Forest health based scenario building as an accessible tool for climate change management in Bruce Peninsula National Park

by

Kelly Dawn Moores

A thesis

presented to the University of Waterloo

in fulfillment of the

thesis requirement for the degree of

Master of Environmental Studies

in

Environment and Resource Studies

Waterloo, Ontario, Canada, 2014

I, hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners. I understand that my thesis may be made electronically available to the public.

____

Signature of Author

____

Date

Abstract

The global climate is changing; there are many predictions about the ecological impacts, and even more uncertainty. Predicted ecological impacts include northward shifting biomes, invasive species, decoupling of biotic interactions, all of which are threats to the ecological integrity (EI) of Canada's National Parks System. To maintain EI, parks must be managed for resilience with climate change in mind. Lack of human and financial resources are restrictions to managing for climate change, challenges exacerbated by government cutbacks in 2012. To overcome these restrictions a tool for informing management in a climate was designed using an existing research program and management based scenario building at the case study location of Bruce Peninsula National Park (BPNP). The tool designed for informing management is called Scenario Building, which accounts for uncertainty and focuses on the essential drivers of the local ecological community. Diversity and health in the forest community are essential drivers in the BPNP ecosystem with interactions at many tropic levels so the forest health research program was selected as the basis for scenarios. Results show a range of tree species that require a variety of soil and moisture regimes. Understanding the ecology of the keystone forest species allows for understanding of how they may reacted to predicted climate changes. Regional climate predictions based on the A2 and B1 primary climate scenarios of the IPCC were integrated with the forest health data, and two levels management option- passive and active to develop 4 scenarios that can inform management of the park. Passive and active management were defined by the number of dollars spent on active management. The 4 scenarios developed were: Scenario 1 B1 Passive Management - Status Quo, Scenario 2 B1 Active Management - Regional Resilience, Scenario 3 A2 Passive Management - Evolving Forests, Scenario 4 A2 Active Management- Anticipatory Restoration. A set of scenarios allows managers to set a management trajectory balances resilience and EI with economic viability in the face of climate change. Analysis of the BPNP scenario suite tell us that BPNP is one park that is in a good position to be able to adapt to a changing climate without major risk to EI, however significant steps can be taken to minimize losses or even improve EI by anticipating needs and investing in active management.

Acknowledgements

Successful completion of this project was the goal from the outset, yet for a long time it felt like it would never really happen. The epiphany that I was actually finishing this thesis was very surreal, and a milestone for which I have many thanks.

First and foremost thank you to my supervisor Dr. Stephen Murphy, for all of the hours you spent reassuring me that this is, in fact, a good project and that it would turn out well. Thank you for your time as well as your academic, emotional, and financial support, nothing about this project would have been possible without it.

Thank you to the University of Waterloo, the Faculty of Environment, and the Department of Environment and Resource Studies for your financial and administrative support, particularly Jennifer Nicholson, who always knows the answer. Thank you to all of the professors who taught the classes I took as well as those I TAed, I learned important things from each experience.

Thank you to NSERC for the funding, and to Dr. Reekie for his instrumental role in helping me achieve that funding.

Thank you to Bruce Peninsula National Park for welcoming my research. Dr. Scott Parker, your role as my committee member and go-to person at the park are greatly appreciated. Thank you also to Jeff Truscott for all of the GIS and mapping data it saved me hours of work and a few potential embarrassing incidences of getting lost looking for sites. Thank you to Katrina Keeshig for providing me with previous forest health monitoring data, and for welcoming me into the Maple Grove staff house and showing me all of the fun of Tobermory summer culture.

Graduate school can be a trying time filled with stress and existential crisis. For the most part I was able to avoid the depth of peril with these issues thanks to the love and support of many. To my many roommates over my time at 7 Moore: Taylor, Cassia, Pam, Neil, Jeff, and Ryan, thank-you for being wonderful people to wake up and come home to every day. Thanks for dealing with my early mornings, academic ranting, and general silliness. Loving where and with whom you live makes a the world a better place. To my lab/fishbowl office mates, thanks for the motivation and the distraction and for not disturbing my frequent desk naps. To the Waterloo Warriors Figure Skating Team, thank you for giving me a place to channel my energy, release stress, and build leadership and camaraderie. Even knowing this project took me much longer as a result of my athletic engagement, I wouldn't trade a second of it. To Parkminster United Church, you lived your welcome and gave me a community away from home and a way for me to feel connected, thank you. To the many other friends I've made, shared laughs, stories, ideas, Sunday potlucks, camping adventures, or frisbee games with: Thank you, your friendship means the world to me. Finally to my parents and family, thank you for your unconditional love, for patiently supporting me through this process, and for not giving up on me every time I said I'm not done yet. I'm done now, and I couldn't have done it without you.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

1.1 Effects of a changing climate on natural systems and protected areas

Meeting the objectives of Parks Canada, including maintaining and restoring ecological integrity, and the goals outlined in the Strategic Network Plan are becoming increasingly difficult as a result of a changing climate. Increased carbon dioxide (CO_2) and other greenhouse gas emissions into the atmosphere, as well as changing land use practices are resulting in changes in temperature and precipitation patterns (IPCC, 2014). These changing patterns are affecting Canada's national and local ecological landscapes. Many of those effects are relevant to maintaining Ecological Integrity in parks and protected areas. The Parks Canada Agency Act defines ecological integrity as "a condition that is determined to be characteristic of its natural region and likely to persist, including biotic and abiotic components and the composition and abundance of native species and biological communities, rates of change and supporting processes" (Parks Canada Act– S.C. 2000, c.32 Section 8). The level of ecological integrity is relative to the desired state of the system and what is considered "characteristic of the region". Species ranges are changing, exotic species are being facilitated by climate shifts, and the complex ecosystem interactions are becoming uncoupled, heralding major changes to all scales, from genetic to biome (Bellard, Bertelsmeier, Leadley, Thuiller, & Courchamp, 2012; Dawson, Jackson, House, Prentice, & Mace, 2011; Urban, Tewksbury, & Sheldon, 2012). In order to grasp the implications of these changes for protected areas management, one must focus on a time scale relevant comparable to that of institutional management plan cycle.

1.1.1 North America, Europe, & Asia: Northward shifting biomes - Changes in Space

Most species have a range of conditions in which they find their appropriate habitat and can survive successfully. Depending on the type of organism and the specific species, there are many factors that contribute to the distribution of a particular species' range. For many species, Temperature is one of the controlling factors (McKenney, Pedlar, Lawrence, Campbell, & Hutchinson, 2007; IPCC, 2007). Temperature change trends under climate change models generally lead to a northward and upward shift in home ranges of a wide array of species at the continental scale (Bartlein, Whitlock, & Shafer, 1997; Loarie et al., 2009; Sala, 2005). This migration of species as they shift upward and northward with their preferred biome is mostly accomplished through dispersal (McKenney et al., 2007; Scheller & Mladenoff, 2008). For many birds and insects, the response is already being seen (Parmesan, 2006). Shifting climate regimes are likely to expand some habitats and contract others (Scott, Malcolm, & Lemieux, 2002; Alo & Wang 2008). It is predicted that boreal forests will expand northward and as a result the tundra currently north of the tree line will contract (Alo & Wang, 2008; Lafleur, Paré, Munson, &Bergeron, 2010). Declining habitat size is a problem for many species but it is only problem number one; it is not sufficient to only continue to have existing suitable climate, species must be able to keep pace with their tolerable, if not ideal, climate as it shifts (Loarie et al., 2009).

Not all species are able to migrate[1] at the same rate, and the rate required to keep pace with changing climate is not uniform either. Loarie et al. (2009) have created a model and a formula to evaluate the velocity with which a species must shift its range if it is to keep pace with its suitable climate. The velocity required is strongly based on topography; in a mountainous area, a lower velocity is required because a small spatial displacement up or down the slope results in a large temperature change. In contrast, in a flat grassland plain a much higher velocity is required, because a species must migrate a significant distance before experiencing an appreciable change in temperature (Loarie et al., 2009).

The paleoecological record is used in several studies to compare the projected redistribution of species to the migrations of species that happened during the transition at the end of the Pleistocene glaciation (14 000 ya) moving into the Holocene inter-glaciation (9000 ya) (Bartlein et al., 1997; Dawson et al., 2011; Loarie et al., 2009; Pearson, 2006). The paleoecological data offers an analogous change in temperature, precipitation, and insolation expected from the current global warming, though over a considerably longer time period. Pearson (2006) estimates that tree species were able to migrate on the order of 100-1000 m/year in response to the retreating glaciation at the end of the Pleistocene. A shifting rate of 1000 m/year would be an a good rate for the range shifting of tree species under current conditions and would certainly be useful in the attempt to keep pace with northward shifting biomes, however, this is an extreme upper limit and there are several factors which add complexity and make this figure an unrealistic best case scenario.

[1] Throughout the literature the term "migrate" is used to describe northward range shifts. It is acknowledged that this is imprecise language. The traditional definition of migration implies that the movement is done by an individual in one generation, and then there is also a return trip within the same year. The use of the term migration in northward shifting biome literature refers to the one directional range shift northward. In the case of non mobile organisms this is accomplished over multiple generations so it is not only individualistic by species or individual, it is the genotypes and phenotypes that are actually moving northward.

