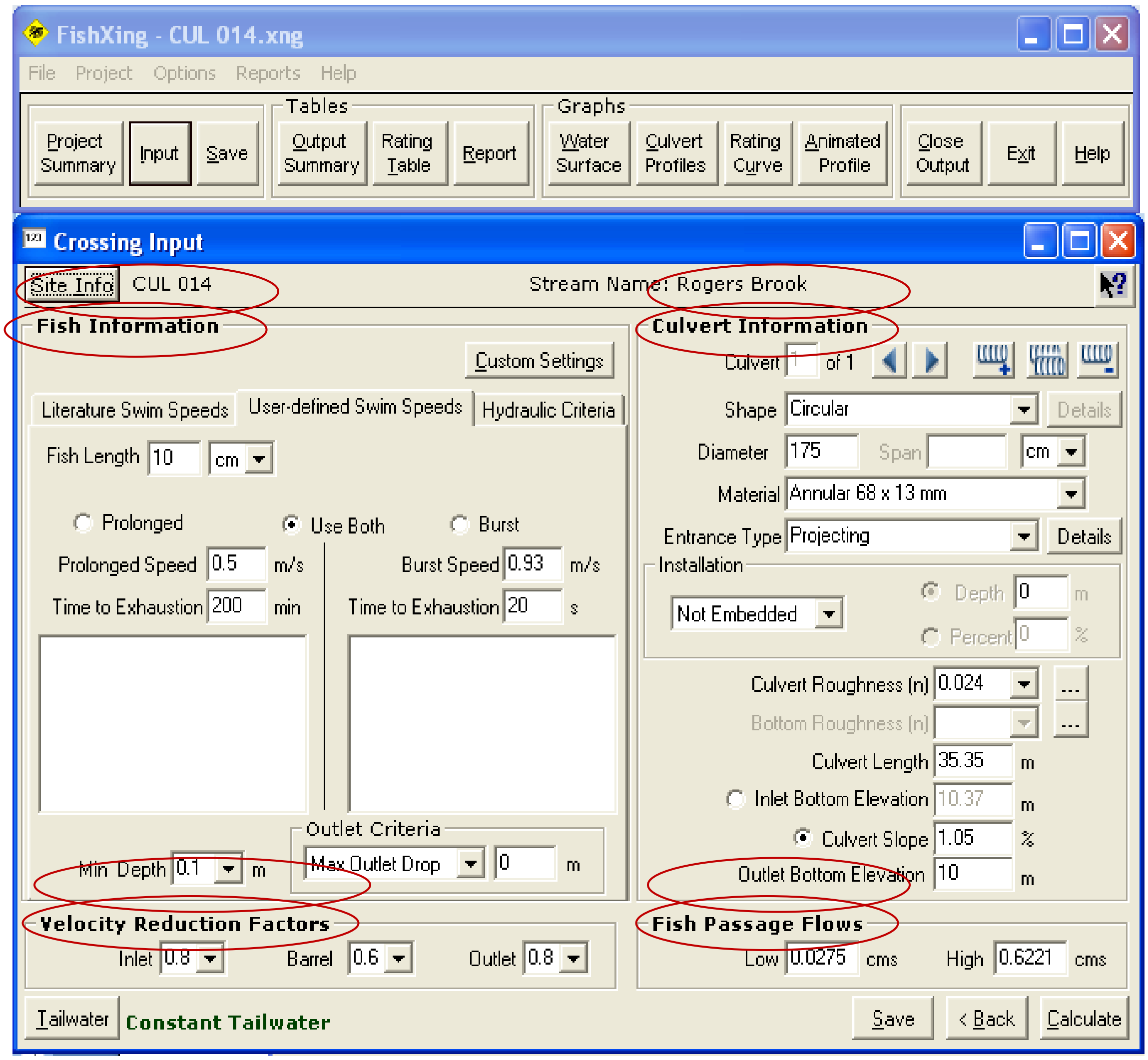


Figure 3.1 FishXing's Input Window

Along with several other Atlantic National Parks (including Terra Nova, Fundy and Gros Morne), Kejimkujik has chosen to use controlled variables in the "Fish

Information" section (Figure 3.1) based on literature surrounding brook trout swimming capabilities discussed in Section 1.4 (Chapter 1) of this thesis. It is important to note that the "Use Both" button is selected taking into account both prolonged (0.5 meters/second) and burst (0.93 meters/second) swim speeds. Likewise, Kejimkujik has chosen to keep "Velocity Reduction Factors" constant where Inlet = 0.8, Barrel = 0.6 and Outlet = 0.8. These numbers are intended to account for areas of reduced velocity within the culvert commonly used by swimming fish to conserve energy. Specifically, the numbers represent the ratio of occupied water velocity to cross sectional average water velocity within the pipe (Cote, 2009).

The Taliwater tab (Figure 3.2) under "Velocity Reduction Factors" (Figure 3.1) calls for outlet pool attributes which are included in the required culvert measurements in Table 3.2. The Kejimkujik Aquatic connectivity project chose to use the "Constant Tailwater" option (Figure 3.2) for all culverts in question.

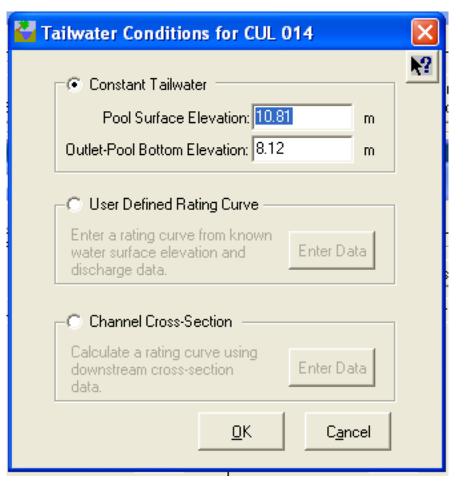


Figure 3.2 Tailwater Control Input Window

The “Culvert Information” section of the input window (Figure 3.1) calls for the additional crossing data in Table 3.2. For more detail on any of the parameters, or the specific protocol used to take the measurements, refer to Cote’s (2009) Aquatic Connectivity Monitoring Protocol or FishXing’s comprehensive help menu.

Finally, FishXing’s input window calls for “Fish Passage Flows” requiring low and high flows (in m^3 / sec.) for the culvert in question (Figure 3.1). These values are among the most important parameters in FishXing’s calculations as the minimum and maximum flows through the culvert determine the hydraulic conditions and therefore ultimately allow or restrict fish movement through the structure.

The less technical approach for determining low/high flows is to perform a channel cross section accompanied by streamflow measurements to determine flow. Although this approach can be carried out within a matter of minutes, it only provides information on the time the measurements were taken. This becomes problematic because (1) it is very difficult to determine when the year’s highest/lowest flow is taking place and (2) capturing high flow in spring melt can be an extremely difficult, dangerous and a sometimes unattainable task. In fact, this problem has been highlighted at Kejimkujik, where significant gaps in the data (specifically high flows) exist both in the Aquatic Connectivity Project, and the Streamflow Monitoring project.

The second and more technical approach to acquiring low/high flows at a specific site is to perform catchment scaling where digital elevation models, watershed boundaries and provincial water data are used to predict high/low flows at any given location. This method, however, requires the expertise of a geomatics specialist, appropriate GIS software, and detailed digital data for the area in question. These requirements are often limiting factors, especially for community groups with limited resources; and therefore in-situ cross section/streamflow measurements (described above) are the next best option. Because this project was undertaken in a National Park where infrastructure was present (Environment Canada gauging station) and GIS resources were available, catchment scaling was the approach used to calculate low/high flow for each of the stream crossings in question. The author of this thesis worked closely with Kejimkujik Geomatics Specialist Sally O'Grady and Technician Daniel Pouliot to determine inputs used to produce catchment scaling results. Channel cross sections and streamflow measurements at all locations were undertaken by the author (to preform spot checks on catchment scaling results) but were not used to populate FishXing.

Because the FishXing model only provides output for single culverts and does not take into account the dynamics of multiple barriers in dendritic systems, the valuable FishXing output was used to populate a connectivity model that assessed the cumulative impacts of multiple barriers and aided in prioritizing restoration (as described in the next section).

3.5 Techniques used to Prioritize Restoration Initiatives

With a comprehensive understanding of the functionality of all stream crossing structures existing on fish bearing streams in the park, the next step was to apply the refined passability values to a prioritization model designed to maximize ecosystem benefit (total increase in accessible habitat) at Kejimkujik. The chosen prioritization model is called the Dendritic Connectivity Index, developed by Cote *et al*, 2009. This model considers the underlying spatial network formed by the presence of multiple interconnected barriers. Based on where a structure exists within the system and the degree of restriction, this model essentially provides a restoration scenario where the remediation of the top rated priority produces the maximum possible ecosystem gain (accessible habitat), the second yields the next statistically viable gain, and so on. Because the DCI incorporates the complexities of multiple barriers in dendritic systems, this approach is believed to be of the most advanced prioritization tools at present. For background information or specific DCI methodology, please refer to the D. Cote's Aquatic Connectivity Monitoring Protocol and stream network research (Cote, 2009; Cote et al., 2009)

In an effort to verify that the Parks Canada DCI prioritization technique was the most efficient method for prioritizing restoration efforts and maximizing ecosystem benefit, the results (rankings) from 2 other prioritization methods were run for comparison. The idea here was to see what the top rated structures (based on other methods of prioritization) would yield in terms of ecosystem benefit (according to the DCI tool). It is important to acknowledge that most environmental operating budgets (especially outside of government) do not enable remediation on all structures in question (highlighting the importance of prioritization) and therefore the ecosystem benefit resulting in the restoration of the top rated priorities is often critical.

The additional prioritization methods included a traditional scoring-and-ranking approach (based solely on FishXing's passability values) and a scenario based completely on Local Ecological Knowledge (LEK). The theoretical restoration scenarios produced by these other techniques were then run through the DCI tool to determine step-wise ecosystem benefit resulting from the particular restoration scheme. This was achievable because the DCI allows the user to override the models proposed restoration ranking (based on maximized ecosystem gains) with a user defined rankings (produced by scoring-and-ranking and LEK in this case). In other words the chosen method for ecosystem benefit comparison is the DCI, as its computational ability assesses the cumulative impacts of multiple barriers (ie takes into account where a crossing is present in the overall system). The assumption here, and backed by the extensive literature review in Chapter 1, is that the DCI framework is the best and most comprehensive tool available to measure ecosystem benefit and aquatic connectivity.

As described in Section 1.7, the most common approach to prioritizing restoration scenarios is a scoring-and-ranking method whereby individual barriers are scored based on a set of assessment criteria (Pess *et al.*, 1998; Taylor & Love, 2003; Karle, 2005). The basic idea with scoring-and-ranking is to move down the ordered list restoring barriers until the specific budget is exhausted (Kemp & O'Hanley, 2010). In this research the results from FishXing and subjective classification (from the secondary assessment on non-culvert structures) were used to put together a restoration scenario where the structure with the lowest passability score was placed first on the list (most important according to this scheme), the structure with the next lowest score was placed second and so on. The resulting scoring-and-ranking restoration scheme was then run through the DCI model and step-wise ecosystem benefit associated with each step was recorded.

A second restoration scenario was compiled based on the Local Ecological Knowledge of local fisherman. In the spring of 2011 a prioritization workshop was held at Kejimkujik comprising of several Resource Conservation staff and a highly knowledgeable group of Kejimkujik's creel census volunteers. Recognizing that collectively, this group of volunteers holds hundreds of years of ecological knowledge pertaining to the park, the group was asked to prioritize all stream crossing structures based on their knowledge of the area. The purpose of the LEK prioritization workshop was to (1) take a step back from hard science/computational models for a moment and take more of a grass roots look at the project, (2) to flush out some information on what the real experts (the local fishermen, some of which have been fishing in the park for 40 years) thought were the most significant and therefore vulnerable habitats in the park, (3) to show the volunteers that Kejimkujik acknowledges their hard work and wants to include their LEK into the management structure, and (4) to compare the results of the parks DCI calculations with a restoration scenario based on the knowledge of the local experts.

The park's DCI calculations, including restoration scenarios provided by LEK and scoring-and-ranking methods, were undertaken by MSc candidate Greig Olford at Dalhousie University. All restoration scenarios were run through GIS and results provide step-wise connectivity improvements based on the different methods of prioritization.

3.6 Restoration Works

After obtaining results from the Parks Canada DCI-based ranking approach, and taking into account the results from the comparison scenarios (specifically the LEK findings), restoration work was initiated attempting to return conditions to their original state. By correcting the aquatic barriers and therefore restoring aquatic connectivity, the park was following its mandate to restore and maintain ecological integrity. In order to ensure restoration work was performed in an environmentally responsible manner, all contractors bidding on the project were required to hold an up to date Watercourse Alteration Certificate (Pouliot, D. 2011). Enforced and approved by the Nova Scotia Department of Environment and Labour and designed through partnership between the Department of Fisheries and Oceans (DFO), the Maritime College of Forestry and Technology, and various Federal and Provincial Governments, this certificate serves as proof that the heavy equipment operator conducting the restoration work holds the highest environmental watercourse alteration credentials (Service Nova Scotia and Municipal Relations, 2011). The watercourse alteration manual comprehensively describes precautionary measures and standard protocols to be followed throughout in stream work and should be referred to whenever protocol is questioned. This section will describe the entire restoration process including: the provincial/governmental guidelines taken into consideration, the selection of potential contractors, the bidding process and the methods used in restoring aquatic habitat.

Through the processes above, a Parks Canada DCI based restoration scenario was constructed and the next step was to submit an Environmental Assessment (EA) to the Department of Fisheries and Oceans (DFO) for in-stream work approval. The EA detailed the potential restoration sites and a full description of the proposed work, following provincial guidelines and best practices**.** Further information on watercourse alteration guidelines can be found online (Department of Fisheries and Oceans, 2011; Service Nova Scotia and Municipal Relations, 2011).

Upon EA approval, and following Parks Canada protocol, an Expression of Interest was sent out to all Nova Scotia contractors holding an up to date watercourse alteration certificate, a certification required by DFO and Parks Canada allowing in stream work to be conducted in fish habitat. Following the bidding practices of the agency, those contractors awarded the tender were notified and restoration dates were scheduled. It is noteworthy that some stream crossings were targeted to be done "in-house" (by Parks Canada themselves) when general works and resource conservation staff agreed that the materials and equipment required existed within the park.

During restoration at each site, Resource Conservation staff (including the author of this thesis) comprehensively detailed/recorded the different steps taken throughout the process. This site specific restoration description was also accompanied by full photo documentation in an effort to (1) ensure best practices were followed, (2) to make the process understandable and easy to follow and (3) so lessoned learned (positive or negative) could be communicated to others in the future. During restoration, officials from DFO visited each site to ensure quality of work, provide recommendations/feedback, and to monitor the aquatic ecosystem. A full detailed description of work at all restoration sites can be obtained from Kejimkujik National Park and National Historic Site of Canada.

3.7 Pre/Post Monitoring

In an effort to ensure quality of work, evaluate the mitigation measures used, and to better understand the potential impacts of restoration works on the aquatic ecosystem, a pre/during/post restoration monitoring program was established. Water quality was evaluated in relation to accepted parameters discussed in section 1.2 of this thesis. This evaluation of restoration work provided water quality information on each of the sites, allowed comparison of the results during and after the work, and document an otherwise overlooked, but critically important component of aquatic connectivity literature.

Physical water quality parameters were measured and recorded at all sites using a calibrated YSI 650 MDS. Water quality parameters monitored included: Temperature, pH, conductivity, salinity, total dissolved solids (TDS), and dissolved oxygen. On each site visit, water was tested at the first distinctive habitat (pool, riffle or run) upstream of the structure in question, and the first and second distinctive habitats downstream. A minimum of 18 water quality samples were collected at each site prior to restoration work providing a general overview (and seasonal variation) of each stream/river in question.

Monitoring was also undertaken throughout all restoration work and for a minimum of one month post restoration. Fish habitat suitability index graphs (Appendix A-C) were used as a threshold and to compare potential changes in water quality resulting from in-stream work.

Total suspended solids were also measured and recorded at each site prior to restoration (a minimum of 6 samples), during the work, one hour after, one week after, and one month after to determine potential impacts on the aquatic environment. Water samples were collected, filtered through a pre weighed Millipore glass fiber filter paper with a 1.2 um mesh size, dried at 140 ^{o}F for 24 hours, and re-weighed to determine total suspended solids in parts per million (ppm) (or milligrams per liter mg/l). The goal was to keep total suspended sediment concentrations during restoration as close to undisturbed levels as possible, and therefore having minimal impact on aquatic organisms. Keeping in mind that DFO can lay charges when concentrations exceed 25 ppm above base levels for prolonged periods, 25 ppm was used as the threshold when evaluation total suspended solids.

3.8 Measuring Success

In an effort to evaluate the success of the mitigation measures used, and to measurably determine overall success of the project, several methods were used. Success was measured on a site specific scale, and was also considered on a park wide scale using both biotic and abiotic components.

Pre, during, and post restoration water quality monitoring data was compared highlighting the success of the mitigation measures used during in-stream work. This was essentially an indicator of the level of disturbance to the ecosystem where minimal changes to baseline levels were considered optimal. Another method used to measure success was to repeat the secondary assessment on all restored structures to show passability improvements as determined by FishXing. If the restoration work was successful, and provincial/DFO guidelines were followed, passability should in theory be 100 percent at all restored crossings. Finally, the DCI tool was used to show measurable improvements in ecosystem benefit by exemplifying the increased connectivity of the park's waterways.

Although water quality measures and theoretical improvements (based on both FishXing and DCI results) were highlighted, the need to physically show success through biotic measures remained. Collectively, all Atlantic National Park's taking part in the Aquatic Connectivity study agreed that showing fish passage through the restored structures was a necessary and achievable measure of success. In combination with the abiotic success measures, it was determined that ultimately, confirming fish passage through all restored structures was mandatory in order to prove success of the work. In order to do so, Kejimkujik deployed several methods to document fish movement. Although some parks including Terra Nova and Fundy chose slightly more technical approaches such as telemetry, Kejimkujik and the author of this thesis choose the more traditional tagging, netting and visual surveying approaches.

Realizing the potential to integrate the parks existing fish tagging program into this study and in order to prove movement through various structures, Resource Conservation staff worked with local anglers to strategically tag fish in areas that would help show movement through the restored structures. This was a strategic move as it would (1) help prove biotic success through mark and recapture methods (using a number 2 gill-plate tag) already being undertaken within the park and (2) provide the local fishermen with another positive gesture recognizing their hard work and important role in managing the park's resources. Finally, parks staff used various netting techniques and even visual surveys to show fish movement.

3.9 Summary

As highlighted above, the methods used in this research took an integrative, multi-stakeholder collaborative approach to identify, prioritize, and restore barriers restricting fish movement in Kejimkujik National Park and National Historic Site of Canada. Through the methods described above, and following protocols agreed upon by several other Atlantic National Parks, Kejimkujik was able to measurably enhance freshwater ecosystem integrity communicated through the Dendritic Connectivity Index (DCI). Moreover, the methods described how Kejimkujik has worked extremely hard to incorporate valuable LEK into the decision making process, resulting in a mutually beneficial relationship and ultimately serving the best interests of the ecosystem in question.

All protocols and procedures used in this research are available to the public. If further information is required, refer to Cote's 2009 Aquatic Connectivity Monitoring Protocol, FishXing's website, Service Nova Scotia watercourse Alteration guidelines, DFO guidelines or contact Resource Conservation at Kejimkujik National Park and National Historic Site of Canada.

Chapter 4

ANALYSIS AND RESULTS

4.1 Introduction

While the previous chapter details the research methods used to most effectively identify, prioritize, and restore aquatic barriers fragmenting the landscape, this chapter highlights the results and findings of the research testing the hypothesis that the DCI method is the most efficient approach to maximizing ecosystem benefit. Moreover, it describes how Kejimkujik has chosen to act upon the findings, and provides detailed results regarding restoration works, pre/during/post monitoring data, and success measures (all of which are less commonly reported on in the literature).

4.2 Preliminary and Secondary Assessment Results

The initial stream crossing inventory found 177 structures within the boundaries of Kejimkujik National Park and National Historic Site of Canada. A total of 132 stream crossings were classified as culverts, 38 as bridges, 3 as dams, and 4 as "other" (Figure

4.1). Omitting the bridges (for reasons highlighted in the previous chapter), and acknowledging the presence of the dams (but not including them in potential restoration schemes for reasons discussed in Chapter 3), the preliminary assessment identified 15 structures (Table 4.1, Figure 4.2) existing on significant fish habitat requiring further investigation (12 culverts and 3 other).

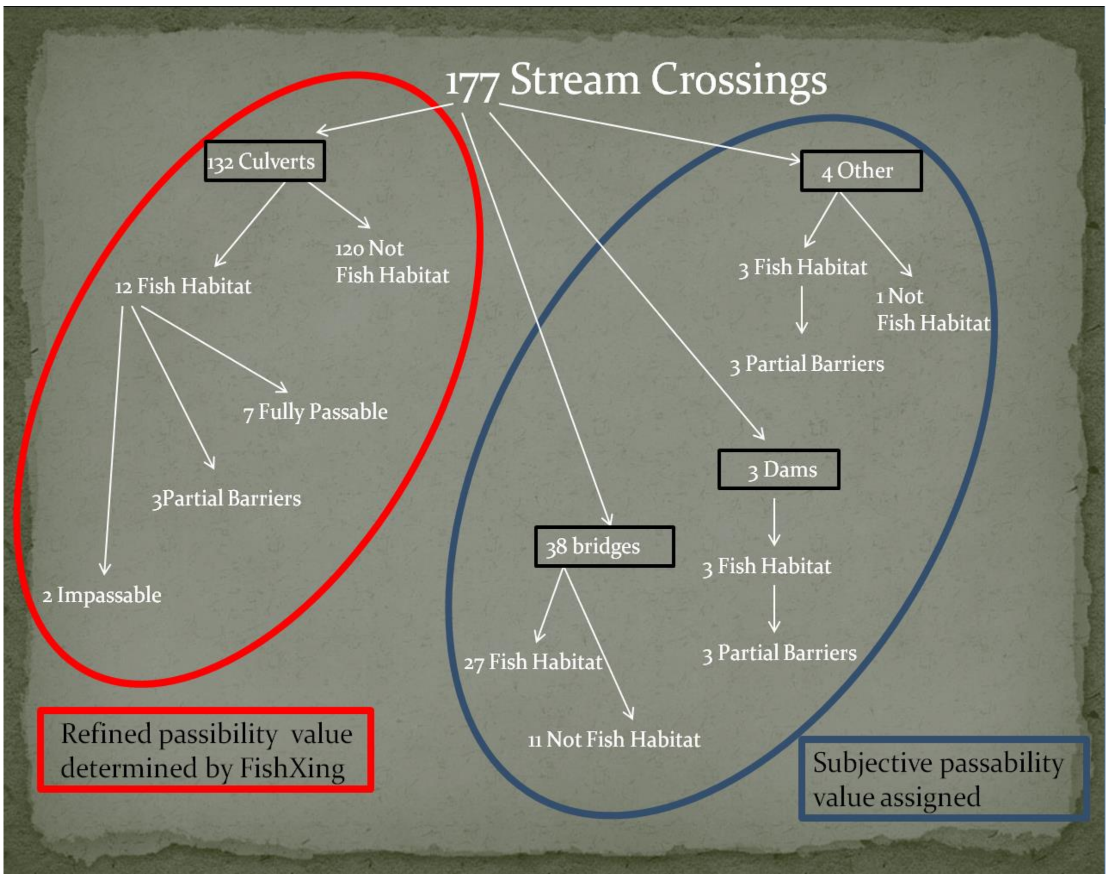


Figure 4.1. Stream Crossing Inventory and Preliminary Classification

Table 4.1. Fifteen Priority Stream Crossing Structures

Culvert ID	Stream Name	Watershed Name	Road/Trail Name	Fish Habitat	Crossing Type
CUL 003	Administration Brook	Unnamed Admin	Main Parkway	Yes	Culvert
CUL 004	Coyote Brook	Unnamed	Main Parkway	Yes	Culvert
CUL 007	Fire Pump Brook	Unnamed	Main Parkway	Yes	Culvert
CUL 014	Rogers Brook	Rogers Brook	Main Parkway	Yes	Culvert
CUL 035	Big Dam Road Brook	Flowing Waters	Big Dam Road	Yes	Culvert
CUL 038	Canning Field Road Brook	Rogers Brook	Canning Field Road	Yes	Culvert
CUL 055	Square Camp Brook	Peskowesk	Peskowesk Road	Yes	Culvert
CUL 078	Loon Lake Road North Brook	Loon Lake Stream	Loon Lake Road	Yes	Culvert
CUL 079	Loon Lake Road South Brook	Loon Lake Stream	Loon Lake Raod	Yes	Culvert
CUL 082	Weather Station Road Brook	Unnamed Admin	Weather Station	Yes	Culvert
CUL 099	Flowing Waters Trail Brook	Flowing Waters	Flowing Waters Trail	Yes	Culvert
CUL 100	Woodyard Road Rogers Brook	Unnamed	Compound Road	Yes	Culvert
CUL 112	Ben Lake Trail Brook	West River	Ben Lake Trail	Yes	Trail Crossing
CUL 175	Cobrielle North Branch Brook	Cobrielle/Mt	Cobrielle Logging Road	Yes	Old Logging Road
CUL 176	Powerline Rogers Brook	Rogers Brook	Powerline Trail	Yes	Trail Crossing

As outlined in the Methodology chapter, the 12 culverts existing on fish bearing streams were subject to the secondary assessment and the collected field data was run through FishXing to produce detailed site specific passability information. It was found that of the 12 culverts existing on fish habitat, 7 were fully passable (CUL 003, CUL 004, CUL 007, CUL 078, CUL 079, CUL 082, CUL 100) 3 were partially passable (CUL 014, CUL 035, CUL 055), and 2 were impassable (CUL 038, CUL099) (Table 4.2a, Table 4.2b, Table 4.2c, Table 4.3). The remaining 3 fish habitat structures (CUL 112, CUL 175, CUL 176) falling within the "other" category were subjectively assigned passability values (through methods described previously) and were all determined to be partially passable (Table 4.2 c, Table 4.3). Figure 4.2 illustrates the 15 priority structures and their spatial distribution within the park. Table 4.3 summarizes the above information. Detailed maps and photographs of each site can be found in the Appendix.

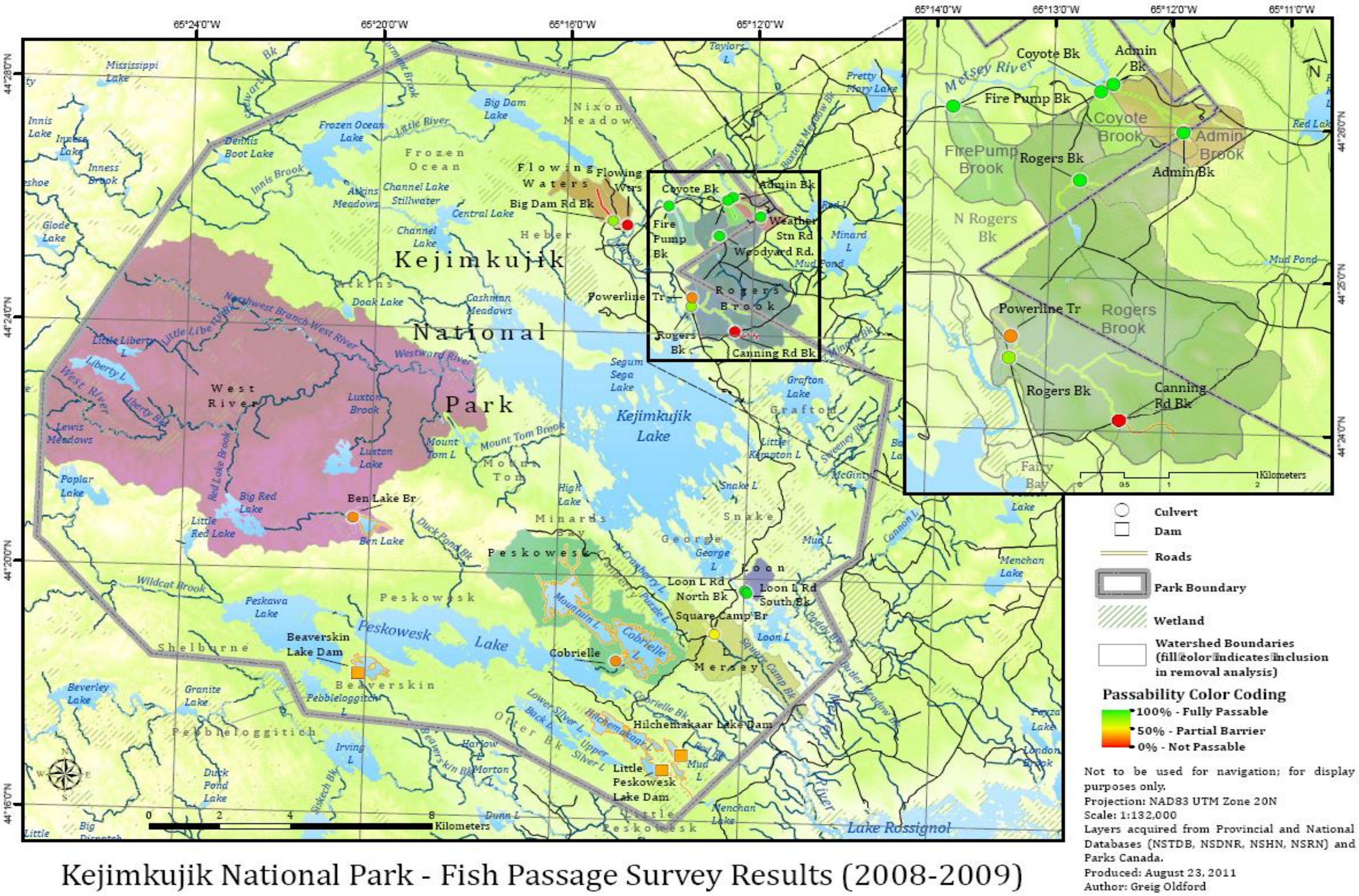


Figure 4.2. Fifteen priority Stream Crossing Structures at Kejimkujik

Table 4.2a. Priority Structure Attributes (CUL 03, CUL 04, CUL 07, CUL 14, CUL 35)

	CUL 03 Administration Brook	CUL 04 Coyote Brook	CUL 07 Fire Pump Brook	CUL 14 Rogers Brook	CUL 35 Big Dam Road Brook
Fish Length(cm)	10	10	10	10	10
Prolonged Speed(m/s)	0.5	0.5	0.5	0.5	0.5
Time to Exhaustion(s)	200	200	200	200	200
Burst Speed(m/s)	0.93	0.93	0.93	0.93	0.93
Time to Exhaustion(s)	20	20	20	20	20
Min. Depth(m)	0.1	0.1	0.1	0.1	0.1
Max Outlet Drop(m)	0	0	0	0	0
Inlet	0.8	0.8	0.8	0.8	0.8
Barrel	0.6	0.6	0.6	0.6	0.6
Outlet	0.8	0.8	0.8	0.8	0.8
Shape	Circular	Circular	Circular	Circular	Circular
Diameter(cm)	106	90	106	175	60
Material	Concrete	Concrete	Concrete	Annular 68*13	Annular 68*13
Entrance type	Headwall	Headwall	Headwall	Projecting	Headwall
Embedded	No	Yes	No	No	No
Percent Embedded	N/A	15.5	N/A	N/A	N/A
Culvert Roughness	0.013	0.013	0.013	0.024	0.024
Bottom Roughness	N/A	0.03	N/A	N/A	N/A
Culvert Length(m)	29.8	19.85	20.4	35.35	7.7
Inlet Bottom Elevation(m)	3.27	3.27	3.02	10.37	2.53
Culvert Slope(%)	0.12	2.02	1.52	-1.05	-0.91
Outlet Bottom Elevation(m)	3.64	3.67	3.33	10	2.46
Low Flow(cms)	0.004207	0.001371	0.002649	0.036119	0.005592
High Flow(cms)	0.057817	0.018843	0.036413	0.496403	0.07685
Passibility Index	1	1	1	0.81	0.86
Barrier Type	N/A	N/A	N/A	Velocity at High Flow	Velocity at High Flow

Table 4.2b. Priority Structure Attributes (CUL 38, CUL 55, CUL 78, CUL 79, CUL 82)

	CUL 38 Canning Field Road Brook	CUL 55 Square Camp Brook	CUL 78 Loon Lake Road North Brook	CUL 79 Loon Lake Road South Brook	CUL 82 Weather Station Road Brook
Fish Length(cm)	10	10	10	10	10
Prolonged Speed(m/s)	0.5	0.5	0.5	0.5	0.5
Time to Exhaustion(s)	200	200	200	200	200
Burst Speed(m/s)	0.93	0.93	0.93	0.93	0.93
Time to Exhaustion(s)	20	20	20	20	20
Min. Depth(m)	0.1	0.1	0.1	0.1	0.1
Max Outlet Drop(m)	0.72	0	0.04	0.02	0
Inlet	0.8	0.8	0.8	0.8	0.8
Barrel	0.6	0.6	0.6	0.6	0.6
Outlet	0.8	0.8	0.8	0.8	0.8
Shape	Circular	Circular	Circular	Circular	Circular
Diameter(cm)	60	60	35	60	41
Material	Annular 68*13	Annular 68*13	Annular 68*13	Annular 68*13	Annular 68*13
Entrance type	Projecting	Projecting	Projecting	Wingwalls	Projecting
Embedded	No	No	Yes	Yes	No
Percent Embedded	N/A	N/A	14	4	N/A
Culvert Roughness	0.021	0.024	0.021	0.021	0.024
Bottom Roughness	N/A	N/A	0.03	0.03	N/A
Culvert Length(m)	9.1	6	6.2	4.1	5.87
Inlet Bottom Elevation(m)	2.46	9.96	2.4	1.899	2.26
Culvert Slope(%)	-1.15	-0.67	-0.48	0.05	2.6
Outlet Bottom Elevation(m)	2.35	10	2.37	1.901	2.42
Low Flow(cms)	0.005421	0.003975	0.002895	0.002895	0.000396
High Flow(cms)	0.07451	0.054624	0.03979	0.03979	0.005442
Passibility Index	0	0.7	1	1	1
Barrier Type	Outlet Drop	Velocity at High Flow	N/A	N/A	N/A

Table 4.2c. Priority Structure Attributes (CUL 99, CUL 100, CUL 112, CUL 175, CUL 176)

	CUL 99 Flowing Waters Trail	CUL 100 Woodyard Road Rogers Brook	CUL 112 Ben Lake Trail Brook	CUL 175 Cobrielle North Branch Brook	CUL 176 Powerline Rogers Brook
Fish Length(cm)	10	10	10	10	10
Prolonged Speed(m/s)	0.5	0.5	0.5	0.5	0.5
Time to Exhaustion(s)	200	200	200	200	200
Burst Speed(m/s)	0.93	0.93	0.93	0.93	0.93
Time to Exhaustion(s)	20	20	20	20	20
Min. Depth(m)	0.1	0.1	0.1	0.1	0.1
Max Outlet Drop(m)	0		N/A	N/A	N/A
Inlet	0.8	0.8	N/A	N/A	0.8
Barrel	0.6	0.6	N/A	N/A	0.6
Outlet	0.8	0.8	N/A	N/A	0.8
Shape	Circular	Circular	N/A	N/A	N/A
Diameter(cm)	60	75	N/A	N/A	N/A
Material	Annular 68*13	Annular 68*13	N/A	N/A	N/A
Entrance type	Projecting	Projecting	N/A	N/A	N/A
Embedded	No	No	N/A	N/A	N/A
Percent Embedded	N/A	N/A	N/A	N/A	N/A
Culvert Roughness	0.021	0.024	N/A	N/A	N/A
Bottom Roughness	N/A	N/A	N/A	N/A	N/A
Culvert Length(m)	5.6	4.38	N/A	N/A	N/A
Inlet Bottom Elevation(m)	2.61	1.47	N/A	N/A	N/A
Culvert Slope(%)	-7.14	0.38	N/A	N/A	N/A
Outlet Bottom Elevation(m)	2.25	1.49	N/A	N/A	N/A
Low Flow(cms)	0.008256	0.002978	0.003032	0.044509	0.000562
High Flow(cms)	0.113465	0.04093	0.041671	0.611713	0.007726
Passibility Index	0	1	0.5	0.5	0.5
Barrier type	Collapsed Culvert	N/A	Collapsed Trail	Old Logging Road in Stream	Collapsed Trail

Table 4.3. Passibility Summary of Priority Structures

Culvert ID	Stream Name	Fish Habitat	Crossing Type	Classification	Passability	Value Obtained Through:
CUL 003	Administration Brook	Yes	Culvert	Fully Passable	1	FishXing
CUL 004	Coyote Brook	Yes	Culvert	Fully Passable	1	FishXing
CUL 007	Fire Pump Brook	Yes	Culvert	Fully Passable	1	FishXing
CUL 078	Loon Lake Road North Brook	Yes	Culvert	Fully Passable	1	FishXing
CUL 079	Loon Lake Road South Brook	Yes	Culvert	Fully Passable	1	FishXing
CUL 082	Weather Station Road Brook	Yes	Culvert	Fully Passable	1	FishXing
CUL 100	Woodyard Road Rogers Brook	Yes	Culvert	Fully Passable	1	FishXing
CUL 035	Big Dam Road Brook	Yes	Culvert	Partially Passable	0.86	FishXing
CUL 014	Rogers Brook	Yes	Culvert	Partially Passable	0.81	FishXing
CUL 055	Square Camp Brook	Yes	Culvert	Partially Passable	0.7	FishXing
CUL 112	Ben Lake Trail Brook	Yes	Trail Crossing	Partially Passable	0.5	Subjective Classification
CUL 175	Cobrielle North Branch Brook	Yes	Old Logging Road	Partially Passable	0.5	Subjective Classification
CUL 176	Powerline Rogers Brook	Yes	Trail Crossing	Partially Passable	0.5	Subjective Classification
CUL 038	Canning Field Road Brook	Yes	Culvert	Impassable	0	FishXing
CUL 099	Flowing Waters Trail Brook	Yes	Culvert	Impassable	0	FishXing

The results from the secondary assessment (Table 4.3) indicate that 7 of the 15 priority structures (CUL 003, CUL 004, CUL 007, CUL 078, CUL 079, CUL 082, CUL 100) are fully passable allowing fish movement 100 percent of the time (all year). Therefore these structures were not considered in restoration prioritization schemes as they have no impact on the aquatic connectivity status of Kejimkujik. The remaining 8 sites however (CUL 014, CUL 038, CUL 055, CUL 099, CUL 100, CUL 112, CUL 175, CUL 176) contributed (at various degrees) to the fragmentation of the aquatic landscape and were assessed by the prioritization schemes that follow.

4.3 Aquatic Connectivity Status of Kejimkjuik

Having identified all of the stream crossing structures potentially affecting the parks aquatic connectivity, and using FishXing (where applicable) to provide refined passability values on the priority structures, the data were run through the DCI model to determine the connectivity status of the park.

As touched upon previously, it was collectively agreed upon (by all Atlantic National Parks) that in each park, aquatic connectivity restoration efforts should attempt to improve the connectivity status to 90 % or better (using the DCI as the common measure of connectivity). Using the passability data above to populate the DCI, results show that the connectivity status of Kejimkujik, as it existed before this project was 93.20 %. This number exceeds the targeted goal of 90 %, and therefore, the logical decision was made to maximize the DCI gain (get it to as close to 100 % as possible) given the parks available Aquatic Connectivity budget and resources. It was determined that in order to maximize ecosystem benefit, restoration decisions must be made in an order where each structure remediation yielded the biggest gain in connectivity, therefore maximizing ecosystem benefit. This process will be described in the next section.

Having made the decision that the three dams existing within the park would not be flagged as potential restoration sites (and therefore would not be included in prioritization considerations), the DCI was run to determine what the connectivity status of the park would be if all other identified structures were restored. It was determined that the park's maximum possible connectivity score would be 97.75%, with the dams accounting for the remaining 2.25 %. Therefore, theoretically, the remediation of the 8 identified structures exhibiting restrictive qualities would collectively improve the parks DCI value by 4.55 %.

4.4 Prioritization Results

The first prioritization scenario (Table 4.4) was put together using a traditional scoring-and-ranking technique based on the passability results from FishXing and subjective classification (seen in Table 4.3). Barriers in this prioritization scheme were ordered in a manner where the structure with the lowest passability score was placed first on the list, the structure with the next lowest score placed second, and so on. The prioritization scenario was then run through the DCI model to determine ecosystem (or DCI) gains based on each restoration step (that would theoretically take place) (Table 4.4). Although this prioritization scenario restores barriers in a manner according to site specific functionality (most restrictive to least restrictive), because it ignores the spatial structure of where barriers exist within the system, the ecosystem gains are not optimal. In other words, if restoration was to take place in this order, the first structure would not necessarily yield the best statistical gain and ecosystem benefit would not be maximized. Take for example the first prioritized barrier CUL 038. Although it is a full barrier to fish movement, the ecosystem gain by restoring it first is much less than if CUL 014, CUL 099, or CUL 175 were restored first.