The first major difference between postglacial re-colonization and the current range shift is that post glaciation species were migrating into a space that was mostly uninhabited. In some ways this is inhibitory, as the supporting nitrogen fixing bacteria or mycorrhizae are not yet present, and prevent establishment (Lafleur et al., 2010). Conversely, uninhabited space can facilitate colonization as trees and other plants are able to establish with minimal competition (Lafleur et al., 2010). Trees looking to migrate northward to keep pace with their shifting biome resulting from climate change must, for the most part disperse into areas that are already inhabited and must compete with the currently established forest (Lafleur et al., 2010). Difficulties in establishment due to competition may be reduced by disturbance and changes to the disturbance regimes in forests which create space and opportunity northward dispersing trees (Scheller & Mladenoff, 2008). Other issues include the difficulties of dispersing through a fragmented habitat and the individualistic nature of species dispersal and the effects on codependent biotic interactions - to be discussed in sections 1.1.4 and 1.1.5 respectively.

1.1.2 Changes in phenology - changes in time

A second way that species can compensate for a changing climate is through changes in the timing of their life cycle events in order to continue matching the surroundings of their abiotic environment. These life cycle events include, but are not limited to, leaf out, flowering, fruiting, mating, and migration; collectively they are called changes in phenology (Bellard et al., 2012). Many species are already adjusting the timing of their life cycle events, the most common changes are those where the physiological response is tied to temperature. Events such as emergence or flowering are happening sooner as a result of a critical temperature being reached earlier and earlier in the year (Charmantier et al., 2008; Parmesan, 2006).

Temperature is not the only trigger for life cycle events; other responses are related to photoperiod, soil nutrients, or thermal stratification in lakes (Walther, 2010). Even among those species responding to temperature, not all respond at with the same rate or magnitude. Mismatches in phenology changes offers the most serious ecological consequences, when important interspecies interactions break down (Van der Putten, Macel, & Visser, 2010; Walther, 2010; Yang & Rudolf, 2010). This will be discussed further in section 1.1.5 on decoupling of biotic interactions.

1.1.3 *In situ* adaptation

Adaptation to climate change through changes in space and shifting home ranges are particularly easy to observe, and have been easy to observe through time in the paleoecological record (Davis & Shaw, 2001; Parmesan, 2006). However *in situ* adaptation also plays an important, though historically less documented role. In situ adaptation is important in preventing local extirpations of species, maintaining productivity in forests as well as facilitating spatial change (Davis, Shaw, & Etterson, 2005). In situ changes can be experienced in two major ways; genetic drift between generations, and changes within a generation, called phenotypic plasticity (Bellard et al., 2012).

Genetic changes are much more difficult to observe and are harder discern in the paleoecological record than spatial range shifts, therefore there have been fewer studies examining the role that evolution plays in allowing species, populations, and communities to deal with climate change (Davis et al., 2005). However the physiological adaptation to climate change plays an important role in assuring the persistence of species. As the genotypes from further south in the range move northward geographically, they are more likely to confer the range of plasticity wide enough for adaptation to a warmer climate to support the continued success of the species in the central part of the range (Davis & Shaw, 2001). The individuals able to establish and survive at the leading edge and in the central part of the range are more likely to carry the genes that will exhibit phenotypes needed for their new environmental conditions than those at the trailing end of the range. This however, makes the large assumption that the traits required for establishment and to survive as a juvenile are not substantially different for those required for success as an adult (Zhu, Woodall, Ghosh, Gelfand, & Clark, 2014).

In addition to evolution that happens through generation turnover, phenotypic plasticity offers a mechanism for increased potential within a generation. Phenotypic plasticity is the ability of one genotype to express several different physiological, morphological, behavioral phenotypes in response to short term changes in the environment (Price, Qvarnström, & Irwin, 2003). Phenotypic plasticity is important for coping with abrupt changes resulting from climate change because it operates on the fastest time sale, helping organisms to survive (e.g. to warmer climate) within that generation (Charmantier et al., 2008). This is important for long lived, sessile organisms such as trees, which are unable to physically shift themselves northward.

1.1.4 Fragmentation and Habitat connectivity

Keeping pace with the changing climate is a substantial challenge for species, migrating across areas that have undergone dramatic land cover change increases that challenge immensely. A problem with the comparison between the Holocene migration rates and current changes is that during the Holocene the path of migration was entirely uninterrupted, save for natural geographic barriers (Bartlein et al., 1997). Now habitat fragmentation has made successful migration an even greater challenge. While corridors remain an important conservation tool, it is unclear whether those corridors will continue to be useful in a changing climate.

Loarie et al. (2009) identified protected areas, such as national parks, provincial parks, and other conservation areas, as important by providing less fragmented habitat, facilitating species making the climate migration. The connection between protected areas and the velocity required to keep pace with changing climate is investigated by calculating residence time, the diameter of the protected area divided by velocity required to traverse that area ($km/km\ yr^{-1}=yr$). The residence time predicts how long it will take for the current climate to cross that protected area (Loarie et al., 2009). The results of the study found that globally, more than 99% of protected areas had a residence time of less than 100 years. Paleoecological data from the warming at the start of the Holocene show a maximum migration rate for tree species at about 1km/year (Pearson, 2006).

This 1km/yr rate of range shift may even be an overestimate if there were other factors contributing to the success of recolonization following the Pleistocene glaciation. Some additional factors would include: refugia or climate buffers for certain species in complex mountain topography, leading to a practical population dispersal rate that is well below the 1km/yr rate needed for species to traverse protected areas within the predicted residence time (Loarie et al., 2009). The Loarie model assesses residency time, not dispersal rates of species, which would each require different variables. The model is also based on only one parameter, which is the change in average annual temperature just above soil surface. The grain size used in the model is 1km, quite fine for a global scale model (Loarie et al., 2009). Despite the generalization and assumptions required to create a model at this scale, the residence time formula still provides support for my own research project. It demonstrates the difficulty for tree species to keep pace with a changing climate, and that protected areas play a vital role in facilitating species migration and adaptation. Through developing a more robust understanding of how individual parks will respond to climate change, more informed management decisions can be made about how to best maintain biodiversity and ecological integrity.

Plants are only able to shift their range substantially and quickly by successful seed dispersal and successful colonization by seeds. While apomictic forms of reproduction can allow range shifts, these generally will be short distance, hence slower. On average tree seeds disperse in the order of tens of metres, which is well below the maximum suggested rate of 100km/year (Pearson & Dawson, 2005). Achieving a dispersal rate that will facilitate keeping pace with range shifts is not likely, e.g. Pearson & Dawson (2005) suggest that this depends on relatively rare occurrences of long range dispersal by birds creating nests or entanglement in mammal fur. However, long range dispersal can at least help overcome habitat fragmentation as a barrier to migration, and that in events of long range dispersal it is not the spatial arrangement so much as the quantity of suitable habitat available that is a determining factor (Pearson & Dawson, 2005).

In addition to inhibiting the spatial migration of species as they attempt to track their preferred climate range, habitat fragmentation places another restriction on the ability of populations to adapt to climate change. Fragmentation can be a large impediment for gene flow among communities (Jump & Penuelas, 2005; Opdam & Wascher, 2004; Scheller & Mladenoff, 2008). Reduced gene flow among populations reduces genetic variability and the ability of individuals transfer the genes to maintain or increase fitness in the new environmental conditions (Jump & Penuelas, 2005). For continued gene flow opportunity successful pollen dispersal is just as important as opportunity for successful seed dispersal as pollen dispersal allows for a maximization in gene recombination (Davis & Shaw, 2001).

There are challenges for both spatial and genetic change to keep pace with changes in ideal climate (Loarie et al., 2009; Opdam & Wascher, 2004), so it is important that populations are able to undergo both processes simultaneously. As the range expands northward and upward and selection pressure confer traits that allow seedlings to better tolerate warmer climates, it may be possible to reduce mortality and possible species extinctions (Bellard et al., 2012). In order to maximize both types of change it is important to have available habitat in which dispersed seedlings can establish and be successful (Lafleur et al., 2010) as well as multiple source populations within a close enough range for sufficient genetic variation (Jump & Penuelas, 2005).

1.1.5 Decoupling of biotic and abiotic interactions

Paleoecological data show that genotypes and phenotypes of species demonstrate individualistic response to warming climate, each moving northward at their own pace based on individual abilities for dispersal and colonization (Bartlein et al., 1997). The individualistic response of species to climate change has been further documented in many studies (Burns, Johnston, & Schmitz, 2003; Parmesan, 2006; Urban et al., 2012). Key issues are whether or not species ranges are expanding or contracting, the rate with which they are shifting, and how fast organisms must shift to keep up. However, genotypes do not exist independent from their populations, communities, landscapes and ecosystem processes so their response is conflated with multiple variables and scales. For example, all of the types of interactions affect individuals, e.g. competition, , predator-prey, mutualism, parasitism-host (Pearson & Dawson, 2003). Interactions that are particularly sensitive to the individual nature of range shifts include mismatches in emergence and flowering between plants and their pollinators. The interaction would be disrupted if insects emerge earlier due to warming and the flowers they rely on for food do not bloom earlier because they are triggered by photoperiod. This leaves the insects without their food source and the flowers without that pollinator. Similar issues can occur in the relationship between birds returning from migration and their insect prey. There are also important relationships happening above and below the soil surface. Many trees have highly improved ecological functioning in the presence of mycorrhizal fungi, as tree species attempt to shift northward by dispersal, it may be possible that they reach soils no longer containing the mycorrhizae on which they depend, making establishment and success in a new environment considerably more difficult (Van Grunsven, Van Der Putten, Martijn Bezemer, Berendse, & Veenendaal, 2010). Further interaction mismatches could result from the temperature lag between the warming of air, and the slower warming of soil (Van der Putten et al., 2010)

Responding to different environmental variables is one potential cause for mismatch; species individually shifting northward and upward with climate change at different rates is another. As species disperse and shift at their own pace, there is no guarantee that the species with which they interact will shift at the same pace, or that there will be analogous species in their new environment to fulfill this interactive role(Van der Putten et al., 2010; Walther, 2010; Yang & Rudolf, 2010).

Urban, Tewksbury and Sheldon (2011) explicated that not all species shifting ranges at the same rate dramatically affects species interactions. The importance of these interactions led to the inclusion of varying dispersal rates and impacts of competition, in addition to change in temperature, in the new model developped by Urban et al. (2011). Previously most models assumed a uniform dispersal rate, or 'all or nothing' success in species ability to track climate change. This assumption is significantly altering the outcomes of models from the way species will react in nature. As species ranges shift following their preferred climatic zone at their own rate, the intenstiy and nature of many species relationships will be altered. The model created by Urban et al. predicts the effect that changing competition structures will have on biodiversity loss associated with climate change (Urban et al., 2012). When differences in dispersal rate, interspecific competition, or both were included into migration models, the risk of extinctions as well as the formation of no-analogue communities increases. Three interelated mechanisms through which competition affects community responses were found: Slowing of climate change tracking by reducing population abundances, difficulty colonizing in newly avaliable niches, and negatively impacting species whose broad niche would otherwise allow them to persist (Urban et al., 2012). It is clear from these results that the more factors that are considered, the more researchers understand the complexity and severity of the threat posed by changing climate.

1.1.6 Invasive species

Invasive species are organisms not endemic of a particular region that had been introduced, intentionally or inadvertently, and have established and become prolific to the detriment of other species or to the ecological integrity of the community as whole. The most common problematic invasive species for forests are often plants, fungi, and insects, though any type of organism has the potential to be invasive. Negative impacts that can result from invasive species include: increased tree mortality, understory dominance preventing regeneration, and reduced species richness (Dukes et al., 2009). Damage caused by invasive species goes beyond ecological damage; it affects all types of ecosystem services. Major damage, such as that caused in BC by the Mountain Pine Beetle would also have the potential to negatively affect visitor-ship and visitor experience in national parks (McFarlane, Stumpf-Allen, & Watson, 2006)

As changing temperature and precipitation patterns affect the range, growth, and success of native species it will also affect introduced, exotic, and invasive species (Dale et al., 2001; Dukes et al., 2009). Studying and managing the impacts of climate change on invasive species is fundamentally different from those on native species for several reasons. Primarily, with native species management efforts are focused on protection and conservation whereas with invasive species the focus is on elimination or controlling the spread of the organisms (Hellmann, Byers, Bierwagen, & Dukes, 2008). Climate change could negatively impact some invasive species but native species are more likely to decline. Invasives are usually generalists, able to succeed under a wide variety of conditions. Conversely, native species are sometimes generalists, also adapted to a wide range of conditions, but often they are adapted to the specific conditions of a particular community or region (Hellmann et al., 2008). Conditions that negatively affect invasive species will not be discussed here, since the reduction in invasive species influences ecological integrity positively rather than negatively and is thus, not a concern.

Invasive species have the potential to flourish under changing climate conditions through many aspects of their invasion pathway (Hellmann et al., 2008). New routes of exposure, higher levels of disturbance facilitating colonization with minimal competition, reduced success of native species reducing competition, reduction in abiotic controls such as frozen soil or low over winter temperatures preventing spread, are all risk factors for increased issues with invasive species. Temperate areas are particularly at risk of increased infestation from invasive pests (Dukes et al., 2009). Cold winters can be a barrier for many invasive pests, so the regional warming (for most locales, including BPNP) associated with climate change is enabling these pests to also move northward and they are having greater success surviving the now milder winters, exposing new environments to infestation (Dukes et al., 2009; Hellmann et al., 2008).

Successful dispersal and establishment are two life history traits that facilitate species becoming invasive, and their generalist nature means that these organisms are likely to be successful in the context of a changing climate (Hellmann et al., 2008). Quick, successful colonization after disturbances, which are predicted to increase in frequency (IPCC, 2007), is one competitive advantage of many invasive plants. Once established and utilizing resources, it is possible that the establishment and proliferation of invasive plants will work against the successful migration and/or establishment of native species that perhaps have narrower climate ranges.

1.1.8 Novel Ecosystems

The field of restoration ecology has developed as a result of conservationist efforts to reclaim and re-naturalize lands that have been strongly ecologically disturbed. In many cases these disturbances are a result of economic activity such as logging or mining (Society for Ecological Restoration International Science & Policy Working Group, 2004). Upon completion of resource extraction projects environmental assessments are requiring restoration and reclamation of the land. As the field of restoration ecology grows it has expanded to national parks as they attempt to restore areas with degraded ecological integrity, or they restore newly acquired properties to bring them to national park ecological integrity standards (Parks Canada, 2009).

Traditionally restoration ecology, focused on returning a site to its historic state, (Hobbs, Higgs, & Harris, 2009). However, with increasing anthropogenic influence, including the effects of climate change, it is becoming increasingly difficult, and expensive, to view the historic state as the only successful outcome of a restoration project. There has been a new perspective emerging in the field of restoration ecology, that restoring an area should be more focused on structure and function than on the exact composition of species from a previous time (Hobbs et al., 2009). Once a system has moved so far away from its historic state and undergone a certain level of change, returning it to that state is unfeasible, restoration ecologist do the best they can, but in lieu of returning to a historic state the system is now different than any previous existing community, called a no-analogue system or a novel ecosystem (Hobbs et al., 2009).

The concept of novel ecosystems is important context for protected areas in a changing climate. When looking ahead to possible future impacts and how they might be mitigated or adapted to for maintaining ecological integrity, it is valuable to consider the novel ecosystem a valid option insofar as it has appropriate structure and function and retains the requisite ecosystem services.

With the inherent complexity of ecosystems there are already many factors for managers to consider as they work to establish and maintain ecological integrity in protected areas systems (Holling, 2001). Climate change will only compound these challenges, as it leads to altered life histories, species assemblages and increased uncertainty. By recognizing these challenges it is hoped that managers of protected systems will take initiative to begin to rethink their management strategies and shift them to take a changing climate into account. Resilience is defined by Westman (1978) as "the ability of an ecosystem to recover from disturbance without human intervention". Building resilience and adapting to climate change early will make the goal of maintaining ecological integrity more manageable as changes progress (Gunderson, 2000; Holling, 1973)

1.2 Protected Areas in Canada

1.2.1 The organization and mandate of protected areas in Canada

In Canada there are many classifications of protected areas that limit or prevent the development of land and the exploitation of its resources, thereby protecting wildlife, biodiversity and ecological processes for future generations. Three federal departments: Fisheries and Oceans, Environment Canada, and Parks Canada are responsible for different types of protected areas at the national level, including Marine Protected Areas, National Wildlife Areas and Migratory Bird Sanctuaries, and National Parks and National Marine Conservation Areas, respectively. Provinces and territories also have several categories of protected area, including provincial parks, ecological reserves, and wilderness areas that vary slightly among jurisdictions. Lands may also be protected regionally, privately, or through land trust organizations. Two large (>10 km^2) protected areas have also been created in the Northwest Territories through Aboriginal Land claim agreements.

Canadian national parks are a major network of protected areas comprising of 42 protected areas totalling over 2.25% of land in Canada as of 2011. The Parks Canada Act legislates that the primary goal of these protected areas is the maintenance or restoration of ecological integrity (Canada National Parks Act – S.C. 2000, c.32 Section 8). Maintaining ecological integrity entails ensuring a condition where native species and biological communities will be able to sustain their composition, abundance, and ecological processes.

The first national park in Canada was created in what is now Banff Alberta in 1883(Parks Canada, 1997). Initially parks were established individually on a case by case basis, until the 1970s when the National Parks Systems Plan was developed to promote a more complete representation of the Canadian landscape through National Parks (Parks Canada, 1997). Per the National Parks Strategic Network Plan, Parks Canada's objective is "To protect for all time representative natural areas of Canadian significance in a system of national parks, to encourage public understanding, appreciation and enjoyment of this natural heritage so as to leave it unimpaired for future generations" (Parks Canada, 1997, 2). This objective has several components: a conservation component, a social component, and a commitment to the ecological integrity of each park. These components are strongly linked to one another, so policies and management must be performed in a way that provides mutually reinforcing benefits for this complex social-ecological system (Gibson & Hassan, 2005).