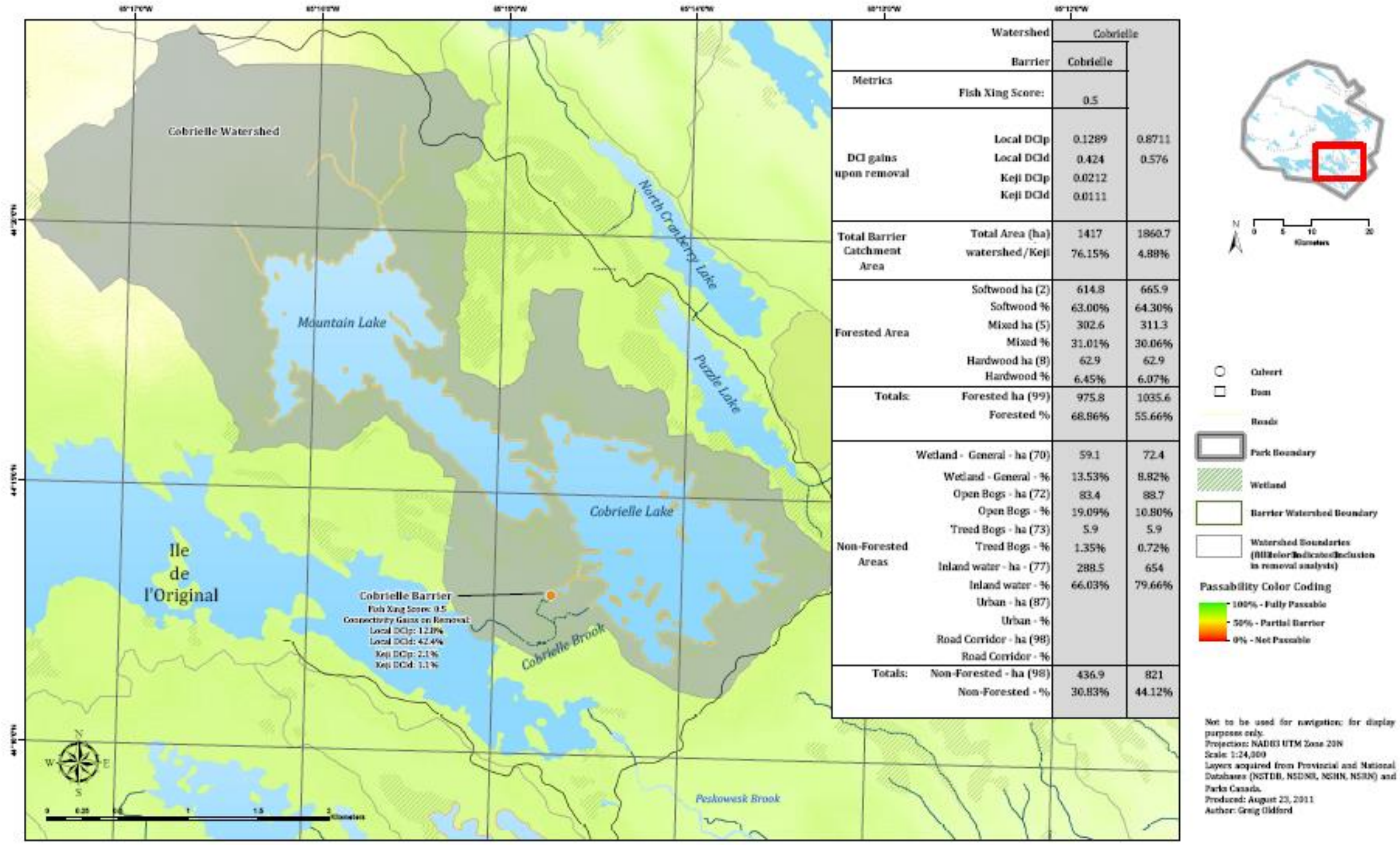
Table 4.4. Prioritization Scenario Based on Scoring-and-Ranking Technique

Culvert ID	Crossing	Fishxing	Ecosystem Gain	Cumulative Gain	Percentage of Possible Gain
CUL 038	Canningfield Road	1	0.400	0.400	8.791
CUL 099	Flowing waters Trail	2	0.770	1.170	16.923
CUL 112	Ben Lake	3	0.320	1.490	7.033
CUL 176	Powerline	4	0.060	1.550	1.319
CUL 175	Cobrielle North Branch	5	2.130	3.680	46.813
CUL 055	Square Camp Brook	6	0.080	3.760	1.758
CUL 014	Rogers Brook	7	0.700	4.460	15.385
CUL 035	Big Dam Road	8	0.090	4.550	1.978
			4.550		**100.000**

The second prioritization scenario (Table 4.5) was based solely on Local Ecological Knowledge (LEK). As with the scoring-and-ranking approach, ecosystem gains during each restoration step are not optimal using the LEK prioritization scenario (Table 4.5). In fact, cumulative gains suggest that the scoring-and-ranking technique is a more effective approach to maximize ecosystem benefit throughout the restoration process (according to the DCI framework). One main reason for this is that LEK ranks CUL 175 low on the ordered list (7th of 8) but it has significant gains upon restoration according to the DCI. The fishermen gave this structure a low priority because of the presence of the Cobrielle South Branch which also connects Peskowesk and Cobrielle Lake's. The South Branch was understood to be a fully passable connection, therefore making the North Branch less significant in the opinion of LEK submissions (Figure 4.3). Another contributing factor was the low ranking of CUL 014 Rogers Brook. Although the potential ecosystem gain associated with restoring this structure is large (3rd biggest potential gain), the local fishermen are confident fish can pass the structure all year around and therefore it was placed last on the list.

Table 4.5. Prioritization Scenario Based on Local Ecological Knowledge

Culvert ID	Crossing	LEK	Ecosystem Gain	Cumulative Gain	Percentage of Possible Gain
CUL 099	Flowing waters Trail	1	0.770	0.770	16.923
CUL 035	Big Dam Road	2	0.090	0.860	1.978
CUL 038	Canningfield Road	3	0.400	1.260	8.791
CUL 176	Powerline	4	0.060	1.320	1.319
CUL 112	Ben Lake	5	0.330	1.650	7.253
CUL 055	Square Camp Brook	6	0.070	1.720	1.538
CUL 175	Cobrielle North Branch	7	2.130	3.850	46.813
CUL 014	Rogers Brook	8	0.700	4.550	15.385
			4.550		**100.000**



	Watershed	Cobrielle	
	Barrier	Cobrielle	
Metrics	Fish Xing Score:	0.5	
DCI gains upon removal	Local DCIp	0.1289	0.8711
	Local DCId	0.424	0.576
	Keji DCIp	0.0212	
	Keji DCId	0.0111	
Total Barrier Catchment Area	Total Area (ha)	1417	1860.7
	watershed/Keji	76.15%	4.88%
Forested Area	Softwood ha (2)	614.8	665.9
	Softwood %	63.00%	64.30%
	Mixed ha (5)	302.6	311.3
	Mixed %	31.01%	30.06%
	Hardwood ha (8)	62.9	62.9
	Hardwood %	6.45%	6.07%
Totals:	Forested ha (99)	975.8	1035.6
	Forested %	68.86%	55.66%
Non-Forested Areas	Wetland - General - ha (70)	59.1	72.4
	Wetland - General - %	13.53%	8.82%
	Open Bogs - ha (72)	83.4	88.7
	Open Bogs - %	19.09%	10.80%
	Treed Bogs - ha (73)	5.9	5.9
	Treed Bogs - %	1.35%	0.72%
	Inland water - ha - (77)	288.5	654
	Inland water - %	66.03%	79.66%
	Urban - ha (87)		
	Urban - %		
	Road Corridor - ha (98)		
	Road Corridor - %		
Totals:	Non-Forested - ha (98)	436.9	821
	Non-Forested - %	30.83%	44.12%

Kejimkujik National Park - Cobrielle Watershed Barriers to Fish Passage

Figure 4.3 Cobrielle North and South Branches.

Interestingly, it could be argued that the spatial dimension (missing in scoring-and-ranking scenario) is present and influencing results in this LEK scheme, as the fishermen are fully aware of where each structure exists within the system. However, ecosystem gains resulting from each incremental step still do not show ecosystem gain maximization indicating (1) the fishermen do not have a full understanding of the ecosystem and the ability of fish to pass the structures, (2) inputs, interactions, and realities beyond the capacity of the computational models (FishXing and the DCI) must exist or (3) one or more of the many assumptions made by FishXing or the DCI does not hold true. This is further discussed in chapter 5 of this thesis.

The final prioritization scenario (suggested by the DCI itself) took into account both the degree of passability of each culvert, and the spatial distribution of the barriers (Table 4.6). Unlike the above methods where prioritization schemes were not influenced by the DCI itself (rather the DCI was used to assess gains associated with the given restoration scheme), this approach used the DCI as the tool to prioritize restoration sites *and* to assess the impacts on ecosystem gains. Because this method was able to assess the cumulative impact of multiple barriers (with refined passability values provided by FishXing), the ecosystem gains based on each restoration step appear optimal (Table 4.6).

Table 4.6. Prioritization Scenario Based on the DCI Approach

Culvert ID	Crossing	DCI	Ecosystem Gain	Cumulative Gain	Percentage of Possible Gain
CUL 175	Cobrielle North Branch	1	2.110	2.110	46.374
CUL 099	Flowing waters Trail	2	0.780	2.890	17.143
CUL 014	Rogers Brook	3	0.590	3.480	12.967
CUL 038	Canningfield Road	4	0.500	3.980	10.989
CUL 112	Ben Lake	5	0.320	4.300	7.033
CUL 035	Big Dam Road	6	0.090	4.390	1.978
CUL 176	Powerline	7	0.080	4.470	1.758
CUL 055	Square Camp Brook	8	0.080	4.550	1.758
			4.550		**100.000**

Based on the interrelationships between and amongst barriers and the influence structures have on each other, the DCI highlights the barrier that will produce the greatest ecosystem gain upon removal and places it first on the ordered list (in this case CUL 175 with a potential gain of 2.11). Next, the DCI assumes this barrier has been restored (no longer has restrictive qualities or influence on other structures), and recalculates all of the possible scenarios (this time there are only 7 barriers considered instead of 8). The DCI then determines what structure will now yield the best gain (in this case CUL 099 with a potential gain of 0.780). This process is repeated until all barriers are theoretically restored (Table 4.6). The benefits of prioritizing restoration efforts in this way are reflected in the ecosystem gain results where without exception, potential ecosystem gains descend (or become smaller) with each restoration step and cumulative gains are maximized from the first to the last structure (Table 4.6, Figure 4.4). The significance of this finding is that if, for example, restoration was to stop after the second structure, the observed ecosystem benefit would be 2.89 in the DCI scenario and only 1.17 and .086 in the FishXing and LEK scenarios respectively (Figure 4.4). In many real world situations where all barriers cannot realistically be restored (due to budgets, resources etc.), the benefits of such an approach become extremely obvious and critically important in decision making.

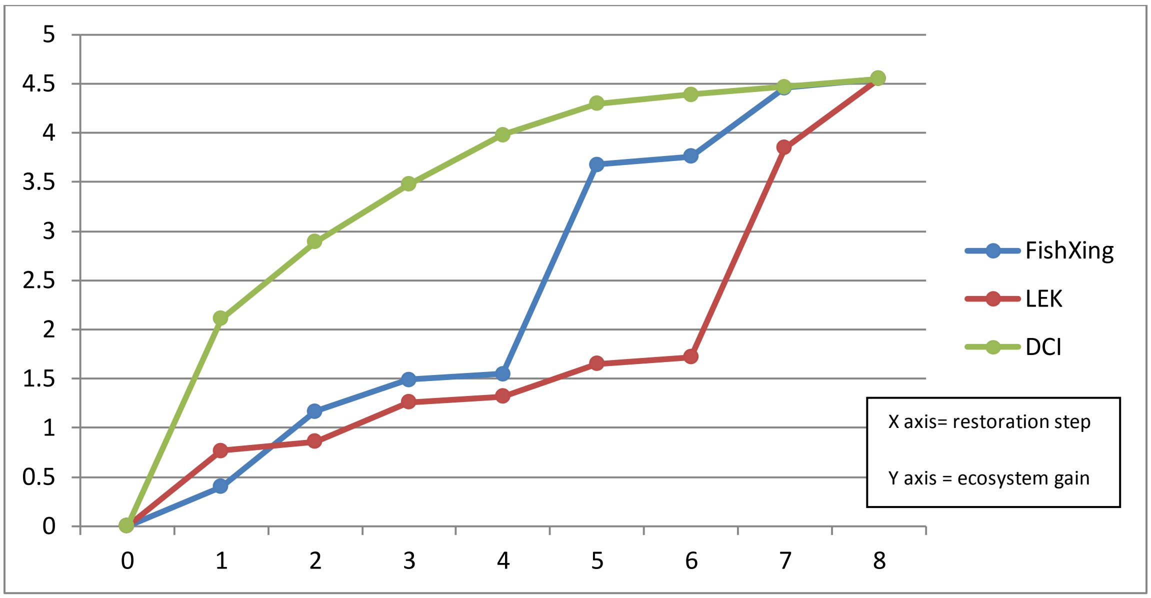


Figure 4.4. Prioritization Comparison Based on Cumulative Ecosystem Gains

The results above clearly indicate that in terms of prioritizing restoration initiatives, the DCI is the best approach to maximizing ecosystem benefit. It has been highlighted that in some cases, the location of where a barrier exists within the system has more significant influence on the connectivity than does the degree of restriction. That is to say that in some cases, fixing a partial barrier can produce more ecosystem gain than restoring a full barrier, depending on the spatial structure of the barriers in question.

This realization could not be measured if a tool such as the DCI had not been used. By assessing the cumulative impacts of multiple barriers, this research has provided a restoration scheme for Kejimkujik that should maximize ecosystem benefit during each phase of restoration (discussed in chapter 5 of this thesis). The significance of this extends far beyond Kejimkujik or the Atlantic National Parks, as the approach can be adopted by others and applied to situations where a restoration budget will only allow the remediation of 1 or 2 structures (where restoring the structures that yield the maximum gain is critical).

4.5 Restoration Works

Although it was originally the intention to restore all structures at Kejimkujik in the sequence determined by the DCI prioritization scheme (therefore maximizing ecosystem gains), the realities of working under government protocols, requirements, and recommendations caused the restoration process to stray from this course. Furthermore, the LEK results had to be seriously considered as knowledge outside of the models computational abilities came into play (see section 5.5 in the discussion).

Because it appeared that time and resources were available to restore all priority structures existing within the park, restoration order veered off track and followed a path where structures were restored in a logical manner as staff, materials, contractors and equipment operators became available. For example, following EA approval, on August

31st 2010, CUL 176 Powerline (Appendix E) was restored (prior to the other sites ranked higher on the DCI list) as parks staff had the internal capacity to properly carry out the work (which in this case was simply clearing debris and the old culvert out of the stream). Likewise, on September 1st 2010, a fish ladder was installed in CUL 014 Rogers Brook (Appendix F) and on September 2nd 2010, CUL 055 Square Camp Brook (Appendix G) was replaced "in house" (meaning by park staff with park equipment) with a culvert having sufficient diameter to handle the flow. On September 9th and 10th 2010, contractors removed the full barrier and erected a bridge at CUL 099 Flowing Waters Trail (Appendix H). In the summer of 2011, while awaiting DFO approval for CUL 035 Big Dam Road and CUL 038 Canningfield Road, restoration at CUL 112 ben Lake trail (Appendix I) took place (which similar to CUL 176 simply required debris clearing). With the "go ahead" from DFO and the certified contractor finally available, on September 21st 2011, CUL 035 Big Dam Road (Appendix J) was replaced with a structure having appropriate diameter to handle the flow. A step by step restoration description for each site can be accessed by contacting Resource Conservation at Kejimkujik. Photos and maps of each of the 8 potential Restoration sites can be found in the Appendix.

To date, and although the materials have been purchased to properly replace the existing culvert with a bridge, Kejimkujik has yet to hear back from DFO regarding approval or recommendations on the proposed habitat alteration at CUL 038 Canningfield Road (Appendix K). This is unfortunate as all three prioritization schemes

(FishXing, LEK and the DCI) assessed CUL 38 as being one on the most important structures to fix (ranking 1st, 3rd and 4th respectively).

Finally, the decision was made to exclude CUL 175 Cobrielle North Branch (Appendix L) as a potential restoration site at present, as LEK has highlighted the presence of the fully passable South Branch. Further investigation is required before making decisions to restore the highly inaccessible structure and future research will help to determine its importance in aquatic connectivity. This will be further discussed in Chapter 5.

4.6 Assessing Ecosystem Impact through Pre/Post Monitoring

This section will summarize the pre/post monitoring results providing insight into the quality of restoration work and the impact (or lack thereof) on the aquatic ecosystem. For the purposes of this thesis, monitoring results will be presented only for sites that were subject to significant habitat alteration (in-stream work with heavy equipment) which include CUL 035 (Big Dam Road), CUL 055 (Square Camp Brook), and CUL 099 (Flowing Waters Trail).

The first such restoration site was CUL 055 (Square Camp Brook), restored "in house" on September 2nd 2010. Interestingly, due to extremely dry weather during the time of work, there was no flowing water at the site and therefore water quality and suspended sediment data are missing for this period (as seen in Figures

4.5through 4.8). The figures below regarding CUL 055 were derived from 24 samples collected between June 29th 2010 and October 9th 2010.

As seen in Figure 4.5, there was a significant drop in Temperature following restoration work at CUL 055. This can be explained by the dates during which the samples were taken (into October), as an annual decline in temperature during this time is expected. Figure 4.6 illustrates an apparent increase in Dissolved Oxygen (D.O.) post restoration which can be explained in part by the relationship between temperature and D.O. whereby a decrease in Temperature causes D.O. saturation levels to increase.

Figure 4.7 shows that post restoration pH levels remain stable and similar to pre/restoration levels. Finally, Figure 4.8 shows that suspended sediment concentrations remain extremely low post restoration, indicating that the restoration had virtually no impact on suspended sediment concentrations in the aquatic ecosystem.