The social objective of Parks Canada has traditionally been met by programs designed for visitors to the parks, including: signage, visitor's centers, guided walks, and interpretive performances. These tools have helped the over 4 million visitors to National Parks each year develop an understanding and appreciation for the natural environment of the park (Parks Canada 2014). Despite their important role, due to the massive 2012 budget cuts these social programs are among the services that parks will have a reduced capacity to provide.

There are people who are at the interface of the social and conservation objectives by volunteering in parks or using them as a venue for ecological, historical, or social science research (Bradford, 2004; Mclennan et al., 2012). Although the social and conservation objectives are closely linked by policy and the effort to maintain ecological integrity within the park, the focus of the present research is on the ability to continue to meet the conservation objective, and maintain ecological integrity in a changing climate. Maintaining ecological integrity in National Parks is already a significant challenge (Parks Canada, 2009), this challenge is compounded by the uncertainties of a changing climate and the ever increasing financial and human resource restrictions resulting from massive budget cuts.

1.2.2 Challenges in a changing climate

Increasing the concentration of greenhouse gases in the atmosphere is already having direct and indirect effects in ecosystems around the world. Global Circulation Models (GCMs) and regional climate models are being used to predict the impact of these temperature and precipitation pattern changes in Canada, as well as specifically for Canadian National Parks (Bartlein et al., 1997; Scott et al., 2002). The majority of these models – that are relevant to Canada - are predicting a northward shift in biomes with increasing temperatures, while changes to precipitation patterns are much less clear (IPCC, 2007). Many challenges for maintaining ecological integrity result from shifting biomes. There is the possibility that conditions may no longer be suitable to some or many of the species currently residing within protected areas, and the possibility for colonization of new and potentially invasive species as their ecological ranges expand (McKenny, Pedlar, Rood, & Price, 2011).

Shifting biomes present an important concern for maintaining ecological integrity on site, but they also complicate the conservation objective of the Strategic Network Plan, which revolves around representation. To facilitate meeting the conservation objective of the National Parks Systems Plan, Parks Canada has divided the country into 39 designated 'natural regions' with the goal of establishing a national park in each natural region for a complete system that is representative of the natural diversity in Canada (Parks Canada, 1997). Most natural regions are defined by the biota that resides within them, often including certain species that are endemic to that particular natural region of Canada. Currently 24 of the 39 natural regions are represented (Parks Canada, 2008). The representation goal has been useful in helping to decide the priorities of Parks Canada and how locations of new parks are selected (Parks Canada, 1997). However, the system plan is implicitly made with the assumption of a stable climate; that parks established to represent specific natural region would be representative of that natural region in perpetuity (Burns et al., 2003). Given that we are no longer living in a world with a stable climate, this assumption is invalid (IPCC, 2014).

According to a survey of Canadian conservation agencies including Parks Canada, employees are aware of both the threats of climate change to their conservation mandate, as well as the opportunity that protected areas have to help reduce the negative impacts of climate change on biodiversity (Lemieux et al 2011). Taking a proactive approach to adaptation would be more cost effective and reduce irreversible damages that would result from failing to anticipate or adapt management and policies until climate change impacts are forcing reactive responses (Intergovernmental Panel on Climate Change, 2014). Unfortunately neither Parks Canada, nor any of the individual national parks, has an adaptation management plan in place for climate change scenarios. Furthermore Parks Canada employees do not believe they have the capacity, in terms of financial or human resources, to review their current management plan or develop a new one based on the realities of climate change (Lemieux, Beechey, Scott, & Gray, 2011). In the spring of 2012, federal budget re-allocations under Bill C-38 introduced substantial cuts to Parks Canada, resulting in +600 of 3000 positions being cut, and many others reduced (Growth, Jobs, and Long-term Prosperity Act, S.C. 2012). As a result of reductions in funding, at BPNP the camping season for visitors has been reduced to only three months (June–August), meaning a more intense concentrated human impact, possibly contributing to the challenge of maintaining ecological integrity.

1.2.3 Role for protected areas in a changing climate

Despite the challenges presented by a changing climate, protected areas, including national parks, can maintain biodiversity and ecological integrity in Canada. Large protected areas provide a buffer zone for species that do not disperse fast enough to keep pace with their northward shifting climate range (Pearson, 2006). Creating networks of protected areas also increases landscape connectivity, providing for larger home ranges for large fauna species, as well as providing a migration route for species moving their home range northward (Pearson & Dawson, 2005). Long term data sets collected in national parks are also an important source of knowledge to help researchers understand changes in trends for phenology, migration times, reproduction rates, growth rates, and species diversity.

Lemieux, Beechey and Gray (2011) asked key questions about the role of conservation agencies and their current mandate and methods, and then provide responses for each including actions that would facilitate adaptation and strengthen policies and management in the face of a changing climate. Many of the responses can be amalgamated into a few central themes:

1. The concept of representation should be examined and the focus shifted towards maintaining ecological function for continued ecological integrity, using ecological restoration as a means to achieving this goal where it makes reasonable ecological and economic sense.

2. Using systems thinking (Holling, 2001), building resiliency and ecological redundancy is the most effective way to maintain ecological integrity (Lemieux, Beechey, & Gray, 2011).

3. Consider new governance regimes across multiple scales, grouping together protected areas with similar features with a single adaptation strategy, or create protected areas with floating boundaries to follow representative or threatened species. Adaptive management is preferable to maintaining the unsustainable status quo, or passive management which would eliminate human interference and evolutionary processes to run their course, which would inevitably lead to significant losses in biodiversity and ecological integrity.

4. Understand that protected areas are a source of knowledge with long term monitoring and data sets, and they also have a significant opportunity for communication

and education about climate change and ecological integrity issues through their programming and interaction with the public (Lemieux, Beechey, & Gray, 2011).

The management and policy response suggestions by Lemieux, Beechey, & Gray have potential to prepare protected areas, including national parks, for uncertain future of a changing climate. However, the limitations outlined by Lemieux et al. (2011) of lacking financial and human resources were made before the most recent round of extreme budget cuts, and are now more pronounced than ever before (Jobs, Growth, and Long-term Prosperity Act, S.C. 2012). The suggestions made by Lemieux et al have become even more difficult to implement, though they are still important for maintaining ecological integrity and fulfilling the potential for national parks to maintain ecosystem function and biodiversity in Canada. In addition to the financial and human resources limitations, a lack of scientific knowledge about the ecological impacts of climate change is preventing movement on the development of adaptation plans (Lemieux, Beechey, Scott, et al., 2011). A strategy is needed to allow park managers to make informed decisions about the future concerns and needs of their parks. The ideal strategy would be flexible enough to be tailored to the individual needs of various ecosystems represented under the National Park System.

1.3 Thesis Goal – Building Climate Change Scenarios for Management of BPNP

The goal of my research was to develop the first phase of building a national climate change adaptation strategy for National Parks and other protected areas. A suite of park specific management scenarios can be developed by examining traditional field data through systems and climate change lenses and then applying those outcomes to the predictions of the primary climate scenarios by the IPCC in the Special Report for Emission Scenarios (SRES) and incorporating various management options. Bruce Peninsula National Park (BPNP) in Ontario was selected as the pilot for this site specific scenario building strategy. BPNP was selected at the study site because it is situated roughly in the center of its ecozone making it a moderate example for study. For studying the effects of climate change choosing a temperate-boreal park makes sense as it is this environment, which has a natural history adapted for four distinct seasons and has the most possibility for impacts resulting from a change in climate relating to any of those seasons. Furthermore, the land form of a peninsula is interesting for study as terrestrial invasions, or range shifts, are only accessible from one direction. BPNP is a forested park that contains forest of mostly northern character but also does include some more temperate species. Through developing a more robust understanding of the importance of forest health as an indicator of overall ecological integrity of the park ecosystem it is hypothesized that the scenario building about the future impacts of climate change on Bruce Peninsula National Park can be used to inform policy and management decisions.

The management goals of BPNP as stated in their 1998 management plan include, but are not limited to: 1. Maintaining viable populations of all existing native species and the variation in vegetation communities that is representative of the Western St. Lawrence Lowlands, including maintaining ecological and evolutionary processes. 2. To rehabilitate areas that have been disturbed to return them as closely as possible to their natural state. 3. Adhere to the requirements of the Canadian Environmental Assessment Act to minimized the degradation of natural systems. 4. Use monitoring to contribute to baseline data on the ecological health of the Upper Bruce Peninsula Ecosystem. 5. Ensure research and analysis about natural resources are the basis of management decisions in the park. 6. To collaborate with organizations outside of the park and contribute research and information toward the goals of maintaining the greater Bruce Peninsula ecosystem as part of the Bruce Peninsula Biosphere Reserve (Parks Canada, 1998). It is the aim of the present research to be in line with these management goals and to provide a framework that will assist BPNP to continue to meet these objectives into the future, amid a changing climate.

One objective of this project is to assist the park in maintaining its own management objectives in a changing climate, while working within the confines of new financial limitations of national parks. The first stage of accomplishing this objective is selecting one major indicator of ecological integrity in the BPNP system. The key indicator selected was trees. The data collected to build the management scenarios uses BPNP's established Forest Health monitoring program. The Forest Health monitoring protocols are based on those established by EMAN (Environmental Monitoring and Assessment Network). Using established protocol means that new training or equipment would not be required for park managers. Although funding for the EMAN program has been discontinued, it remains a commonly used source for protocol with a standardized set of methods.

The second stage of this objective is accomplished by building management oriented climate change scenarios for BPNP using the primary climate scenarios of the IPCC Special Report on

Emission Scenarios. The findings of the primary climate scenarios are applied to the forest health results to show the implications for the future health of the trees, and then the impacts of passive or active management are applied. The management scenarios present four imaginings of possible futures to help in decision making and facilitate the adaptive management process.

A second objective of this research is to promote collaboration between the academic community and National Parks, a model that has the potential to be increasingly beneficial for parks and is in line with the sixth management objective of BPNP as stated above. University collaboration is a way to supplement park research that would otherwise have gone unmonitored, unexplored, or unanalyzed due to personnel restrictions.

A third objective of this research is to begin the first stage of an iterative process of building management scenarios based on existing monitoring protocols which, if effective, it can be used as a template for other national parks as a time and cost efficient way to plan for climate change. This method would prevent parks from having to establish an entirely new "climate change" research program. Scenarios developed through this process can be used at many parks to inform park policies and make important decisions about how to best meet the conservation and social objectives of the Parks Canada mandate at a wider scale.

Chapter 2 Assessing the State of the Park as of 2012

2.1 Study Site -Bruce Peninsula National Park and Environs

2.1.1 Historical Background

For thousands of years before European settlement in the mid 1800s, what is now called the Bruce Peninsula had been a traditional territory of the Saugeen Ojibway Nation and the Chippewas of Saugeen Unceded First Nation (Wildlands League, 2005). Some of the land on the Peninsula continues to be held by the Saugeen Ojibway Nation; but as a result of being coerced into two treaties that reduced their right to the land in 1836 and 1854, a land claim was filed in 1994 claiming breach of trust by the crown and has yet to be resolved (Wildlands League, 2005).

The forests within Bruce Peninsula National Park undergone significant disturbance as a result of European settlement in the late 1800s, logging was the dominant industry in the region. At that time, two of the most ecologically and economically important species were *Pinus strobus* L. (white pine) and *Thuja occidentalis* L. (eastern white cedar) and *Tsuga canadensis* (L.) Carr. (eastern hemlock) (S.L. Ross Enviornmental Research Limited, Mosquin Bio-Information Ltd., & Horler Information Inc., 1989). Other species also logged later on included *Acer saccharum* L.(sugar maple), *Tilia americana* L. (basswood), and *Quercus rubra* L (red oak). Within 10 years of the construction of the Tobermory Mill in 1881, all of the large white pines had been removed, and by the early 1900s there was little large timber remaining on the peninsula (Wildlands League, 2005).

As a result of the extensive slash left behind from logging several forest fire events that have had dramatic effects on the biotic and abiotic features of the park. The most influential of these fires happened in 1908 where a large section of the peninsula, including what is now the park, burned so intensely that, not only were the forests incinerated, but the soils and the seed bank were devastated as well (S.L. Ross Enviornmental Research Limited et al., 1989). The rapid removal of so many large, long lived trees, coupled with the frequency and intensity of forest fires the late ninetieth and early twentieth centuries had a profound impact and resulted in a lasting change to the forest ecology of the region (Kelly & Kischak, 1992). Success in re-colonizing after the fire was seen in trees that are capable of vegetative reproduction such as *Thuja occidentalis* L. (eastern white cedar), *Betula papyrifera* Marsh. (white birch), and *Populus temuloides* Michx. (trembling aspen) (Burns & Honkala, 1990). Trees that have proliferated since that time include *Thuja occidentalis*, *Larix laricina* (Du Roi) K. Koch (tamarack), *Abies balsamea* (L.) Mill. (balsam fir), and *Betula papyrifera*.

Cultivating crops for agriculture is a challenge on the peninsula due to the thin soil, however, most places with adequate soil were transformed into hayfields or used for grazing of livestock, thus removing all of the large, often deciduous trees inhabiting those areas. Fishing was another main industry in the early settlement times of the Peninsula. As with timber, over-harvesting soon caused a decline in the more profitable fish resources which was exacerbated by the invasion of *Petromyzon marinus* L. (sea lamprey) (Wildlands League, 2005).

Despite the fact that the resource economies of the Bruce Peninsula were struggling by the 1920s as a result of over exploitation, the natural features of the area, including the Niagara Escarpment, unique flora and fauna, and sunken shipwrecks began to draw tourists and cottagers from the growing cities further south in the province (Wildlands League, 2005).

2.1.2 Physical Description

The Bruce Peninsula is a narrow peninsula (ranging 7.9km -35 km averaging 15-19km in width) that separates Lake Huron, to the south, from Georgian Bay to the north. The park itself is 275 km^2, and was established in 1987. Immediately following its establishment a thorough biophysical report was done of the park by S.L. Ross Environmental Research Ltd and published in 1988. Before the Bruce Peninsula National Park, and adjacent Fathom Five National Marine Park, were established, much of the area was already protected as provincial parks. Little Cove Provincial Park, Cyprus Lake Provincial Park, and part of Cabot Head Provincial Park were all absorbed and amalgamated into what is now Bruce Peninsula National Park (Canada, 1987).

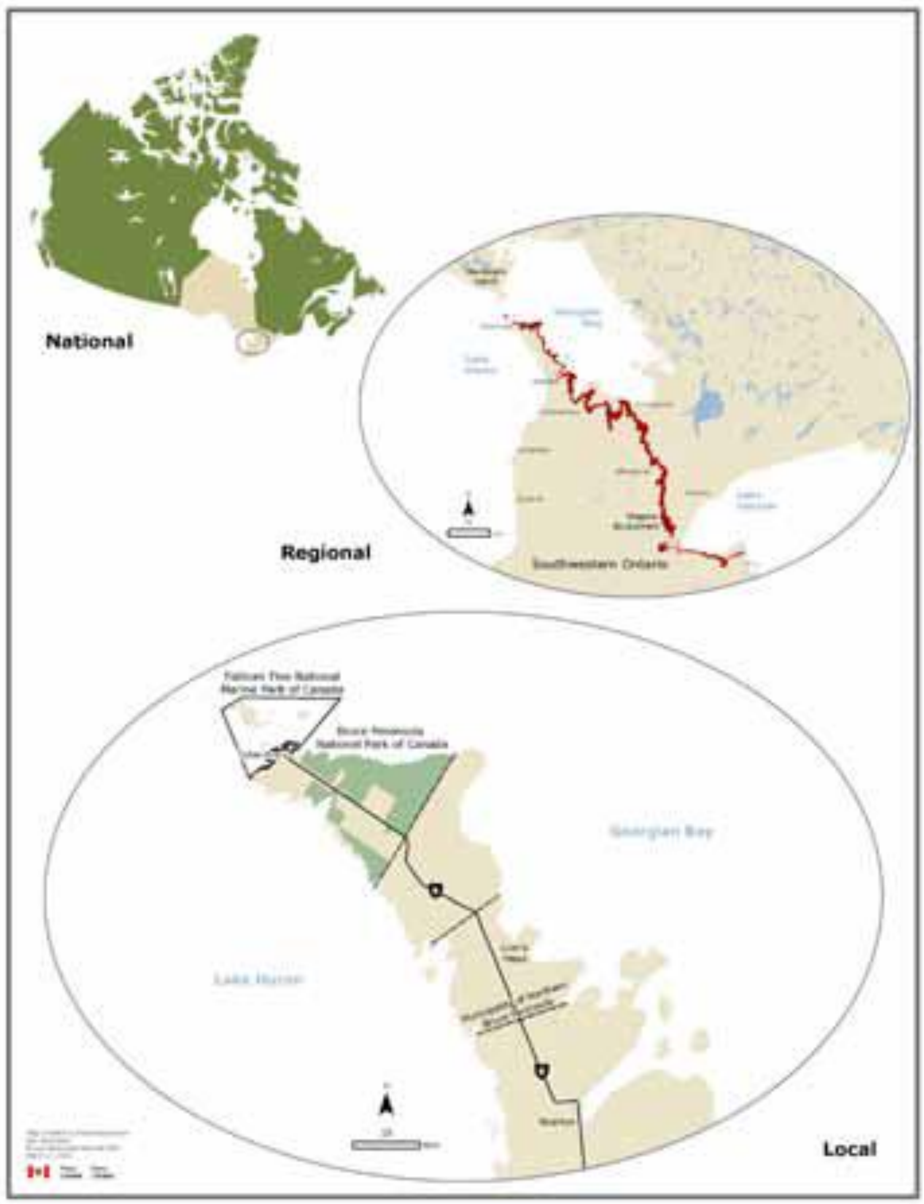


Figure 1: Map depicting the location of Bruce Peninsula National Park in a national, regional and local contexts (Parks Canada, 2013)

Although Bruce Peninsula National Park is small in size compared to some other Canadian national parks, it is quite heterogeneous, containing many sub system environments within the park boundaries (S.L. Ross Enviornmental Research Limited et al., 1989). BPNP was chosen for this study because of the heterogeneous landscape. It contains deciduous, coniferous and mixed forests, as well as open alvars and abandoned agricultural fields. All four types of wetland: fen, bog, marsh, and swamp are also all represented within the park (S.L. Ross Enviornmental Research Limited et al., 1989).