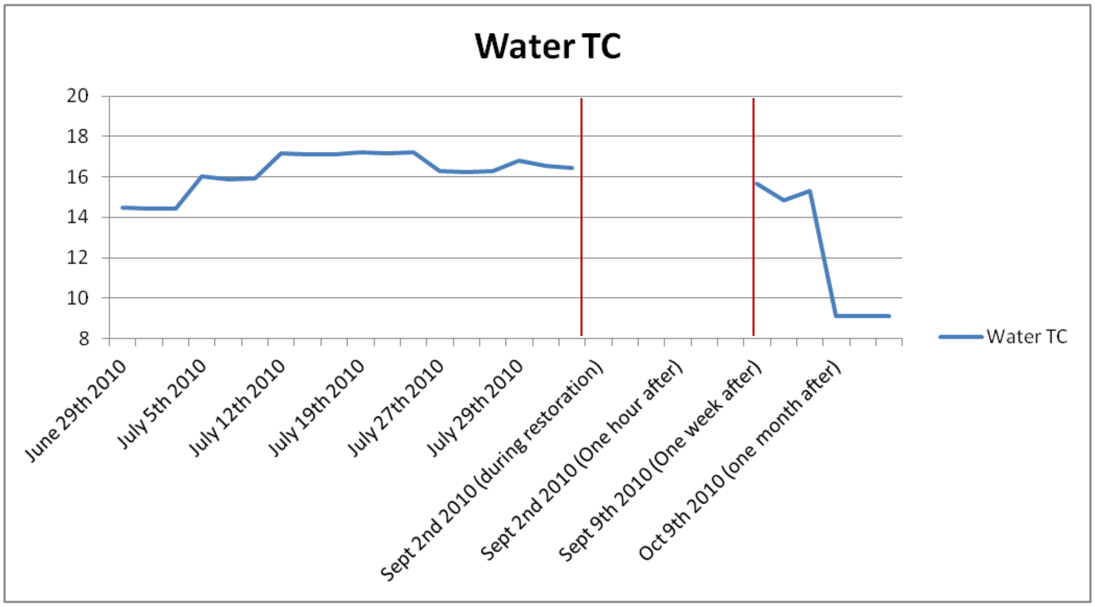


Figure 4.5 CUL 055 Water Temperature- Pre/Post Restoration

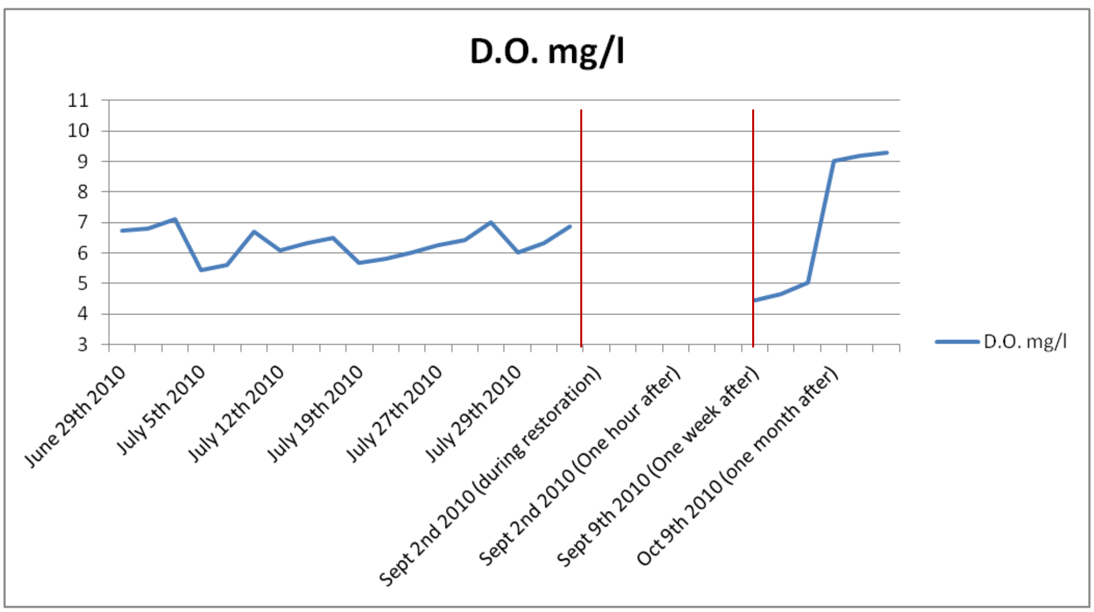


Figure 4.6 CUL 055 Dissolved Oxygen - Pre/Post Restoration

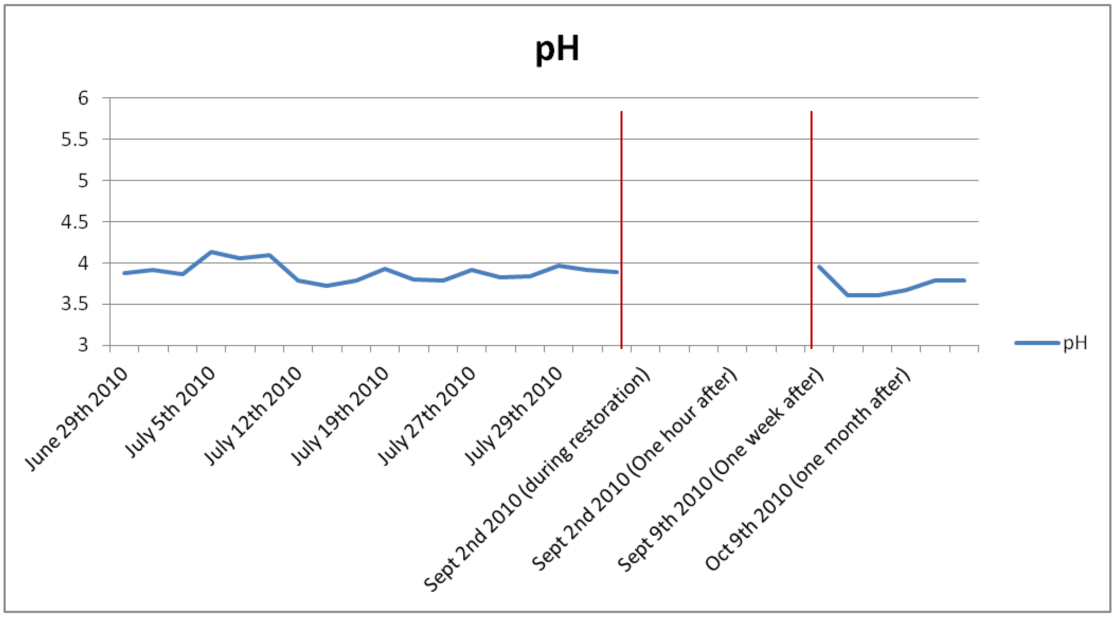


Figure 4.7 CUL 055 pH - Pre/Post Restoration

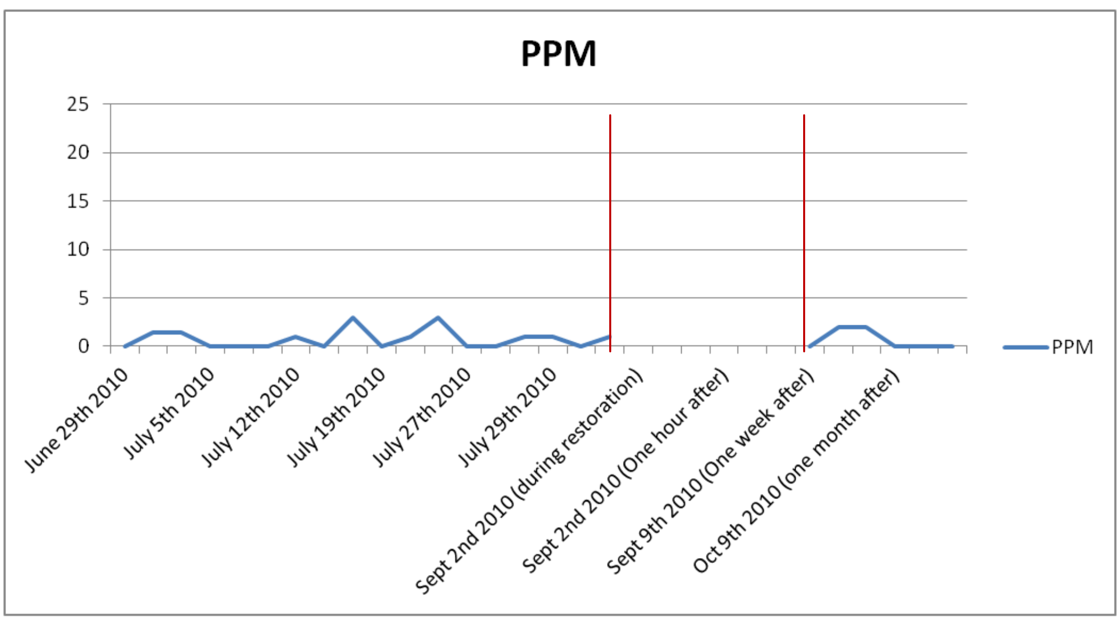


Figure 4.8 CUL 055 Suspended Sediment - Pre/Post Restoration

The second restoration site requiring heavy equipment was CUL 099 (Flowing Waters Trail), restored on September 9th and 10th 2010. The figures below regarding CUL 099 were derived from 35 samples collected between June 29th 2010 and October 15th 2010. 9 of these samples were collected during the in-stream work (values between the red lines in each figure).

Figure 4.9 illustrates that the restoration work had no impact on temperature (as could be expected). Following restoration, the data does highlight a decrease in temperature however as explained above, this is a result of seasonal variation and not related to the restoration work itself. Results in Figure 4.10 show that during restoration, D.O. concentrations dropped dramatically for a short period of time (one single data point) but recovered within an hour. As explained in Kejimkujik's step by step restoration description (contact Resource Conservation for more information) this sample was taken in the area isolated between cauffer dams which explains the decrease (water was not running in this area). Figure 4.10 shows that post restoration, D.O. levels increased which again can be explained by its relationship with temperature.

Interestingly, pH values appear to slightly decrease during the restoration work and appear to remain slightly below average post restoration (Figure 4.11). This phenomenon was poorly understood but could be attributed to equipment calibration issues; restoration materials (crushed rock) used in-stream, an acid rain event, or natural inputs. It should be noted that water quality data from 2011 shows that pH values returned to baseline levels.

Figure 4.12 clearly indicates that during restoration, suspended sediment levels increased to a maximum of 80 ppm; however, concentrations returned to natural levels within an hour of in-stream work taking place. It should be emphasized that the 80 ppm reading was observed in the work area (between the cauffer dams) and never entered the ecosystem (it was pumped into the woods as described in Kejimkujik's step by step restoration description). Results here clearly show that although suspended sediment levels were increased during restoration, they quickly returned to natural levels indicating minimal stress on aquatic organisms.

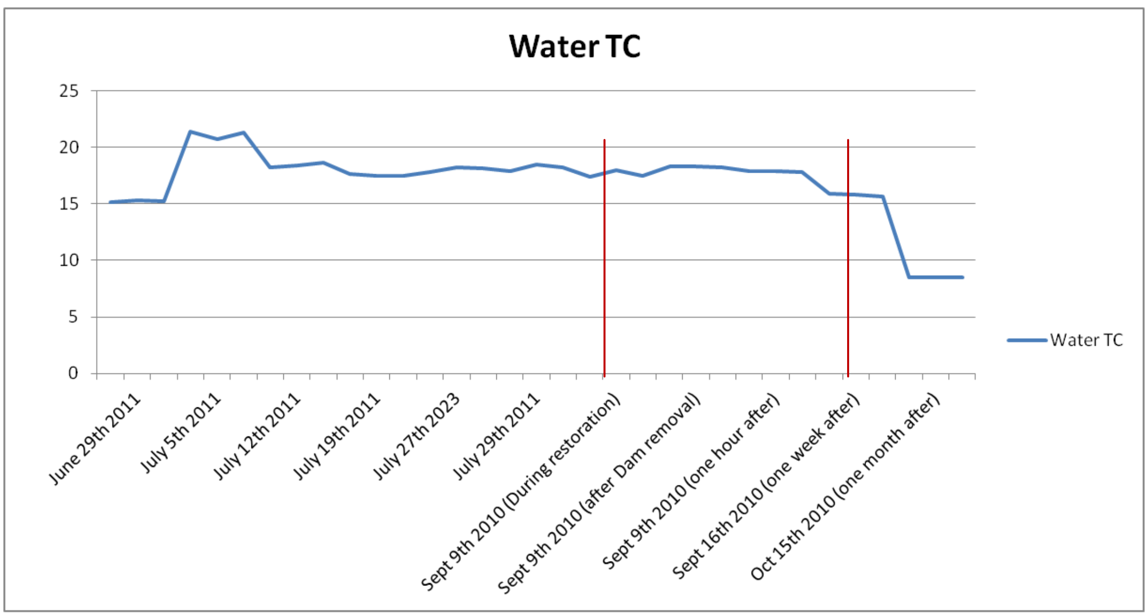


Figure 4.9 CUL 099 Temperature - Pre/Post Restoration

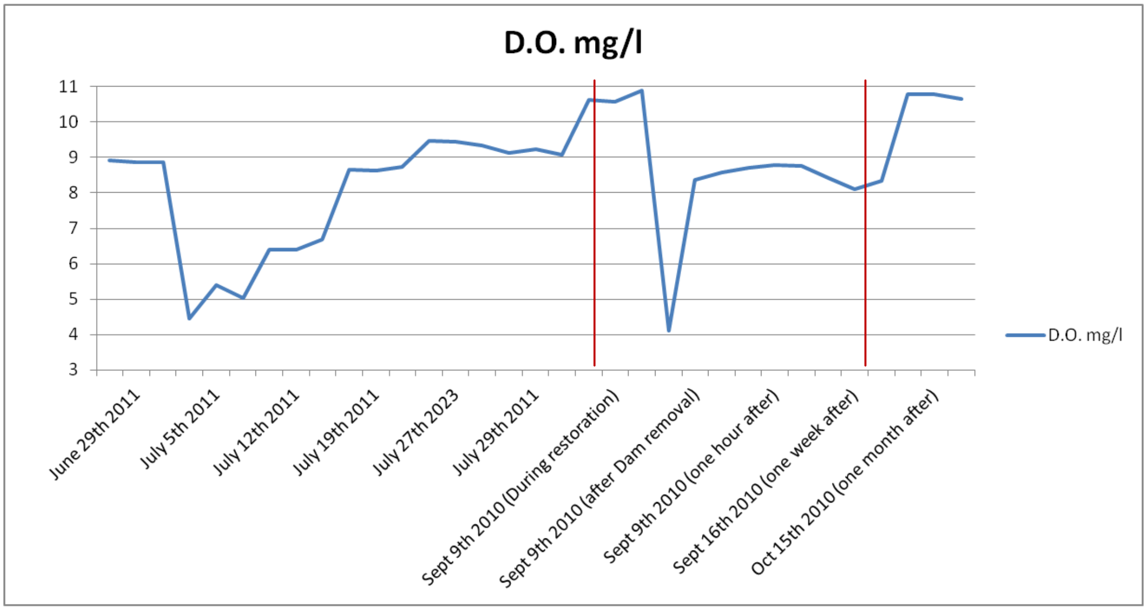


Figure 4.10 CUL 099 Dissolved Oxygen - Pre/Post Restoration

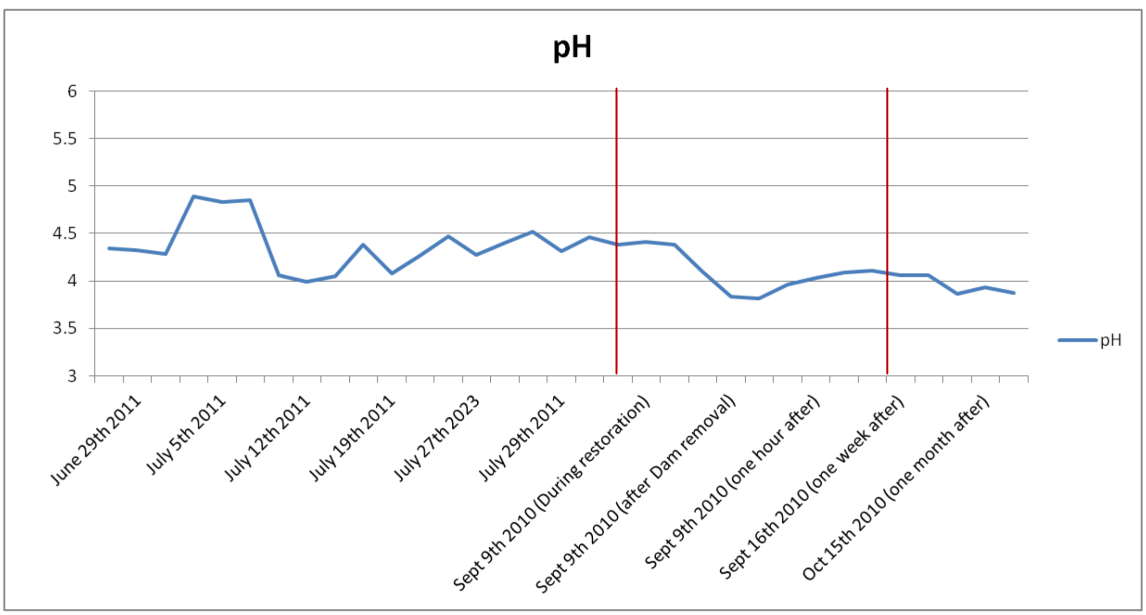


Figure 4.11 CUL 099 pH - Pre/Post Restoration

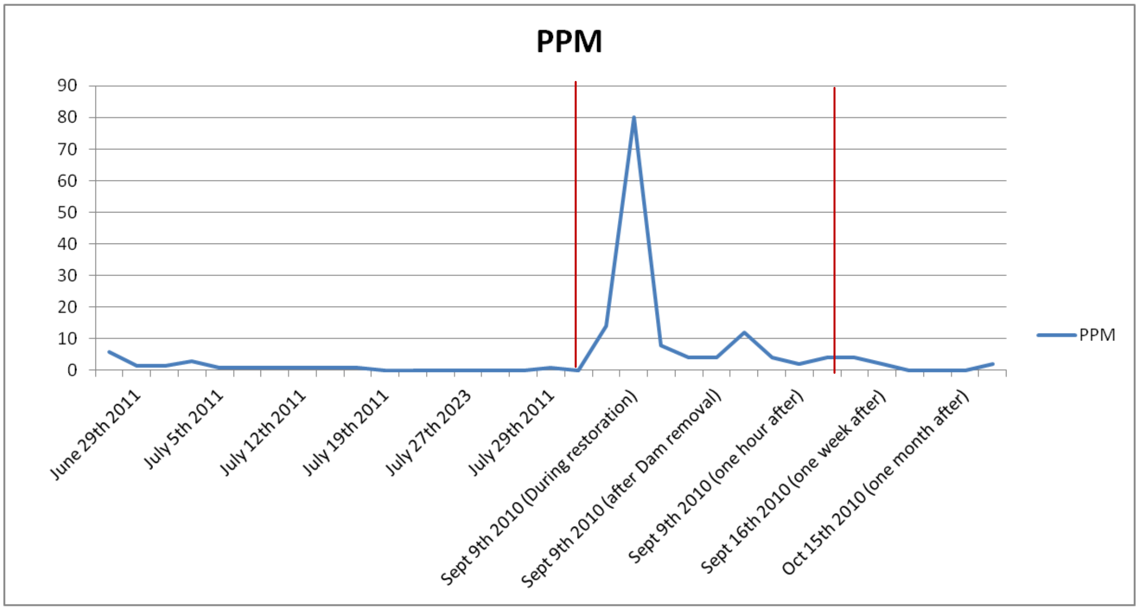


Figure 4.12 CUL 099 Suspended Sediments - Pre/Post Restoration

The final restoration site requiring significant habitat alteration was CUL 035 (Big Dam Road), where restoration occured on September 21st 2011. Because this structure was restored in 2011 (and therefore more pre monitoring data existed), the figures below were constructed using 51 readings, 9 of which were taken during restoration.

Similar to the other sites, there was no apparent change in temperature during restoration and folowing the work, Temperatures began to decline due to seasonal variation (Figure 4.13). Similar to CUL 099, D.O. concentrations declined during restoration (in the isolated work area) but returned to normal levels within an hour of completion (Figure 4.14).

A considerable increase in pH was observed (1 data point) during restoration work (Figure 4.15) at CUL 035. Again, this was not fully understood but because it was not a negative change, and values returned to normal within an hour of restoration work, further investigation was not required and did not occur.

Suspended sediment concentrations increased to a maximum of 152 ppm during restoration work, however results clearly indicate that levels returned to normal post restoration (Figure 4.16). It should be noted that due to impropper removal of the upstream cauffer dam, increased suspended sediment loads did enter the ecosystem for a short period of time. This will be further discussed in Chapter 5. For more information regarding a step by step description of restoration works at CUL 099 (Big Dam Road) please contact Resource Conservation at Kejimkujik.