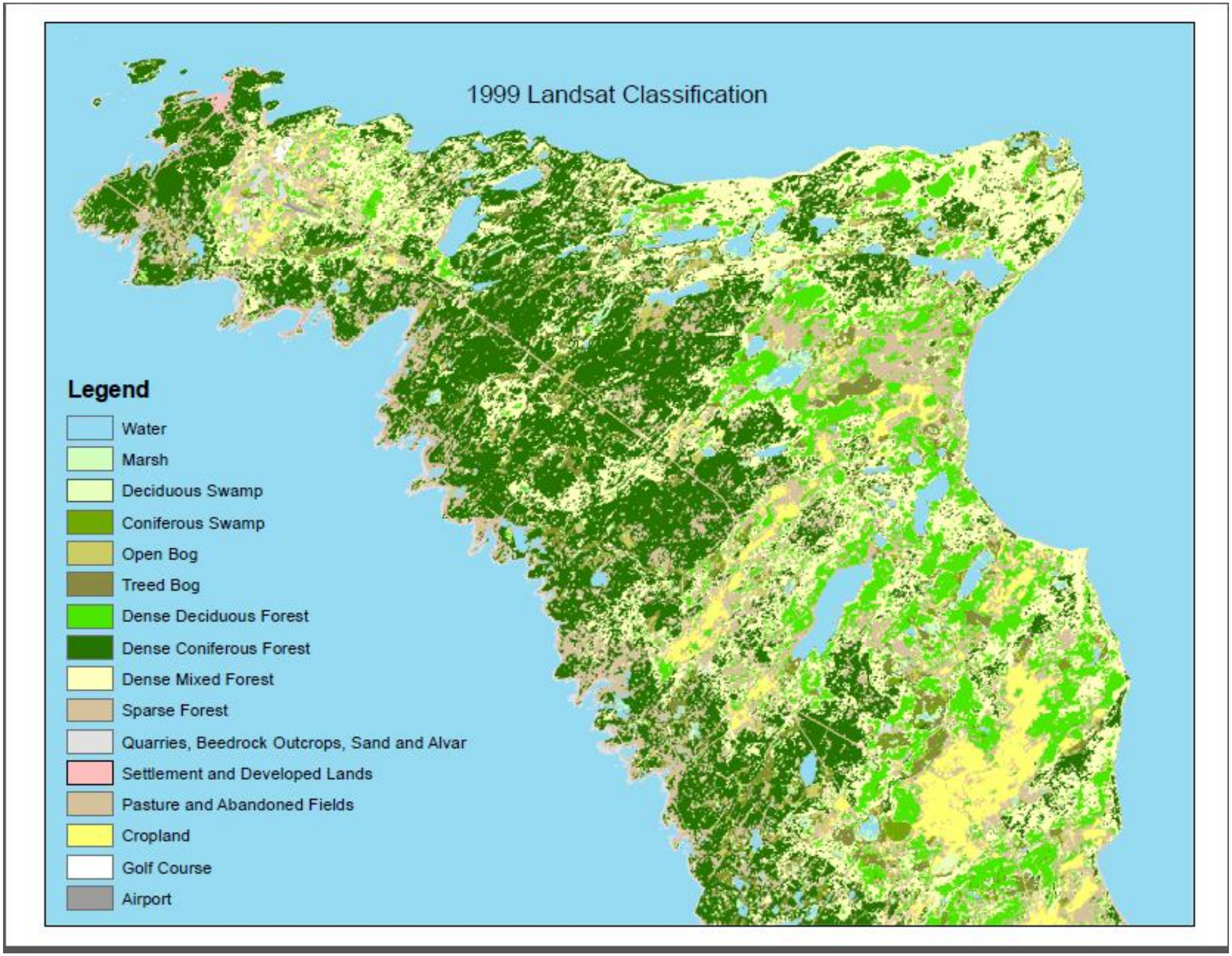


Figure 2: Land cover classification for the northern Bruce Peninsula done by satellite image (Parks Canada, 1999)

Bruce Peninsula is situated in the center of the St. Lawrence Lowlands eco-zone but is within a few hundred kilometres of zone transition and is therefore vulnerable to climatic changes. The geographic isolation associated with the peninsula landform means this will likely have less of an impact in Bruce Peninsula National Park. Newly colonizing species can only arrive from one direction and that is venturing north, up the peninsula, so park ecologists will be able to track and monitor arrival. That does not mean however, that the park is not susceptible to significant changes in dominance and structure which could have significant secondary or tertiary impacts across multiple trophic levels.

Within Bruce Peninsula National Park classification and monitoring that has taken place and is maintained at regular intervals. Geographic information systems (GIS) data that covers the park has been collected using monitoring sites and air photos. The outputs from these data were used by park managers for selecting sites that represent the various subsystems within the park. There are 12 deciduous plots and 16 coniferous plots for the Forest Health Monitoring Program, which had been a part of the park's regular monitoring network and were set to be monitored every 5 years. The plots were established in stages, some sites, including Pendall Point, Horse Lake Trail, Emmett Lake, and Cameron Lake Dunes, have already had one round of monitoring and assessment but others, including Cameron Trail, and Bartley Lake, were more recently established and had not yet had a full monitoring cycle completed.

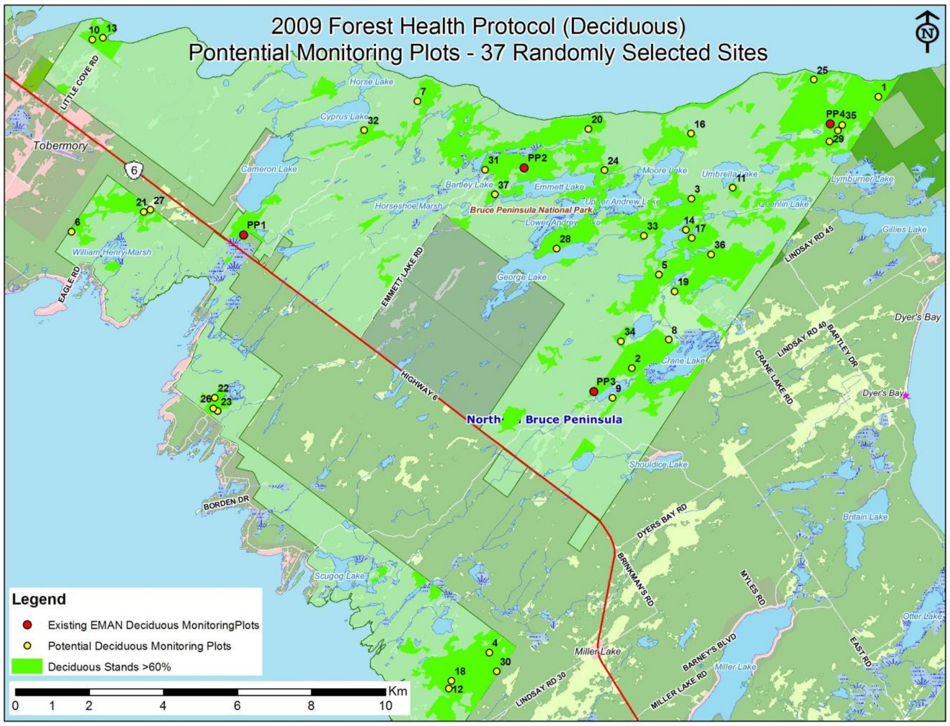


Figure 3 Potential and established monitoring plots for forest health of deciduous forest (Parks Canada, 2009)

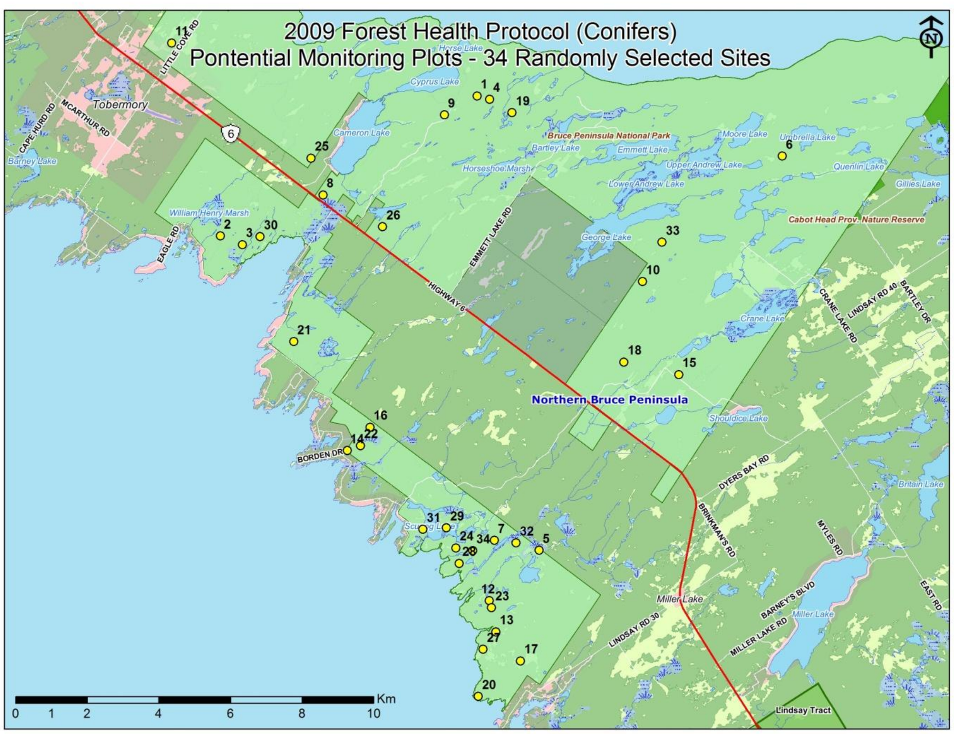


Figure 4: Potential and selected monitoring plots for forest health of conifers (Parks Canada, 2009)

2.2 Methods

2.2.1 Data Collection in 2012

Using aerial photographs and GIS maps of Bruce Peninsula National Park produced by Parks Canada's Jeff Truscott, sites on the park property that are already being used for forest monitoring were located. Six sites were selected from those monitored by Parks Canada through the forest health program. Selection criteria included accessibility by foot from main roads, and for maximization of spatial representation within the park. Sites are 20m x 20m and were establish over the past 10 years using the protocol from EMAN. EMAN was an initiative of Environment Canada made up of government and non-government organizations, aboriginal organization, academic institutions and community groups. The network united those groups interested in being able to better detect, describe and report changes to their local environment. The project ran from 1994-2010 with one of the largest outcomes being the development of standardized protocols for monitoring so that research performed across Canada would be comparable at a national and international scale.

Table 1: Names and forest type of the 6 sites surveyed for forest health for this research at Bruce Peninsula National Park

Site Name	Forest Type
Emmett Lake	Deciduous
Bartley Lake	Deciduous
Cameron Lake Dunes	Deciduous
Horse Lake Trails	Coniferous
Pendall Point	Coniferous
Cameron Trail	Coniferous

Three sites are deciduous dominated forest, and the other three are coniferous dominated forest. The classification as either deciduous or coniferous forest was designated by the Parks Canada researchers at the time of establishment. Site numbering and naming systems were adopted from Parks Canada Records to maintain consistency and minimize confusion. At each site the four corners and the center of the plot were marked with a stake. Starting in the south west corner all of the trees within the boundary were marked with a numbered tag in a spiralling ring from the perimeter of the site into the center. Only trees larger than 10cm diameter at breast height (DBH) were tagged or counted. Some trees had lost their tags or the tag was hidden by the falling of the tree, most were accounted for while others were denoted tm (tag missing). In many cases the location of the tree allowed a conclusive deduction of the original number.

Tagged trees were identified by species and measured for DBH 1.3m from the ground. Most trees were marked with spray paint at this height for consistency, as well as colour coded for their status as alive or dead. The status of the trees was assessed, as well as their crown class, which describes the height of the tree in relation to the general canopy. Notes of major stem defects were also collected. Trees with any dead status (dead standing, dead fallen, dead broken, or dead leaning) were not measured for DBH or crown class, stem defects were still noted and the level of decay from 1-5 was also recorded.

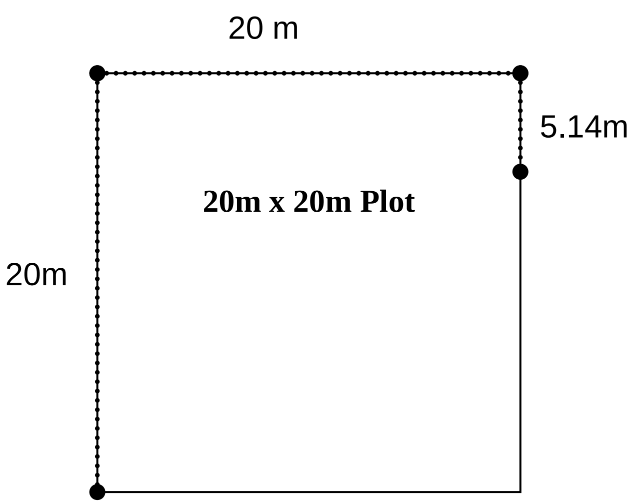


Figure 5: Example of 45.14 meters transect for down woody debris

In addition to the standing trees, the amount and quantity of coarse woody biomass on the forest floor was analyzed by measuring downed woody debris. Downed woody debris was measured by walking transects along the edges of the plot. A total of 45.14m was walked, complete edges from A-B and B-C and then 5.14m of the edge from C-D. Along each transect the species (if possible), diameter, decomposition class, type (log or stump), and location are recorded for all downed woody debris intersected. For complete details on the adaptation EMAN protocol for site selection, establishment and monitoring used by BPNP, please see appendix.

2.2.2 Data Analysis

Composition was analyzed for the sites individually as well as collectively to create a proxy for the overall park forests. It was assessed using basic descriptive statistics looking at empirical number of trees and proportion per species by tree number and basal area.

Comparisons were made about the number of trees/basal area per site, and the number of living versus dead trees.

Mortality is one of the three metrics used by park managers and other academic researchers to assess forest health (McCanny et al., 2012). The *State of the Park Report* was based on the assessment of 8 plots within the park from 2005 to 2008 published in 2010. The present assessment was completed in 2012 and continues the data set, however some sites used for the present study had been newly established monitoring plots and do not have the historical dataset for comparison. Mortality is the proportion of trees that have died over a certain time span.

$$\%\ Mortality = \frac{\#\ trees\ that\ died}{total\ \#\ live\ trees} * \frac{100\%}{\#\ of\ years}$$

In the *Rationale for the State of the Park Report* the thresholds for mortality set by Parks Canada and based on the literature are >3% good, 3-5% fair, < 5% poor (Sajan, 2006; McCanny et al., 2012). Of the 6 plots assessed for this project 3 of them were plots recently established by the park with no historical data. Of the 3 that were established Pendall Point and Horse Lake were included in the 2010 *State of the Park Report*. The 2010 *State of the Park Report* uses a most recent monitoring year of 2008 so the mortality since that time and a trend can be established for those two plots. Cameron Trail had been monitored once in 2011 so this data is more recent that the *State of the Park Report*, but does allow the first year of mortality data to be calculated.

The second metric used in the *State of the Park Report* to assess forest health is downed woody debris. Downed woody debris has been measured by park management as a cumulative total area of all of the logs and stumps that intersect the transect path.

The third metric of the *State of the Park Report* is annual growth rate. Annual growth is measured by taking the DBH, which is measured for each tree, and using that to calculate basal area (BA), and from basal area, plot basal area (PBA) is calculated. Where *i* is the year that the measurements were taken and *j* is each of the *n* individual trees in the plot. The number 400 represents the area of the plot in m^2. The units of plot basal area were $cm^2/\ m^2$, which is equivalent to m^2 /ha.

$$BA = \pi \left(\frac{dbh}{2}\right)^2 \qquad PBA_i = \frac{\sum_{j=1}^{n} BA_{ij}}{400}$$

Using PBA for two time points five years apart, annual growth rate (GR) can be calculated for a particular plot, where the subscripts two points in time and *T* the number of years – in this case 5.

$$GR = \frac{100 * (PBA_2 - PBA_1)}{T * PBA_1}$$

Managers at BPNP have not found a threshold with which to assess annual growth. At for the 2010 *State of the Park Report* scatter was measured using the standard deviation and square root of the variance (McCanny et al., 2012).

2.3 Results

Figure 6 depicts the variation in diversity and abundance of tree species within the six plots surveyed. Only the living trees are counted in the abundance, density and dominance values. Quantity of dead trees is assessed separately. *Acer saccharum* is the most abundant tree amongst the deciduous plots with a total of 58 trees. *Thuja occidentalis* is the most abundant among the coniferous plots, and the most abundant overall with 155 trees. Overall the deciduous plots had a greater diversity of species present. The coniferous plots have a total of 7 different species present. The deciduous plots have a total of 10 species present.