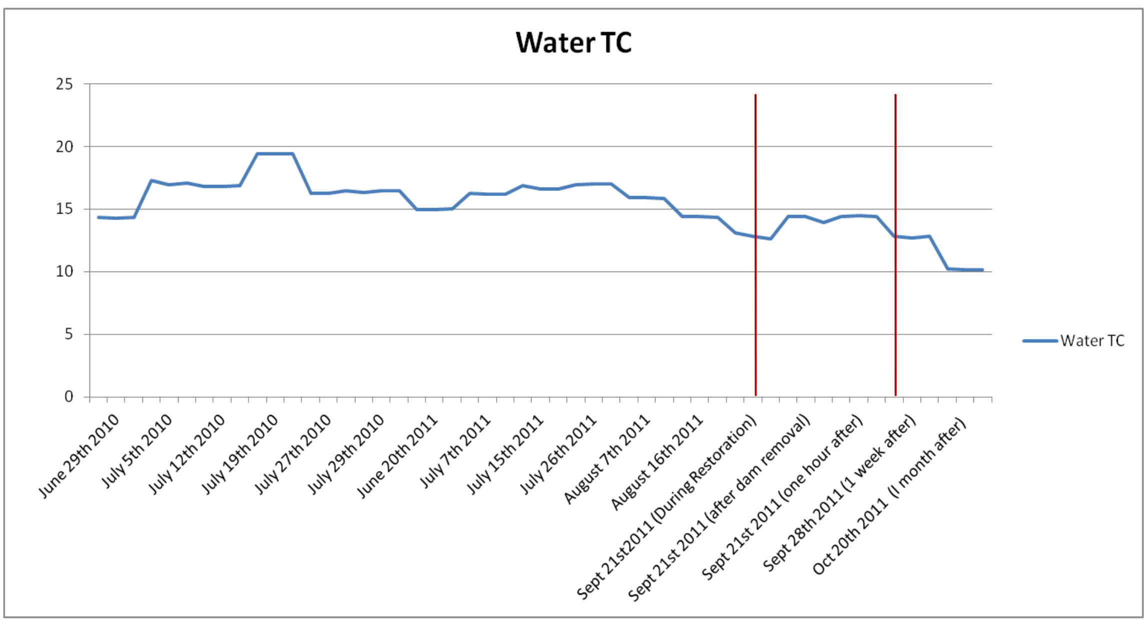


Figure 4.13 CUL 035 Temperature - Pre/Post Restoration

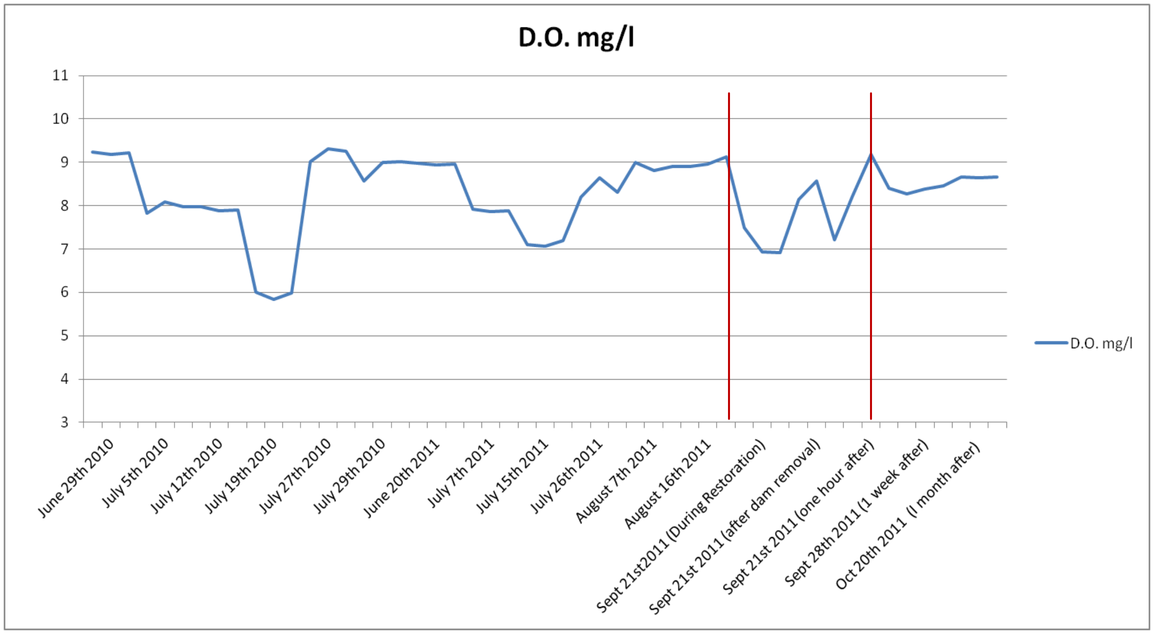


Figure 4.14 CUL 035 Dissolved Oxygen - Pre/Post Restoration

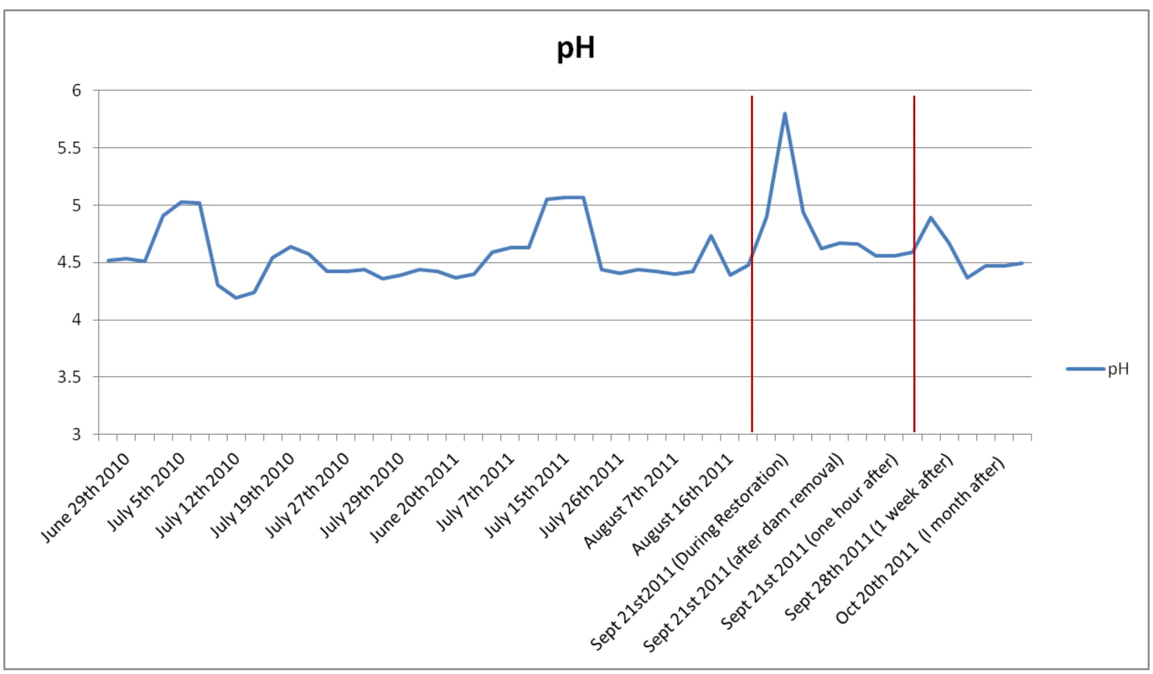


Figure 4.15 CUL 035 pH - Pre/Post Restoration

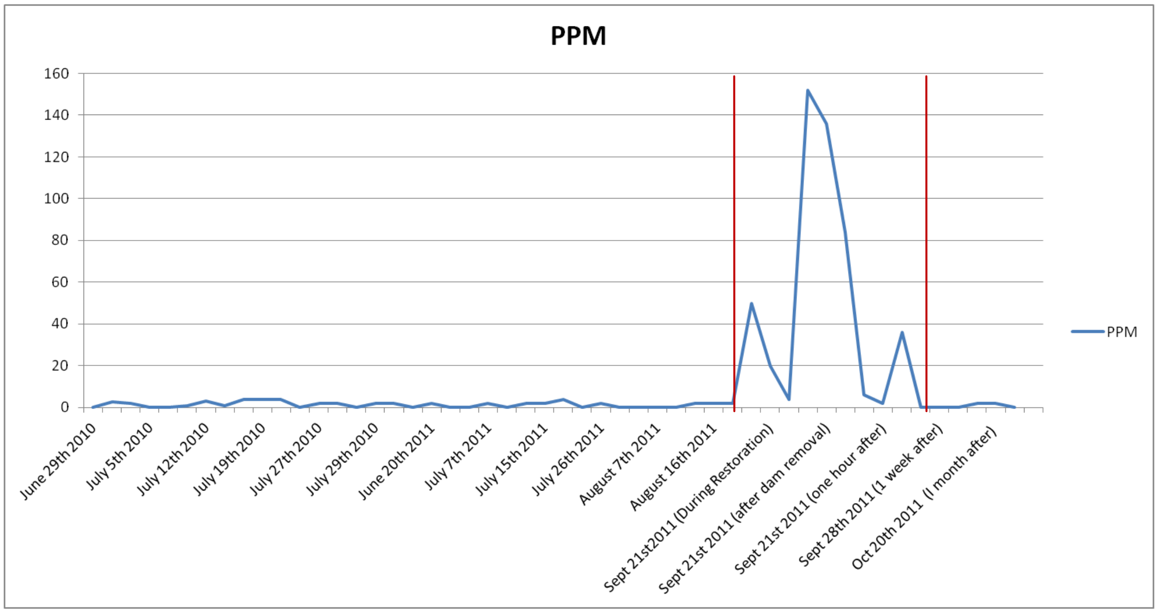


Figure 4.16 CUL 035 Suspended Sediment - Pre/Post Restoration

4.7 Measuring Success

As described in the Methodology Chapter, several techniques (biotic and abiotic) were used to measure the success of the restoration. The first technique was to repeat the secondary assessment on all restored structures assessing passability improvements as determined by FishXing and by subjective classification. Results in Table 4.5 clearly show that all restored structures have post passability scores of 1 or fully passable (and therefore do not negatively affect the parks connectivity status). This is an indication that appropriate guidelines and best practices were followed and that the restored structures facilitate fish movement (according to FishXing).

Culvert ID	Stream Name	Pre Restoration Passability	Post Restoration Passability	Value Obtained Through:
CUL 035	Big Dam Road Brook	0.86	1	FishXing
CUL 014	Rogers Brook	0.81	1	FishXing
CUL 055	Square Camp Brook	0.7	1	FishXing
CUL 112	Ben Lake Trail Brook	0.5	1	Subjective Classification
CUL 175	Cobrielle North Branch Brook	0.5	N/A	Subjective Classification
CUL 176	Powerline Rogers Brook	0.5	N/A	Subjective Classification
CUL 038	Canning Field Road Brook	0	N/A	FishXing
CUL 099	Flowing Waters Trail Brook	0	1	FishXing

Table 4.7 Pre/Post Restoration Passability Scores

A second technique used to measure success was to assess the impact of the restoration work on the parks connectivity (DCI) score. As discussed in section 4.5, having made the decision to exclude CUL 175 (Cobrielle North Branch) and still awaiting EA approval on CUL 038 (Canningfield Road), the DCI was run based on the restoration work undertaken and the parks DCI was determined to be 95.11 %. Therefore, according to the DCI calculations, the restoration work described above has shown to provide a 1.91 % improvement in aquatic connectivity at Kejimkujik. Considering CUL 175 will not be included in the parks calculations, this is 1.91 of a possible 2.44 % increase in connectivity (CUL 038 accounts for the remaining .53 percent increase and is pending EA approval).This will be further discussed in chapter 5.

Assessing the level of disturbance to the ecosystem (through water quality monitoring results) was the third success measure used. The pre/post monitoring results indicate that on the whole, mitigation measures during restoration work were successful at minimizing disturbance to the aquatic environment.

Confirming Fish Passage through restored structures was the fourth and final measure used to demonstrate project success. As mentioned in the methodology chapter, several techniques were used to show fish movement including tagging, netting, and visual surveys. At the time this thesis was written, visual confirmation of fish passage was observed at CUL 055 Square Camp Brook (September 20th 2010), CUL 099 Flowing Waters Trail (September 24th 2010) and CUL 035 Big Dam Road (September 12th 2011). Furthermore, the mark and recapture tagging method proved effective at CUL 014 Rogers Brook where Tag # R74 was applied to a fish in a downstream pool (by long time volunteer Reg Baird) on August 11th 2011 and the fish was subsequently recaptured upstream of the culvert by Rick Brunt (Resource Conservation) on September 27th 2011. Hundreds of fish were strategically tagged throughout the park and it is anticipated that fish movement will be documented (via tagging) at many of the other sites in the future.

4.7 Summary

The results above indicate that the DCI prioritization method is the most efficient approach to maximizing ecosystem benefit compared to other methods. However, as touched upon here, and as will be discussed in the next chapter, the model is only as good as the data used to populate it. It has been highlighted that the integration of LEK can help identify realities otherwise missed by approaches such as the DCI, and can greatly influence restoration decisions (as seen in the case of Kejimkujik).

The results above also indicate that overall (conveyed through pre/post monitoring, various success measures and DCI results) the restoration work carried out at Kejimkujik was of high quality and had minimal negative impacts on the environment. Furthermore, the DCI improvement (1.91 out of a possible 2.44) shows that significant progress was made and upon remediation of the remaining barrier (currently awaiting EA approval) aquatic connectivity will be fully restored (under the scope of this project).

Chapter 5

DISCUSSION AND CONCLUSIONS

5.1 Introduction

The results from Chapter 4 are discussed below in accordance with the information provided in Chapters 1-3. Conclusions and discussion regarding the techniques, protocols, and models used in the Kejimkujik Aquatic Connectivity project will follow. Furthermore, recommendations will be made based on the lessons learned throughout this research, as the author considers research knowledge dissemination critical considering the state of federal and provincial environmental funding.

5.2 Project Design Considerations

Throughout the Aquatic Connectivity Project at Kejimkujik, several key findings have surfaced. Albeit seemingly straightforward, the importance of determining what structures will be included in the scope of an aquatic connectivity project (based on resources, capabilities etc) is critically important. That is to say, by including structures that do not have standardized methods for determining specific (or refined) passability (such as natural obstacles or dams), uncertainty and inaccuracies can result. For example, at Kejimkujik, all dams and natural obstacles were assigned subjective passability values (all received a 0.5 passability score) and uncertainty (in an otherwise very specific and precise model) exists for 2 reasons. First, all culverts were assigned refined passability values (through the secondary assessment and FishXing) with detailed passability scores ranging anywhere between 0 and 1. When most of the data populating the DCI is extremely detailed and then several barriers are added with less detailed values (subjective scores), it can only be assumed the accuracy is decreased. This became extremely important and obvious at Kejimkujik, where CUL 175 (a non-culvert obstacle with a subjective 0.5 passibility score) was determined by the DCI to be the structure most significantly affecting the park's aquatic connectivity. Because subjective classification only permits 0 (impassable), 0.5 (partially passable), and 1 (fully passable), an accurate representation of passibility was not possible, because no standardized methods exist. If for example, the structure passed fish 90 percent of the time, given the approach used in this study, it would still be assigned a 0.5 (because it's not fully passable) and would still be the DCI's top priority, when in reality, it should most likely be at the end of the prioritization list.

The second cause for uncertainty in the approach is the fact that, unlike a restored culvert, we are unable to measurably determine improvement in passability (post restoration) for non- culvert structures as no standardized methods exist (it is simply assumed that a bridge does not have restrictive qualities). For example, following *culvert replacement* restoration work, all restored culverts were re-run through FishXing to determine specific post restoration passability (which in theory should be 1 or fully passable). Therefore, if any of the restored culverts did not fully pass fish post restoration, it would at least be acknowledged and reflected in the DCI score. When restoration occurred where a barrier was replaced with a non-culvert structure (bridge or simple debris removal) the post restoration passibility was assumed to be 1 (fully passable) as was the case at CUL 99, CUL 112 and CUL 176 in this research. However, if significant restoration mistakes were made during non-culvert restoration activities, they would not necessarily be recognized (because it is assumed that a bridge is not a barrier) and would therefore not be reflected in the post restoration DCI score (or any future calculations). It is therefore recommended that a standardized, post restoration evaluation is developed and applied in the future.

The topic of determining what structures to include in a project leaves much room for debate. It could be argued that because methods are not readily available to determine specific passability at non culvert sites, only culverts should be included and other structures should be addressed separately. However, some would argue that leaving out structures (such as dams) that are clearly contributing to aquatic fragmentation would be a significant mistake.

In conclusion, deciding which structures to include is, in reality, project specific and is highly dependent on the resources and capabilities of the group conducting the research. It is highly recommended that this decision be seriously considered prior to initiating work as making quick decisions to include or not to include a structure mid project can have serious implications and consequences. Furthermore, it is recommended that well informed decisions are made when subjectively determined passability scores are assigned. Finally, it is recommended that subjective scores are not limited to 0, 0.5 and 1, as it could strengthen the DCI's accuracy (and better reflect reality) if more detailed scores could be assigned (based on expertise, local knowledge etc).

5.3 FishXing Input Considerations

As described in previous chapters, FishXing has proven to be an extremely useful tool, allowing the refinement of the interim passability value designated 0.5 or partially passable. By refining this value, more detailed barrier information populates the DCI, and it is therefore assumed the accuracy of the output is increased. Although the author does fully believe that FishXing is a powerful and useful tool, some questions arise regarding various aspects and assumptions of the model. The following discussion is not intended discredit FishXing, rather it is to highlight some areas for future work that could potentially help overcome some of the uncertainty and strengthen the approach.

The first FishXing input that has received increased attention (highlighted by the literature and by personal correspondence) is the literature defined fish swim speeds. Throughout the project and speaking with others in the field, there has been significant debate regarding the swimming performances of brook trout. The main point of argument is that literature data is derived from laboratory tests where conditions do not necessairly mimic the natural environment and therefore affect fish performance to some unknown extent. Although this is a valid point, it appears that at present, this is the best available approach to obtaining accurate swim speeds. In an effort to standardize inputs and consistency within various National Parks, Parks Canada has chosen to adopt literature speeds described in previous chapters. Although there is still some question regarding the true accuracy of the proposed speeds, this at least provides some consistency until new research delivers a more accurate representation of fish performance in natural conditions. It is highly recommended that groups undertaking such a project consult with others (NGO's and/or Government agencies) prior to simply accepting a literature value. In order to maintain consistency and compare results, it is important that fishxing inputs (including swim speeds) are streamlined wherever possible.

The second FishXing input that is subject to debate is "Fish Passage Flows" (describing high and low flows for each culvert). These values, along with fish swimming performance, essentially determine whether a fish will be able to pass the structure in question. The problem here is that acquiring accurate annual flows at each site can be (1) extremely time consuming, (2) resource dependant (GIS/staff capabilities), and (3) dangerous during high water events. The most accurate approach to gathering discharge data is to perform channel cross-sections throughout the year capturing all water levels and most importantly high and low flows. This becomes increasingly difficult as the number of structures increases and is often unattainable due to winter conditions and lack of staff (especially in winter/spring months).

For the reasons described above, it appears that the most common approach (and the one used in this research) is to perform catchment scaling in a GIS environment, providing theoretical discharge values. It is important to note that this technique is not possible without local gauging stations and therefore this should be a consideration in the early project planning stages prior to committing to this approach (Kejimkujik has Environment Canada gauging stations located within the park). A second limiting factor for this technique is that watershed data for the area in question are necessary, as is a GIS specialist to perform the work. Both requirements, and especially the latter, can be absent especially in community groups and therefore this must be seriously considered prior to starting a connectivity project using a GIS based approach.

Although catchment scaling is one of the best (and most realistic) approaches at present, the author of this thesis is suspicious that values do not necessarily reflect reality, especially in situations where sites exist on very small headwater perennial streams (like Kejimkujik). For example, at Kejimkujik discharge values were derived from scaling back from the Mersey River which has an annual discharge range of 2.35 to 53.2 cubic meters per second (m^3/sec^{-1}). In a highly dynamic and complex system with various spatial responses to rainfall and snow melt (percolation, runoff, etc.), it is difficult to be confident in results derived from scaling back from a catchment area of 71,000 hectares (Mersey River) down to small tributaries with catchment areas ranging between 9 to 845 hectares (observed at Kejimkujik), especially when a small change in discharge can have a large impact on FishXings outputs. For example, an change in high flow from 0.496 cm/s (number used in this research) to 0.632 cm/s (a number derived from another gauging station in the area) at Rogers brook (845 hectares) would change the current passibility score from 0.81 to 0.55 which would, intern affect the DCI score significantly.

Acknowledging that catchment scaling is the most readily available approach to determining flow data (especially in projects with hundreds or thousands of sites), the author of this thesis set up several data loggers (from which one can extrapolate discharge values) at various sites in Kejimkujik to determine how close values on the ground match up with the values derived from catchment scaling. At the time this thesis was written, insufficient data was available to make conclusions on the correlation between catchment scaling values and observed values (still generating a curve). The results, when completed, will be lodged with Kejimkujik National Park and National Historic Site of Canada.

5.4 DCI Considerations

While the DCI has proven to be an effective tool for prioritizing restoration initiatives, the application of the model at Kejimkujik has highlighted some room for improvement. Unlike the previous recommendations that consider project design and FishXing inputs that populate the DCI, this particular recommendation proposes a small addition to the framework itself, and one that the author feels is necessary to better represent reality.

At present, the DCI framework does not take into account the quality/quantity of habitat at each particular barrier. Although the preliminary assessment separated and excluded structures that do not exist on fish bearing streams, some weighting system should be applied to help emphasize the quality/quantity of habitat at each site. For example, at Kejimkujik, the majority of the 15 potential structures exist on small headwater streams; however, some structures (namely CUL 014 Rogers Brook and CUL 099 Flowing Waters Trail) exist on larger water bodies with extreme habitat significance (for example one of Kejimkujiks main spawning grounds exists just upstream of CUL 014). Although it would become difficult to automatically assign weights to different size streams (knowing for example that smaller streams are typically important refuge/spawning areas), and thresholds would have to be determined, a weighting system is recommended to better represent habitat significance.

The most obvious suggestion would be to simply assign a weight based solely on stream order. This would be the most straightforward approach and script could be written to automatically apply weight without any user input. Another suggestion would be to assign some sort of weight based on annual discharge at each site. In theory once thresholds dividing habitat significance were determined; barrier classes could be extrapolated from discharge data and manually fed into the DCI.

Although no concrete framework has been proposed to assign habitat quality weights to individual barriers, the above suggestions provide relatively straightforward techniques requiring little to no user effort. It is believed that the DCI approach would benefit from a habitat significance weighting system.

5.5 Prioritization Results

Prioritization results described in the previous chapter have highlighted several key findings and also leave much room for discussion. The results suggest that according to cumulative ecosystem gains, the DCI approach is most effective at prioritizing restoration initiatives. It has also been suggested that the scoring-and-ranking prioritization scheme (FishXing) is more effective at prioritizing restoration initiatives compared to the LEK scheme. This section will describe however, that the LEK approach has in fact highlighted critically important information that was missed by the other approaches. The implications this has on all of the DCI cumulative ecosystem gain results will be discussed below.

As described in Chapter 4, the scoring-and-ranking (FishXing) prioritization approach appears to maximize ecosystem gains more than the LEK approach in large part due to the low ranking of CUL 075 Cobrielle North Branch and CUL 014 Rogers Brook in the LEK assessmennt (both of which are recognized by the DCI to greatly improve connectivity upon restoration based on their current passability score and where they are in the system). The interesting point here is that local knowledge has highlighted that these structures, and especially CUL 175, do not in fact impede fish passage to the extent that the secondary assessment data suggests. In fact, it is believed that CUL 175 is not a problem at all as the nearby south branch can pass fish year round. This information provided by LEK would have serious consequences on all DCI (and hence all ecosystem gain) calculations and because re-evaluation would be necessary, Kejimkujik has chosen to omit CUL 175 from its potential restoration sites at present. Therefore, although cumulative gains suggest that a scoring-and-ranking (FishXing) prioritization scheme would benefit the ecosystem more so than a LEK approach, in reality this might not be the case. Although the DCI prioritization would still produce the best restoration scenario in terms of ecosystem gains (because of its ability to compute spatial distribution and passability), the LEK findings would most certainly affect the ranking of restoration sites. This has been a clear example of how the DCI approach is only as good as the data that populates it, and the critical importance of consulting with local experts and integrating citizen science into the decision making process. It has also shown that a loosely assigned subjective passability score (as seen at CUL 175) has the potential to greatly affect all results further highlighting the topic of section 5.3.

The information above highlights another important realization and consideration (which to some extent is a limiting factor) for any group choosing to adopt this approach. This realization is the fact that specialized expertise (GIS technician) is required to run the DCI and the process can be extremely time consuming (and therefore costly). In the case of Kejimkujik (a study area with only 15 potential barriers) the process of acquiring the data, setting up the framework, and running the model took roughly 2 weeks to obtain results. It could only be assumed that for a project with hundreds or even thousands of potential barriers, much more time would be required to perform the calculations (and would therefore be costly for groups without the specialized expertise). In fact, several local NGO's in the province have expressed difficulty in finding (and affording) someone capable of running the DCI.

Another difficulty that has emerged is that due to the nature of the technique, the average researcher does not have the capability to re-run the model (even once it has been set up) to get updated results should significant findings/required changes come into play. This was experienced in this research, as time and resources were not readily available to recalculate the DCI based on the significant LEK findings. This has serious consequences as researchers can be left to make restoration decisions based assumptions.

5.6 The Importance of Integrating LEK

This aquatic connectivity research at Kejimkujik has highlighted that the integration of LEK is critically important. If local ecological knowledge was not present in this research, it is highly likely that restoration efforts would have been focused primarily on CUL 175 (as according to the DCI it accounts for roughly half of the total potential ecosystem gain in the park), a site that would involve significant resources and a large portion of the available budget. This would have had serious consequences on aquatic connectivity in the park, as restoring many of the structures actually fragmenting the landscape might not have occurred.

The LEK findings prove significant, and show that incorporating local experts can greatly improve the success of a project. In the case of Kejimkujik, LEK showed that 2 of the 8 potential barriers were misinterpreted by the secondary assessment. This misinterpretation of structure passability could prove problematic, especially in larger projects with hundreds or thousands of potential barriers. It is highly recommended that whenever necessary, LEK is built into the project framework, as it inevitably leads to better informed decisions.

5.7 Restoration Work and Ecosystem Gain Improvements

As described in Chapter 4, although it was the intention to fully restore all structures in the manner outlined by the DCI, restoration work did not take place in this way for several reasons. Kejimkujik restored structures in a less than optimal manner, and this section will describe what this has meant in terms of overall park DCI improvements.

Having made the decision to exclude CUL 175 from potential restoration sites (until further investigation takes place), it was found that the remaining 7 sites could collectively offer an ecosystem gain of 2.44 %. As described the previous chapter, at present all structures have been restored with the exception of CUL 038 (which is still awaiting EA approval from DFO) and have improved the parks DCI 1.91 %. Because EA approval stalled restoration at CUL 038, structures yielding less ecosystem gain were restored first. An important realization quickly surfaces when respective ecosystem gains are examined. Table 4.6 showed that the ecosystem gain associated with restoring the last 4 structures on the list (CUL 035, CUL 055, CUL 112, and CUL 176) equals 0.57 %, while restoring only CUL 038 yields a gain of 0.50%, an ecosystem improvement similar to the last 4 structures combined. This highlights the importance of restoring structures in the order proposed by the DCI (even when resources will allow remediation of all sites), If more effort would have been put into acquiring EA approval for CUL 038, the remediation of this one structure would have produced nearly as much ecosystem gain as the 4 structures systematically ranked below it combined.

The description above highlights the importance of following the restoration scheme in a perfect scenario where resources are available to restore all structures in question. However, an interesting realization presents itself and should also be given serious consideration especially in situations where limited resources are a determining factor. Although the restoration of CUL 038 has the potential to produce nearly as much ecosystem gain as the 4 structures ranked below it, the cost associated with restoring this structure is actually higher than the cost associated with restoring the following 4 structures combined. Let's say for example that the remaining restoration budget in the project was 10, 000 dollars. This would be the total cost of restoring CUL 038 resulting in a 0.50 percent overall ecosystem gain. In reality, it would actually cost less than the 10, 000 dollar budget to restore CUL 035, CUL 055, CUL 112, and CUL 176 resulting in a

0.57 percent overall ecosystem gain. In summary, if the above scenario was the case at Kejimkujik, it would be more beneficial (maximizing ecosystem gain) to restore the last 4 structures prior to restoring CUL 038, as more ecosystem gain would result from less money making it a more effective approach given finite resources.

Although this finding does appear to work against the current DCI prioritization framework, it is a realization that must be seriously considered as current restoration budgets for NGO's in the province are increasingly limited. It is highly recommended that groups consider restoration costs prior to simply following a restoration scheme based solely on theoretical ecosystem gains. In an effort to help overcome this potential problem, Greig Olford, a graduate student at Dalhousie University is currently developing a model (complimenting the DCI) that takes restoration costs into consideration, ensuring that ecosystem gain is maximized given a specified budget.

5.8 Pre/Post Monitoring Results

Pre/Post monitoring results described in the previous chapter clearly indicate that with the exception of CUL 035 (which will be described below), all restoration work had minimal impact on the aquatic ecosystem indicating the mitigation measures were effective at keeping parameters under stress levels for fish and other aquatic organisms. Credit for this success must be given to the Nova Scotia watercourse Alteration Guidelines, and the contractors who were able to execute the protocol.

As touched upon in Chapter 4, the improper removal of the upstream cauffer dam at CUL 035 caused increased suspended sediment loads to enter the system for a short period of time. Although levels reached 152 ppm during the hour after the removal of the upstream cauffer dam, levels dropped back down to baseline concentrations within an hour of completion. Therefore, although the DFO guideline of 25 ppm was exceeded, it is believed that the event had minimal effects on aquatic organisms as the increased sediment load timeframe was so short and the increase did not enter lethal ranges. It should also be noted that the sediment load increase was comparable to that which results from conducting a benthic invertebrate survey. The point here is that levels did not escalate to extreme concentrations where detrimental effects on aquatic organisms resulted. It is believed that DFO's regulations are more applicable to larger scale projects where suspended sediment concentrations far exceed 25 ppm for extended periods of time.

In summary, although suspended concentrations did exceed DFO's 25 ppm threshold, the temporary increased concentrations had minimal impact on aquatic life at Kejimkujik. The important thing here is that reasons for the increased sediment loads experienced at Kejimkujik were documented and understood.

5.9 Summary and Conclusions

It appears that at present, due to the model's ability to assess the cumulative impacts of multiple barriers in dendritic systems, the DCI is the best tool available to optimize ecosystem benefit and maintain ecological integrity. The results have shown that traditional scoring-and-ranking approaches have significant limitations. The results have also shown that the integration of LEK can prove beneficial in an aquatic connectivity project. This research has described how on their own, scoring-and-ranking and local ecological knowledge prioritization approaches are not optimal, but can complement and greatly strengthen the DCI therefore helping decision makers make better informed decisions. This research has highlighted the idea brought forward by many scholars including Kemp and O'Hanley (2010), that the well planned removal of aquatic barriers is a very effective means of restoration, and one that if done correctly, can maximize ecosystem benefit.

The DCI should be viewed as a tool that can help to prioritize restoration initiatives, however it should not be considered the "be all end all" approach. It is believed that in some situations, the DCI is the most appropriate prioritization tool however some community groups hoping to adopt and apply the model could potentially find the approach resource demanding. The recommendations above attempt to help overcome some of the potential problems that can arise, and provide information that should be considered prior to fully engaging/committing to such a project. Through the application of the DCI at Kejimkujik National Park and National Historic Site of Canada, this research has provided data and recommendations that should strengthen the value of the DCI approach and help advance aquatic connectivity research.

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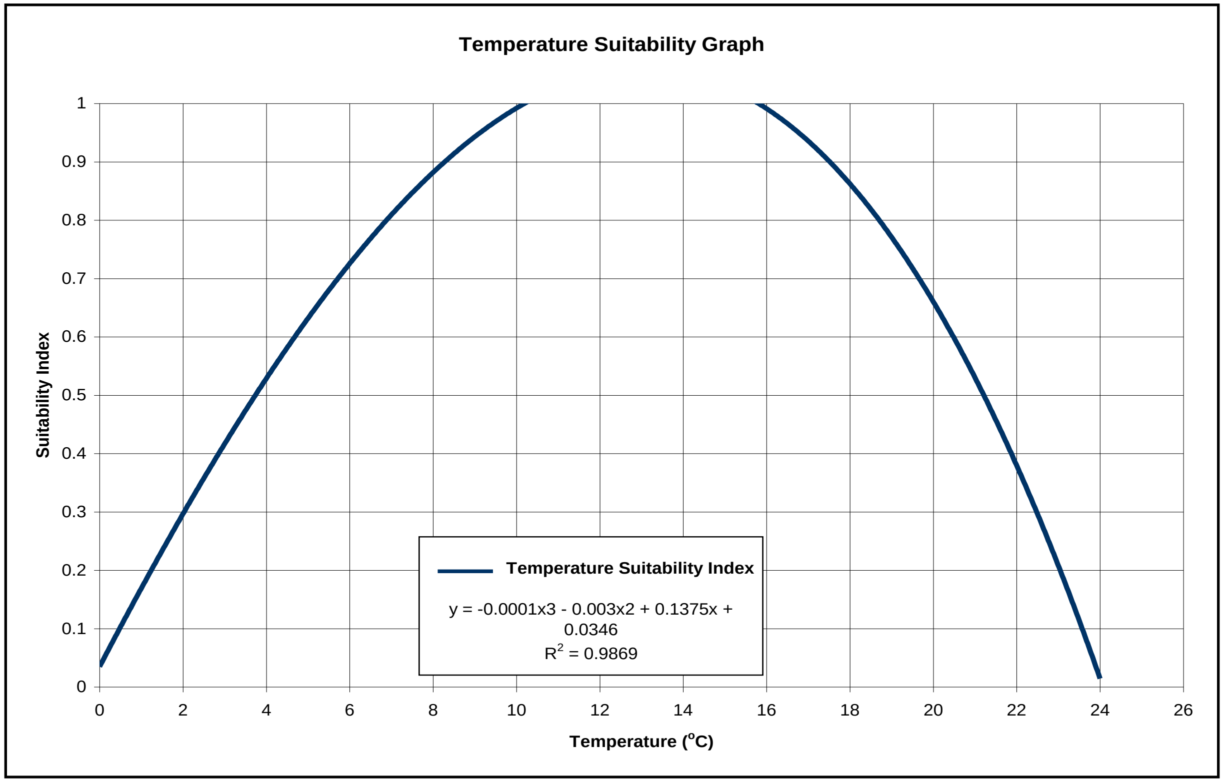
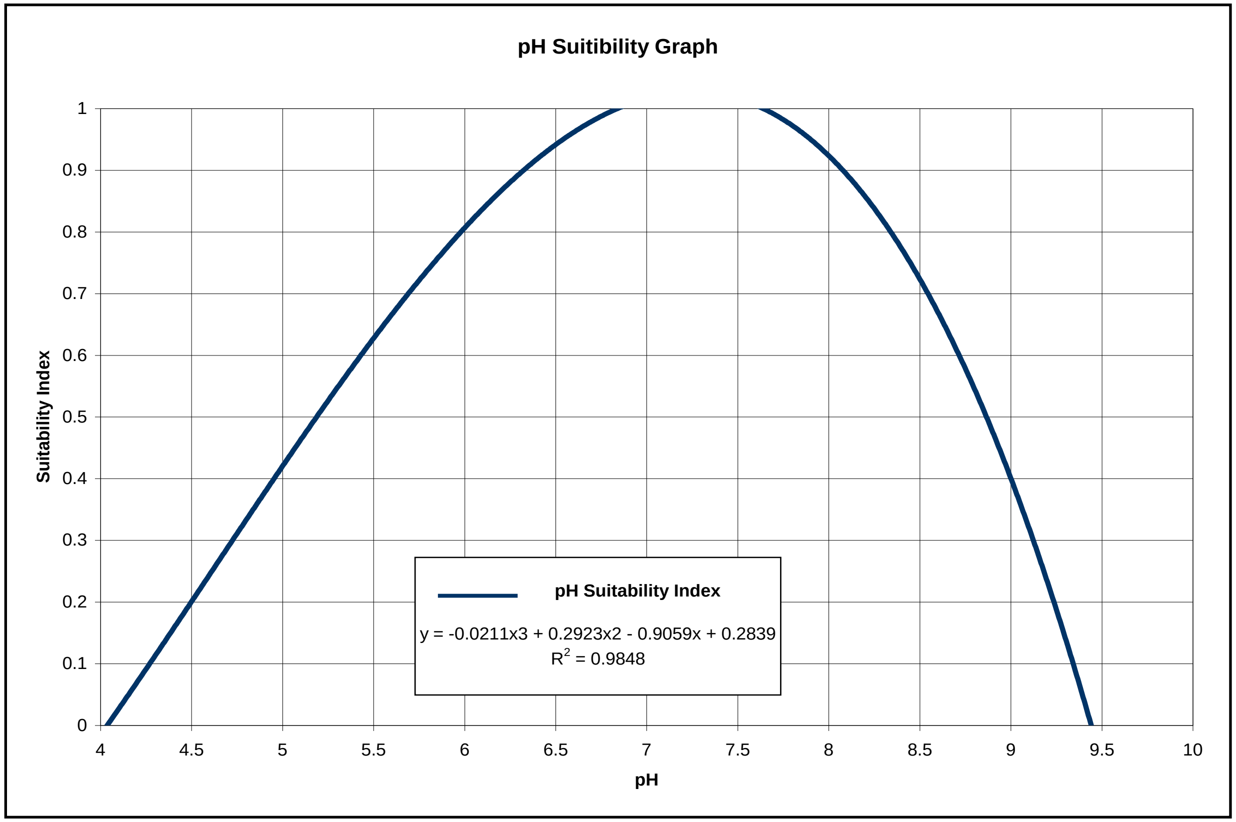
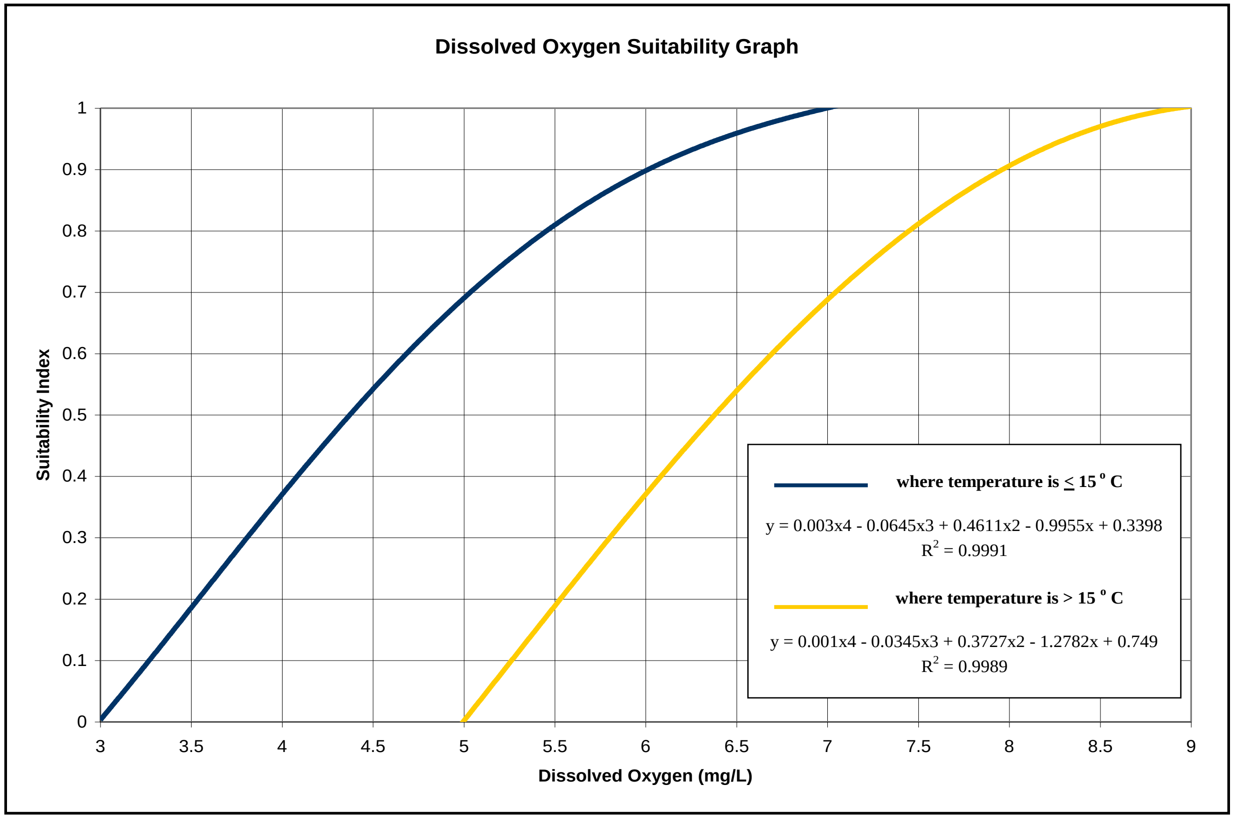
APPENDICIES



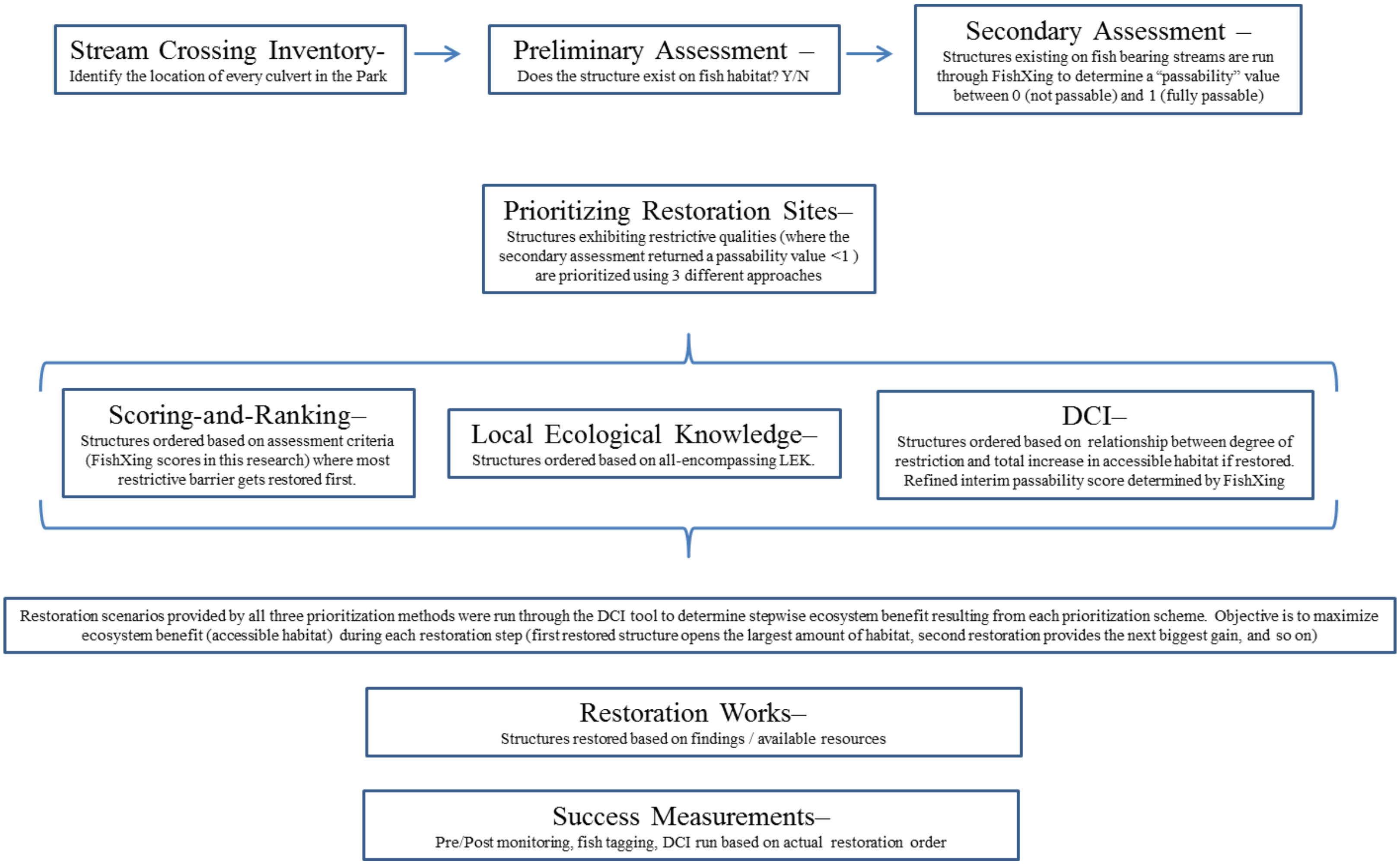
Appendix A. Temperature Suitability Index Graph



Appendix B. pH Suitability Index Graph



Appendix C. Dissolved Oxygen Suitability Index Graph

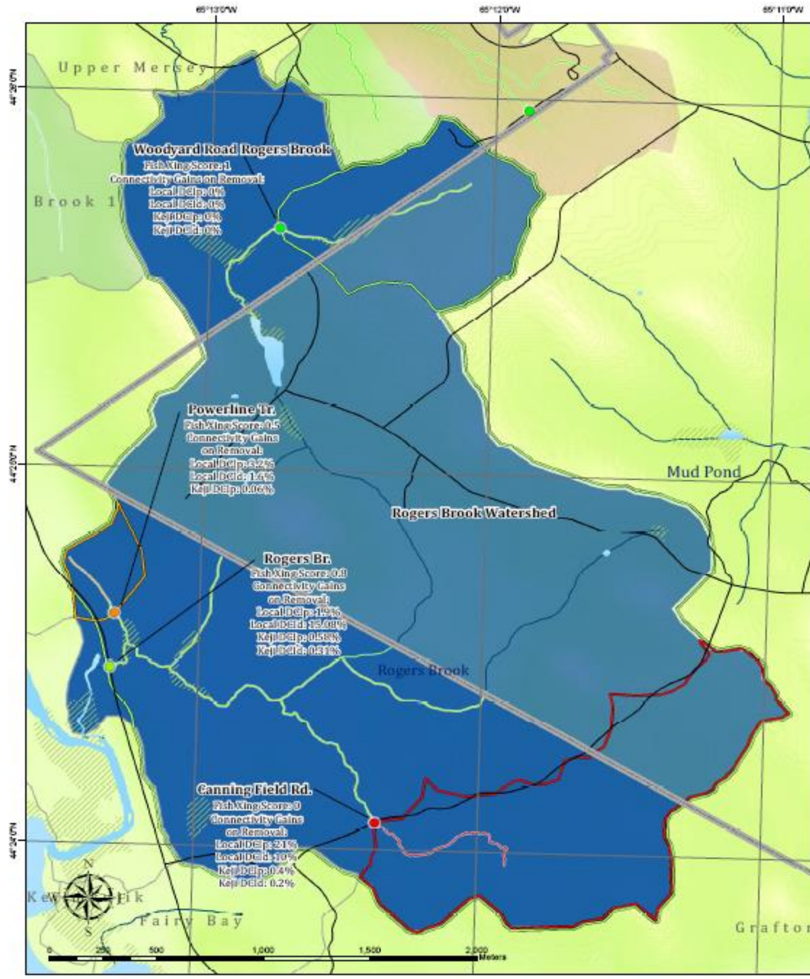


Appendix D. Methodology Flow chart

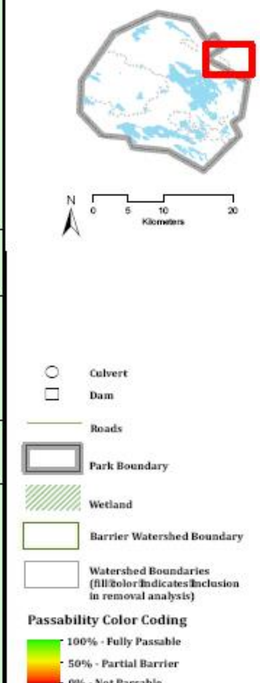
Appendix E. CUL 176 Powerline
UTM X 323106.96, UTM Y 4916136.65
Pre Restoration Passability 0.5
Post Restoration Passability 1
Barrier type: Blockage

Pre Restoration

Post restoration



Watershed		Rogers Brook Watershed				
	Barrier	Rogers Brook	Canning Field Road Brook	Powerline Rogers Brook	Woodyard Road	
Metrics	Fish Xing Score:	0.81	0	0.5	1	
DCI gains upon removal	Local DCIp	0.0186	0.2101	0.0326	0	0.7303
	Local DCId	0.1508	0.1008	0.016	0	0.7049
	Keji DCIp	0.0058	0.004	0.0006	0	
	Keji DCId	0.0031	0.002	0.0003	0	
Total Barrier Catchment Area	Total Area (ha)	693.1	190.5	64	57.9	778.8
	watershed	89.00%	24.46%	8.22%	7.43%	2.04%
Forested Area	Softwood ha (2)	410.7	89.4	44.2	24.6	428.6
	Softwood %	61.71%	47.18%	92.08%	45.64%	61.59%
	Mixed ha (5)	227.4	100.1	3.8	9.8	239.9
	Mixed %	34.17%	52.82%	7.92%	18.18%	34.47%
	Hardwood ha (8)	21.6			13.7	21.6
	Hardwood %	3.25%	0.00%	0.00%	25.42%	3.10%
Totals:	Forested ha (99)	665.5	189.5	48	53.9	695.9
	Forested %	96.02%	99.48%	75.00%	93.09%	89.36%
Non-Forested Areas	Wetland - General - ha (70)	0.5	0.5			1.6
	Wetland - General - %	1.81%	50.00%	0.00%	0.00%	1.93%
	Open Bogs - ha (72)	0.7				1.9
	Open Bogs - %	2.54%	0.00%	0.00%	0.00%	2.29%
	Treed Bogs - ha (73)	4.8			2.6	4.8
	Treed Bogs - %	17.39%	0.00%	0.00%	65.00%	5.79%
	Inland water - ha - (77)					42.4
	Inland water - %					51.15%
	Urban - ha (87)	3.6	0.5		1.4	4.1
	Urban - %	13.04%	50.00%	0.00%	35.00%	4.95%
	Road Corridor - ha (98)	18		18		18
	Road Corridor - %	65.22%	0.00%	100.00%	0.00%	21.71%
Totals:	Non-Forested - ha (98)	27.6	1	18	4	82.9
	Non-Forested - %	3.98%	0.52%	28.13%	6.91%	10.64%

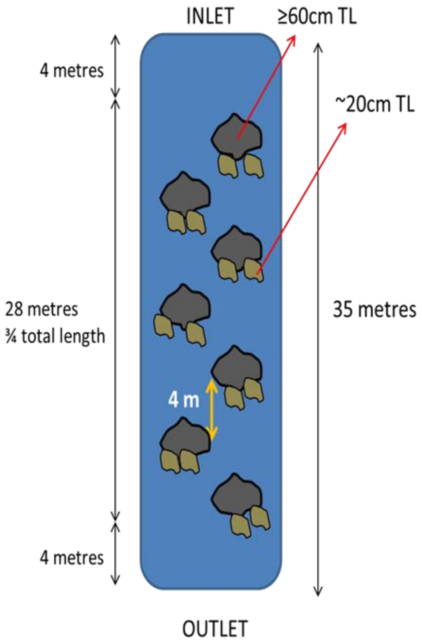


Not to be used for navigation; for display purposes only.
Projection: NAD83 UTM Zone 20N
Scale: 1:19,000
Layers acquired from Provincial and National Databases (NSTDB, NSDNR, NSHN, NSRN) and Parks Canada.
Produced: August 23, 2011
Author: Greig Oldford

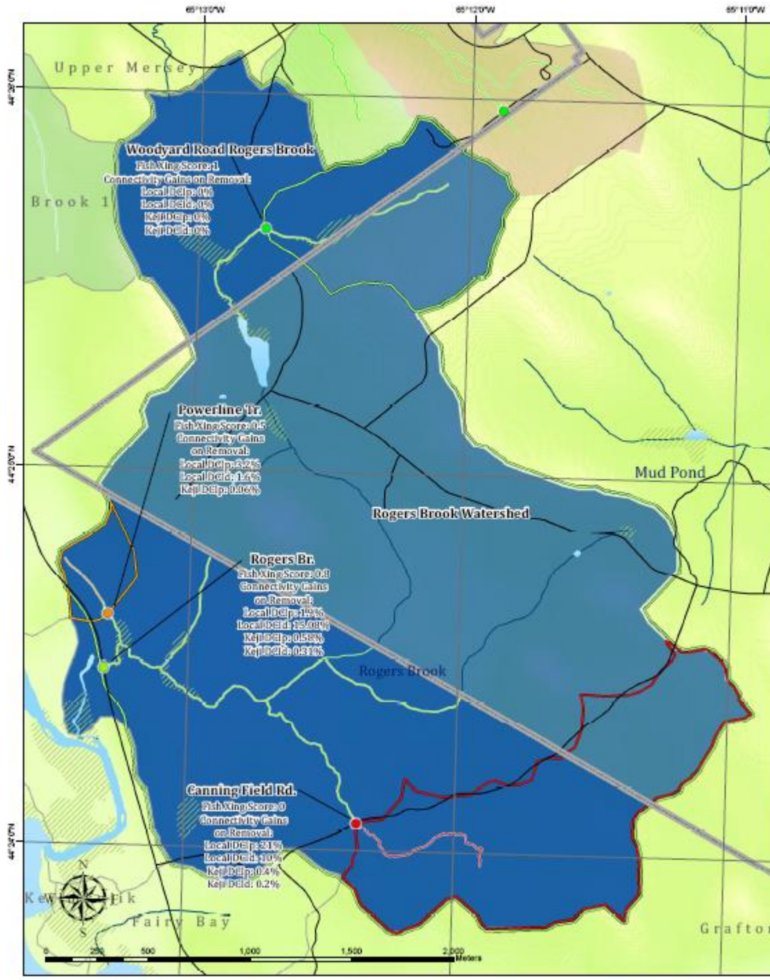
Kejimkujik National Park - Rogers Brook Watershed Barriers to Fish Passage

Appendix F. CUL 014 Rogers Brook
UTM X 323102.91, UTM Y 4919558.80
Pre Restoration Passability 0.81
Post Restoration Passability 1
Barrier Type: Velocity

Pre Restoration



Post Restoration diagram



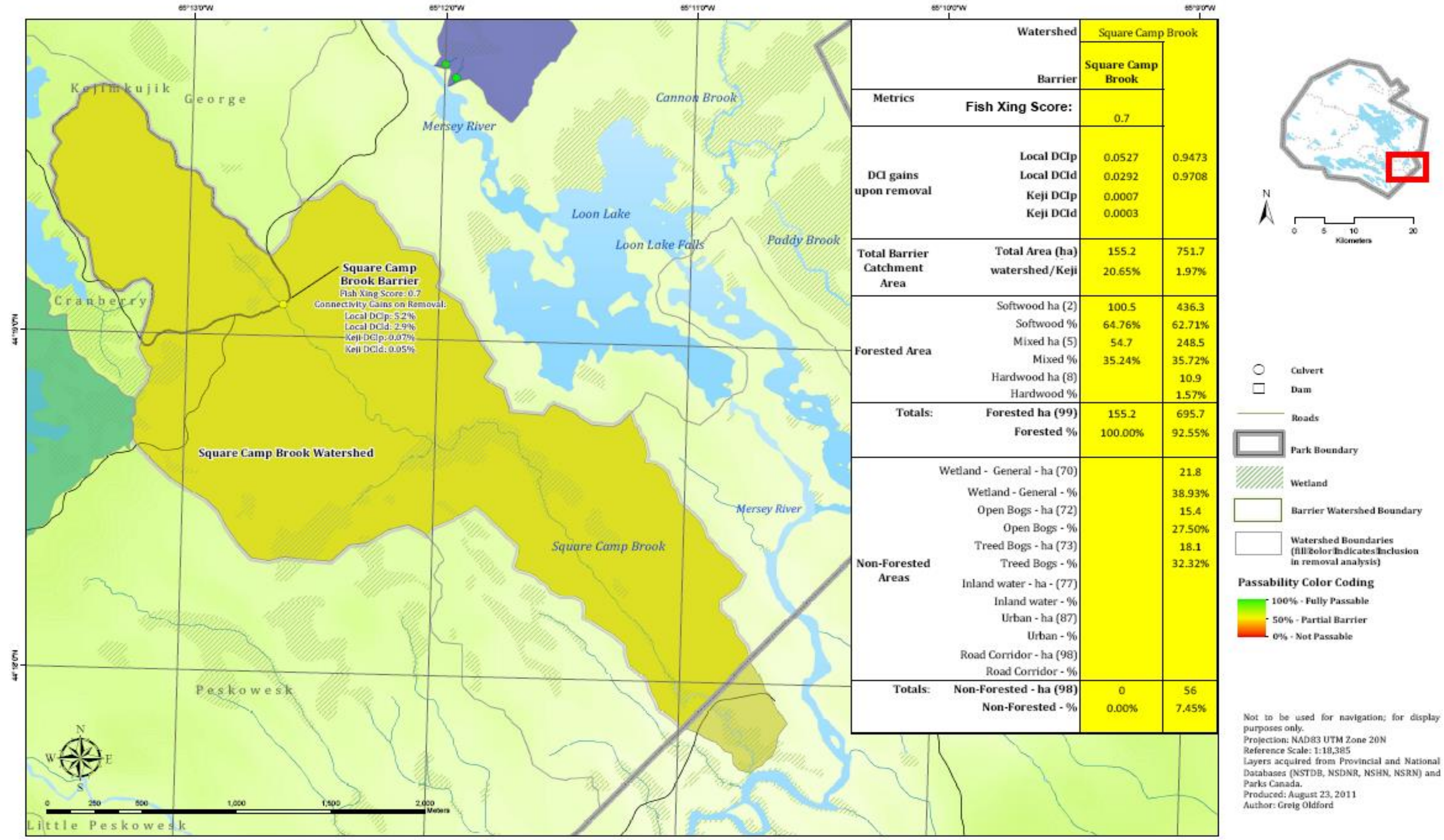
Metrics	Watershed / Barrier	Rogers Brook Watershed: Rogers Brook	Canning Field Road Brook	Powerline Rogers Brook	Woodyard Road	
	Fish Xing Score:	0.81	0	0.5	1	
DCI gains upon removal	Local DCIp	0.0186	0.2101	0.0326	0	0.7303
	Local DCId	0.1508	0.1008	0.016	0	0.7049
	Keji DCIp	0.0058	0.004	0.0006	0	
	Keji DCId	0.0031	0.002	0.0003	0	
Total Barrier Catchment Area	Total Area (ha)	693.1	190.5	64	57.9	778.8
	watershed	89.00%	24.46%	8.22%	7.43%	2.04%
Forested Area	Softwood ha (2)	410.7	89.4	44.2	24.6	428.6
	Softwood %	61.71%	47.18%	92.08%	45.64%	61.59%
	Mixed ha (5)	227.4	100.1	3.8	9.8	239.9
	Mixed %	34.17%	52.82%	7.92%	18.18%	34.47%
	Hardwood ha (8)	21.6			13.7	21.6
	Hardwood %	3.25%	0.00%	0.00%	25.42%	3.10%
Totals:	Forested ha (99)	665.5	189.5	48	53.9	695.9
	Forested %	96.02%	99.48%	75.00%	93.09%	89.36%
Non-Forested Areas	Wetland - General - ha (70)	0.5	0.5			1.6
	Wetland - General - %	1.81%	50.00%	0.00%	0.00%	1.93%
	Open Bogs - ha (72)	0.7				1.9
	Open Bogs - %	2.54%	0.00%	0.00%	0.00%	2.29%
	Treed Bogs - ha (73)	4.8			2.6	4.8
	Treed Bogs - %	17.39%	0.00%	0.00%	65.00%	5.79%
	Inland water - ha - (77)					42.4
	Inland water - %					51.15%
	Urban - ha (87)	3.6	0.5		1.4	4.1
	Urban - %	13.04%	50.00%	0.00%	35.00%	4.95%
	Road Corridor - ha (98)	18		18		18
	Road Corridor - %	65.22%	0.00%	100.00%	0.00%	21.71%
Totals:	Non-Forested - ha (98)	27.6	1	18	4	82.9
	Non-Forested - %	3.98%	0.52%	28.13%	6.91%	10.64%

Kejimkujik National Park - Rogers Brook Watershed Barriers to Fish Passage

Appendix G. CUL 055 Square Camp Brook
UTM X 323742.97, UTM Y 4909601.78
Pre-Restoration Passability 0.7
Post Restoratrion Passibility 1
Barrier Type: Velocity

Pre Restoration

Post Restoration



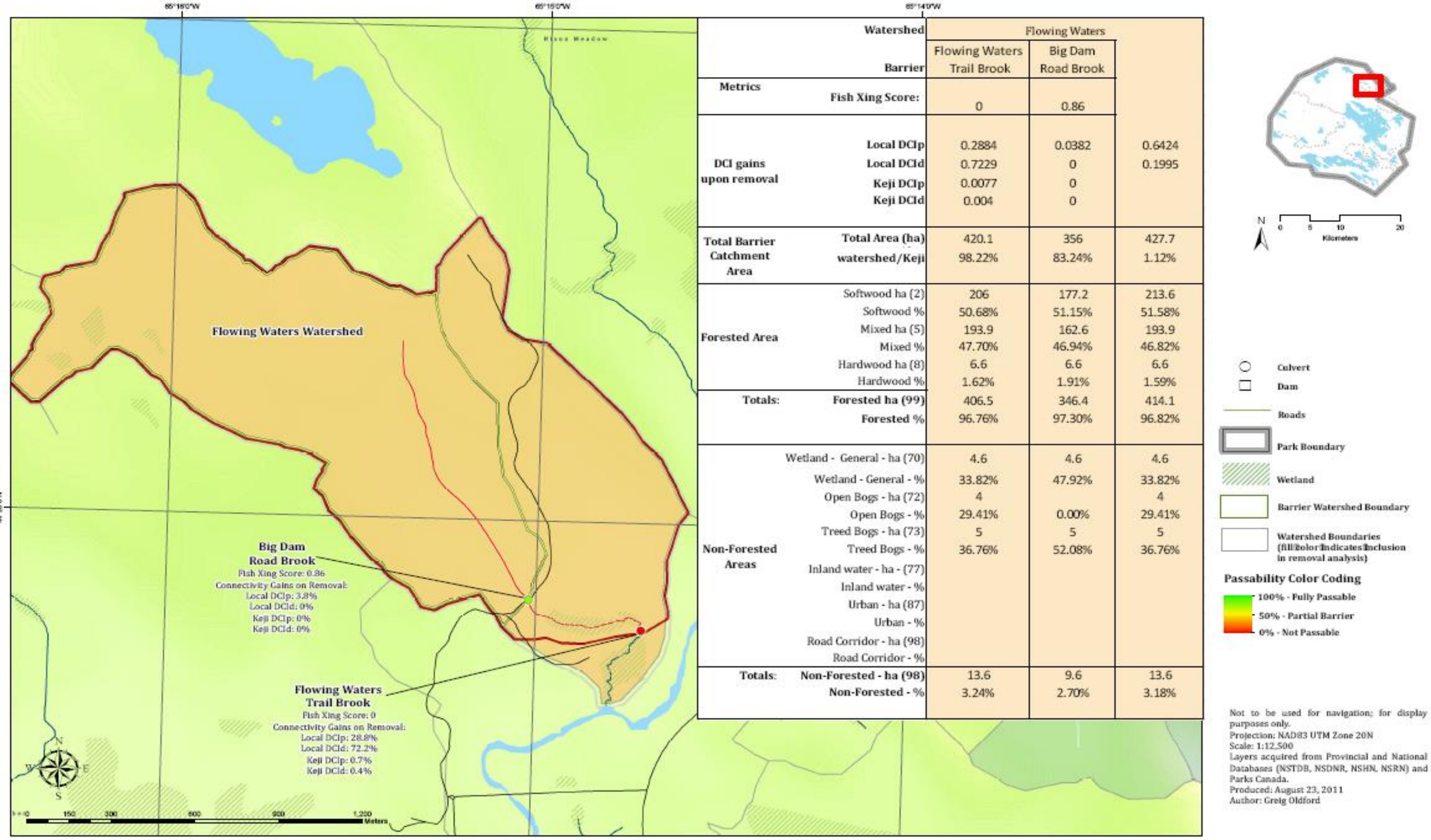
	Watershed	Square Camp Brook	
	Barrier	Square Camp Brook	
Metrics	Fish Xing Score:	0.7	
DCI gains upon removal	Local DCIp	0.0527	0.9473
	Local DCId	0.0292	0.9708
	Keji DCIp	0.0007	
	Keji DCId	0.0003	
Total Barrier Catchment Area	Total Area (ha)	155.2	751.7
	watershed/Keji	20.65%	1.97%
Forested Area	Softwood ha (2)	100.5	436.3
	Softwood %	64.76%	62.71%
	Mixed ha (5)	54.7	248.5
	Mixed %	35.24%	35.72%
	Hardwood ha (8)		10.9
	Hardwood %		1.57%
Totals:	Forested ha (99)	155.2	695.7
	Forested %	100.00%	92.55%
Non-Forested Areas	Wetland - General - ha (70)		21.8
	Wetland - General - %		38.93%
	Open Bogs - ha (72)		15.4
	Open Bogs - %		27.50%
	Treed Bogs - ha (73)		18.1
	Treed Bogs - %		32.32%
	Inland water - ha - (77)		
	Inland water - %		
	Urban - ha (87)		
	Urban - %		
	Road Corridor - ha (98)		
	Road Corridor - %		
Totals:	Non-Forested - ha (98)	0	56
	Non-Forested - %	0.00%	7.45%

Kejimkujik National Park -Square Camp Brook Watershed Barriers to Fish Passage

Appendix H. CUL 099 Flowing Waters Trail
UTM X 321311.74, UTM Y 4922057.64
Pre Restoration Passibility 0
Post Restoration Passibility 1
Barrier Type: Collapsed Culvert

Pre Restoration

Post Restoration



	Watershed	Flowing Waters		
	Barrier	Flowing Waters Trail Brook	Big Dam Road Brook	
Metrics	Fish Xing Score:	0	0.86	
DCI gains upon removal	Local DCIp	0.2884	0.0382	0.6424
	Local DCId	0.7229	0	0.1995
	Keji DCIp	0.0077	0	
	Keji DCId	0.004	0	
Total Barrier Catchment Area	Total Area (ha)	420.1	356	427.7
	watershed/Keji	98.22%	83.24%	1.12%
Forested Area	Softwood ha (2)	206	177.2	213.6
	Softwood %	50.68%	51.15%	51.58%
	Mixed ha (5)	193.9	162.6	193.9
	Mixed %	47.70%	46.94%	46.82%
	Hardwood ha (8)	6.6	6.6	6.6
	Hardwood %	1.62%	1.91%	1.59%
Totals:	Forested ha (99)	406.5	346.4	414.1
	Forested %	96.76%	97.30%	96.82%
Non-Forested Areas	Wetland - General - ha (70)	4.6	4.6	4.6
	Wetland - General - %	33.82%	47.92%	33.82%
	Open Bogs - ha (72)	4		4
	Open Bogs - %	29.41%	0.00%	29.41%
	Treed Bogs - ha (73)	5	5	5
	Treed Bogs - %	36.76%	52.08%	36.76%
	Inland water - ha - (77)			
	Inland water - %			
	Urban - ha (87)			
	Urban - %			
	Road Corridor - ha (98)			
	Road Corridor - %			
Totals:	Non-Forested - ha (98)	13.6	9.6	13.6
	Non-Forested - %	3.24%	2.70%	3.18%

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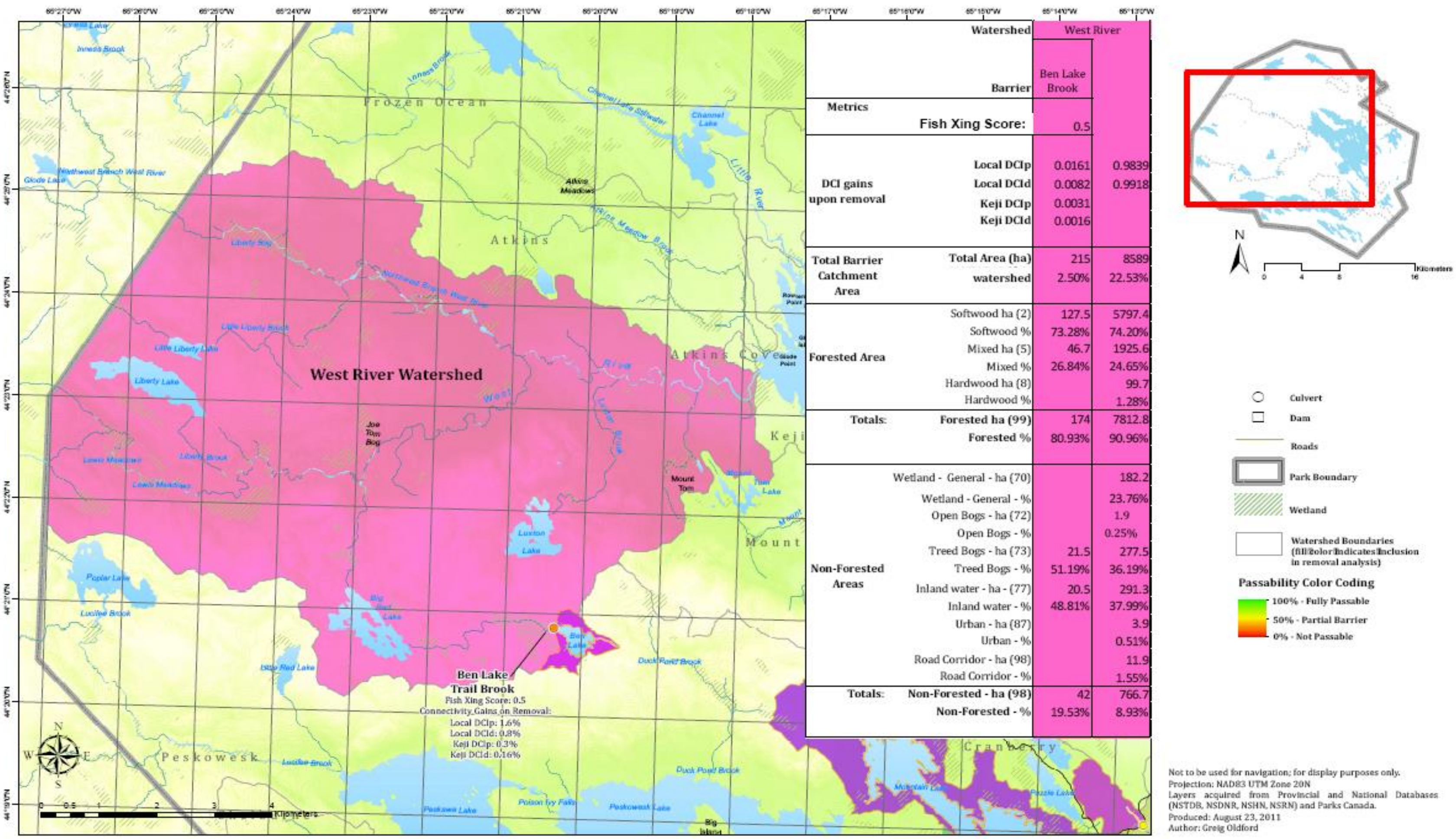
Projection: NAD83 UTM Zone 20N
Scale: 1:12,500
Layers acquired from Provincial and National Databases (NSTDB, NSDNR, NSHN, NSRN) and Parks Canada.
Produced: August 23, 2011
Author: Greig Oldford

Kejimkujik National Park - Flowing Waters Watershed Barriers to Fish Passage

Appendix I. CUL 112 Ben Lake Trail
UTM X 313539.52, UTM Y4913207.77
Pre Restoration Passability 0.5
Post Restoration Passability 1
Barrier Type: Debris

Pre Restoration

Post Restoration



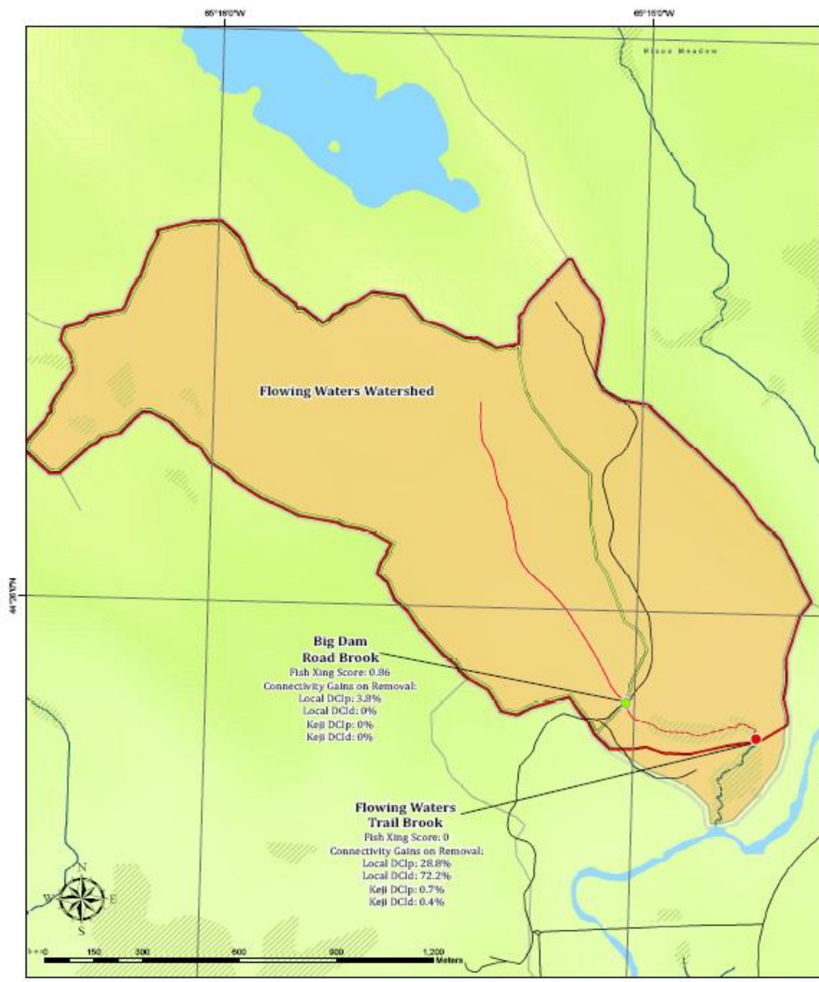
	Watershed	West River	
	Barrier	Ben Lake Brook	
Metrics	Fish Xing Score:	0.5	
DCI gains upon removal	Local DCIp	0.0161	0.9839
	Local DCId	0.0082	0.9918
	Keji DCIp	0.0031	
	Keji DCId	0.0016	
Total Barrier Catchment Area	Total Area (ha)	215	8589
	watershed	2.50%	22.53%
Forested Area	Softwood ha (2)	127.5	5797.4
	Softwood %	73.28%	74.20%
	Mixed ha (5)	46.7	1925.6
	Mixed %	26.84%	24.65%
	Hardwood ha (8)		99.7
	Hardwood %		1.28%
Totals:	Forested ha (99)	174	7812.8
	Forested %	80.93%	90.96%
Non-Forested Areas	Wetland - General - ha (70)		182.2
	Wetland - General - %		23.76%
	Open Bogs - ha (72)		1.9
	Open Bogs - %		0.25%
	Treed Bogs - ha (73)	21.5	277.5
	Treed Bogs - %	51.19%	36.19%
	Inland water - ha - (77)	20.5	291.3
	Inland water - %	48.81%	37.99%
	Urban - ha (87)		3.9
	Urban - %		0.51%
	Road Corridor - ha (98)		11.9
	Road Corridor - %		1.55%
Totals:	Non-Forested - ha (98)	42	766.7
	Non-Forested - %	19.53%	8.93%

Kejimkujik National Park - West River Watershed Barriers to Fish Passage

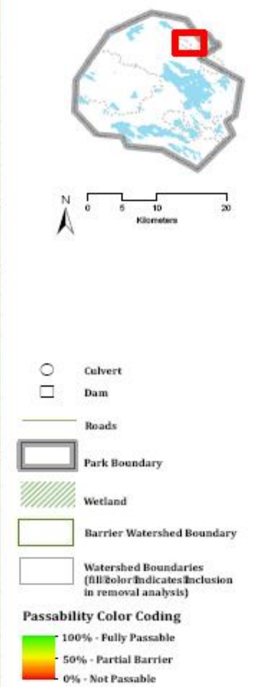
Appendix J. CUL 035 Big Dam Road
UTM X 320915.68, UTM Y 4922186.96
Pre-Restoration Passability 0.86
Post Restoration Passibility 1.00
Barrier Type: Velocity

Pre Restoration

Post Restoration



	Watershed	Flowing Waters		
	Barrier	Flowing Waters Trail Brook	Big Dam Road Brook	
Metrics	Fish Xing Score:	0	0.86	
DCI gains upon removal	Local DCIp	0.2884	0.0382	0.6424
	Local DCId	0.7229	0	0.1995
	Keji DCIp	0.0077	0	
	Keji DCId	0.004	0	
Total Barrier Catchment Area	Total Area (ha)	420.1	356	427.7
	watershed/Keji	98.22%	83.24%	1.12%
Forested Area	Softwood ha (2)	206	177.2	213.6
	Softwood %	50.68%	51.15%	51.58%
	Mixed ha (5)	193.9	162.6	193.9
	Mixed %	47.70%	46.94%	46.82%
	Hardwood ha (8)	6.6	6.6	6.6
	Hardwood %	1.62%	1.91%	1.59%
Totals:	Forested ha (99)	406.5	346.4	414.1
	Forested %	96.76%	97.30%	96.82%
Non-Forested Areas	Wetland - General - ha (70)	4.6	4.6	4.6
	Wetland - General - %	33.82%	47.92%	33.82%
	Open Bogs - ha (72)	4		4
	Open Bogs - %	29.41%	0.00%	29.41%
	Treed Bogs - ha (73)	5	5	5
	Treed Bogs - %	36.76%	52.08%	36.76%
	Inland water - ha - (77)			
	Inland water - %			
	Urban - ha (87)			
	Urban - %			
	Road Corridor - ha (98)			
	Road Corridor - %			
Totals:	Non-Forested - ha (98)	13.6	9.6	13.6
	Non-Forested - %	3.24%	2.70%	3.18%



Not to be used for navigation; for display purposes only.
Projection: NAD83 UTM Zone 20N
Scale: 1:12,500
Layers acquired from Provincial and National Databases (NSTDB, NSDNR, NSHN, NSRN) and Parks Canada.
Produced: August 23, 2011
Author: Greig Oldford

Kejimkujik National Park - Flowing Waters Watershed Barriers to Fish Passage

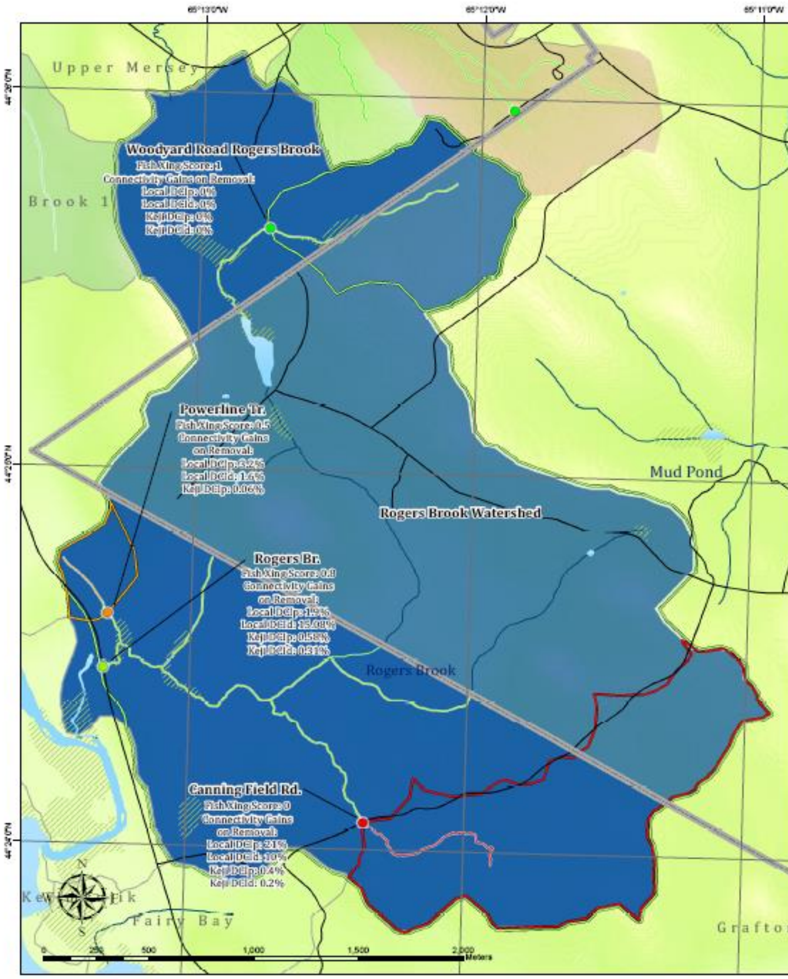
Appendix K. CUL 038 Canningfield Road

UTM X 324331.58, UTM Y4918822.22

Pre Restoration Passability 0

Post Restoration Passability N/A

Barrier Type: Outlet Drop

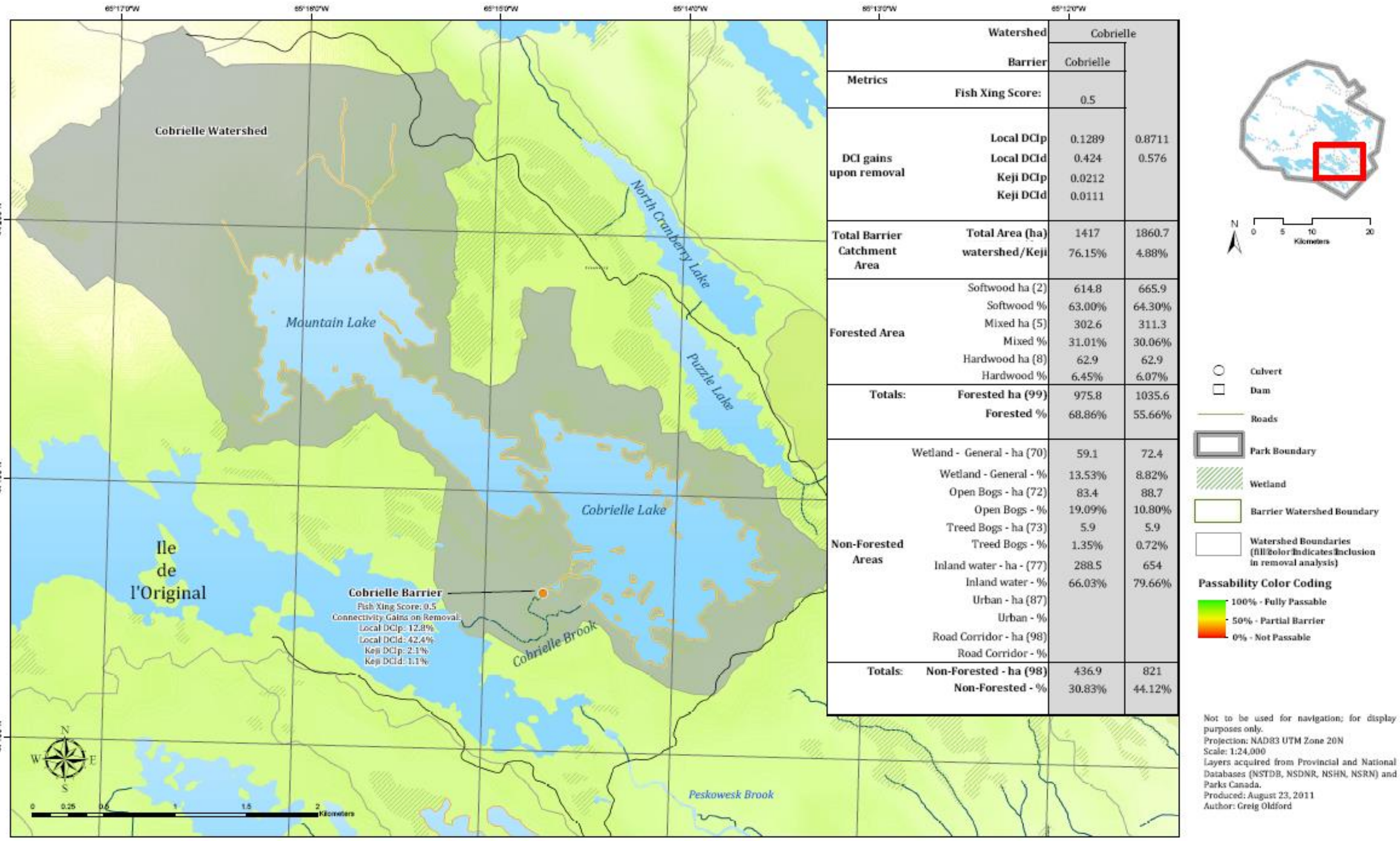


Watershed		Rogers Brook Watershed				
	Barrier	Rogers Brook	Canning Field Road Brook	Powerline Rogers Brook	Woodyard Road	
Metrics	Fish Xing Score:	0.81	0	0.5	1	
DCI gains upon removal	Local DCIp	0.0186	0.2101	0.0326	0	0.7303
	Local DCId	0.1508	0.1008	0.016	0	0.7049
	Keji DCIp	0.0058	0.004	0.0006	0	
	Keji DCId	0.0031	0.002	0.0003	0	
Total Barrier Catchment Area	Total Area (ha)	693.1	190.5	64	57.9	778.8
	watershed	89.00%	24.46%	8.22%	7.43%	2.04%
Forested Area	Softwood ha (2)	410.7	89.4	44.2	24.6	428.6
	Softwood %	61.71%	47.18%	92.08%	45.64%	61.59%
	Mixed ha (5)	227.4	100.1	3.8	9.8	239.9
	Mixed %	34.17%	52.82%	7.92%	18.18%	34.47%
	Hardwood ha (8)	21.6			13.7	21.6
	Hardwood %	3.25%	0.00%	0.00%	25.42%	3.10%
Totals:	Forested ha (99)	665.5	189.5	48	53.9	695.9
	Forested %	96.02%	99.48%	75.00%	93.09%	89.36%
Non-Forested Areas	Wetland - General - ha (70)	0.5	0.5			1.6
	Wetland - General - %	1.81%	50.00%	0.00%	0.00%	1.93%
	Open Bogs - ha (72)	0.7				1.9
	Open Bogs - %	2.54%	0.00%	0.00%	0.00%	2.29%
	Treed Bogs - ha (73)	4.8			2.6	4.8
	Treed Bogs - %	17.39%	0.00%	0.00%	65.00%	5.79%
	Inland water - ha - (77)					42.4
	Inland water - %					51.15%
	Urban - ha (87)	3.6	0.5		1.4	4.1
	Urban - %	13.04%	50.00%	0.00%	35.00%	4.95%
	Road Corridor - ha (98)	18		18		18
	Road Corridor - %	65.22%	0.00%	100.00%	0.00%	21.71%
Totals:	Non-Forested - ha (98)	27.6	1	18	4	82.9
	Non-Forested - %	3.98%	0.52%	28.13%	6.91%	10.64%

Kejimkujik National Park - Rogers Brook Watershed Barriers to Fish Passage

Appendix L. CUL 175 Cobrielle North Branch
UTM X 319661.91, UTM Y 4910520.82
Pre Restoration Passability 0.5
Post Restoration Passability N/A
Barrier Type: Debris

Photo Unavaliable



	Watershed	Cobrielle	
	Barrier	Cobrielle	
Metrics	Fish Xing Score:	0.5	
DCI gains upon removal	Local DCIp	0.1289	0.8711
	Local DCId	0.424	0.576
	Keji DCIp	0.0212	
	Keji DCId	0.0111	
Total Barrier Catchment Area	Total Area (ha)	1417	1860.7
	watershed/Keji	76.15%	4.88%
Forested Area	Softwood ha (2)	614.8	665.9
	Softwood %	63.00%	64.30%
	Mixed ha (5)	302.6	311.3
	Mixed %	31.01%	30.06%
	Hardwood ha (8)	62.9	62.9
	Hardwood %	6.45%	6.07%
Totals:	Forested ha (99)	975.8	1035.6
	Forested %	68.86%	55.66%
Non-Forested Areas	Wetland - General - ha (70)	59.1	72.4
	Wetland - General - %	13.53%	8.82%
	Open Bogs - ha (72)	83.4	88.7
	Open Bogs - %	19.09%	10.80%
	Treed Bogs - ha (73)	5.9	5.9
	Treed Bogs - %	1.35%	0.72%
	Inland water - ha - (77)	288.5	654
	Inland water - %	66.03%	79.66%
	Urban - ha (87)		
	Urban - %		
	Road Corridor - ha (98)		
	Road Corridor - %		
Totals:	Non-Forested - ha (98)	436.9	821
	Non-Forested - %	30.83%	44.12%

Kejimkujik National Park - Cobrielle Watershed Barriers to Fish Passage