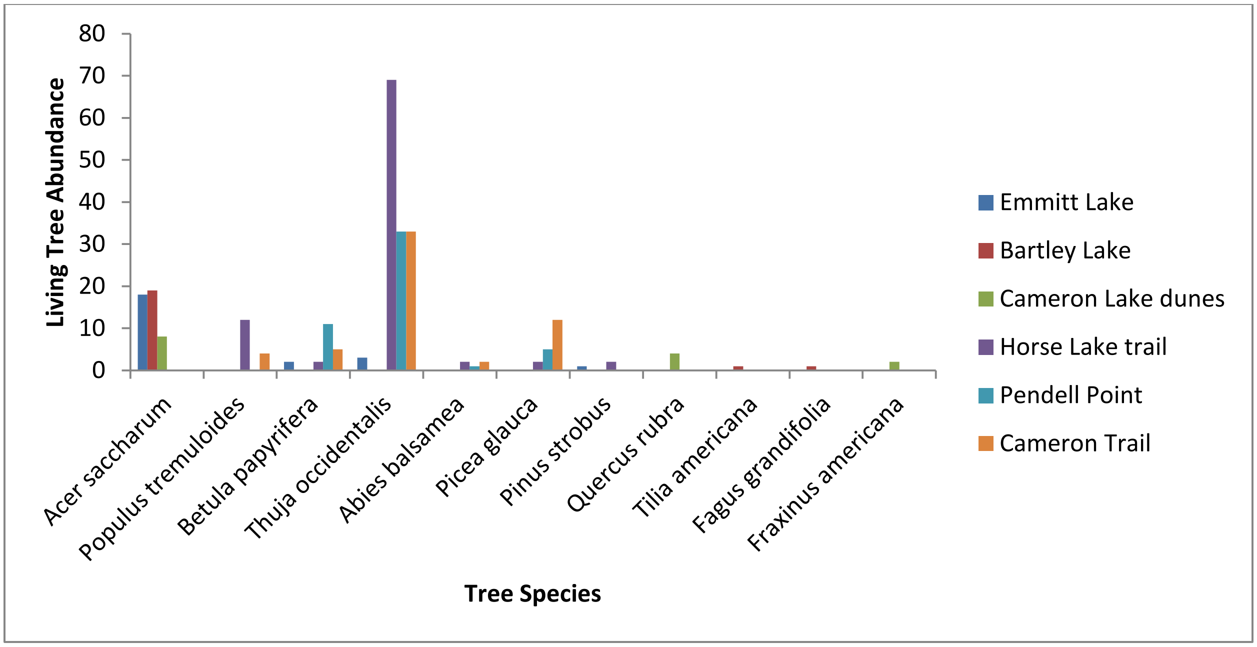


Figure 6: Diversity of tree species and their abundance at all plots, coniferous and deciduous, at BPNP

The total tree abundance is depicted in Figure 7. The coniferous plots had a higher abundance of trees of trees present than the deciduous plots.

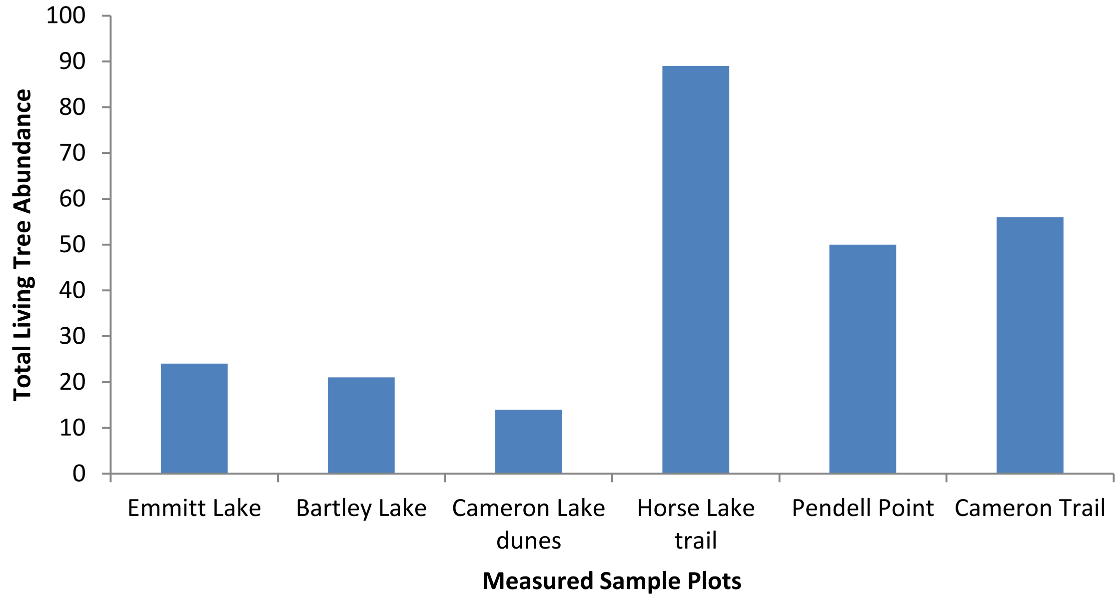


Figure 7: Total number of living trees inhabiting each plot surveyed at Bruce Peninsula National Park

Relative density indicates the proportion of a particular species compared to those of other species present. The relative density of the 5 densest species is shown individually, and all the remaining species have been grouped together. The tree with the highest relative density (54%) is *Thuja occidentalis*, which was also the most abundant tree overall (Figure 8).

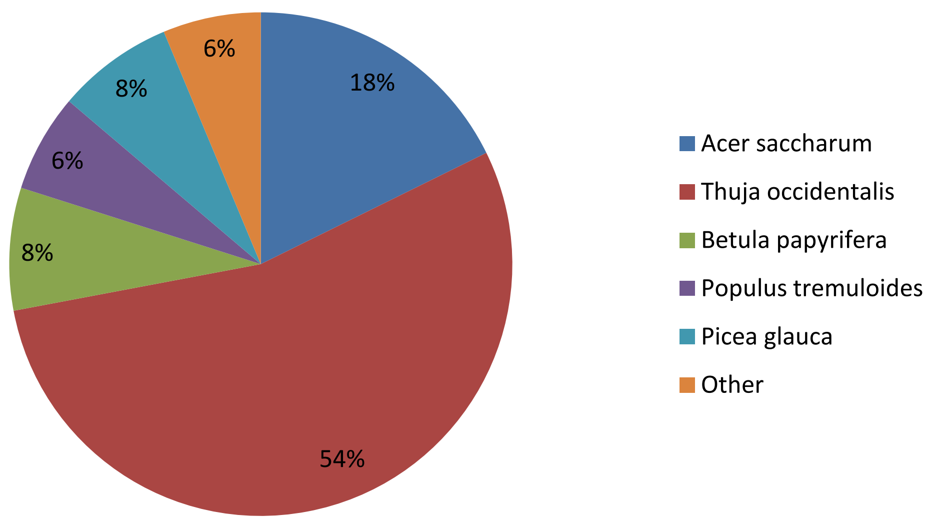


Figure 8: Relative density of the 5 most abundant species and other species combined

Dead trees were also counted. Figure 9 shows the number of dead trees per site, as well as the percentage of all the trees surveyed at the site that are dead. While Emmitt Lake had only 15 dead trees total, that amounted to the highest percentage at 38.5%. Horse Lake Trail had the overall highest number of dead trees at 27, but because of the high tree density at that site, the percentage of dead trees is only 23%.

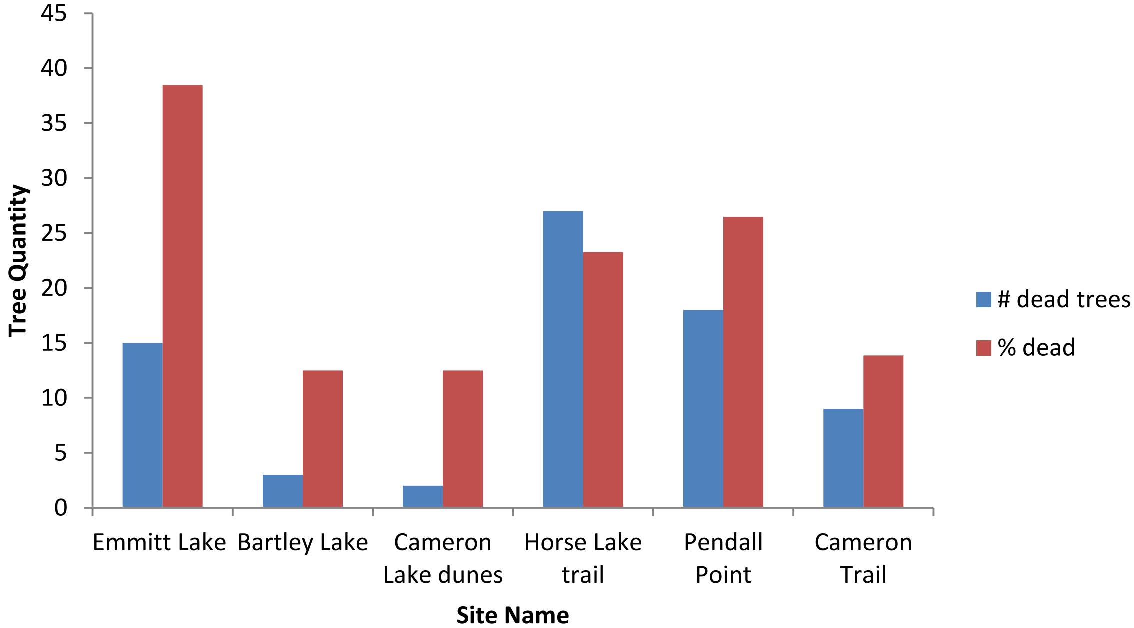


Figure 9: Count of dead trees and compared percentage of dead trees per sampling site

The number and percentage of dead trees was also assessed by species. Overall the tree survey found 11 living species overall and of those, 6 species also had dead specimens surveyed. Three dead individuals were also recorded that showed a level of decay that prevented confident identification.

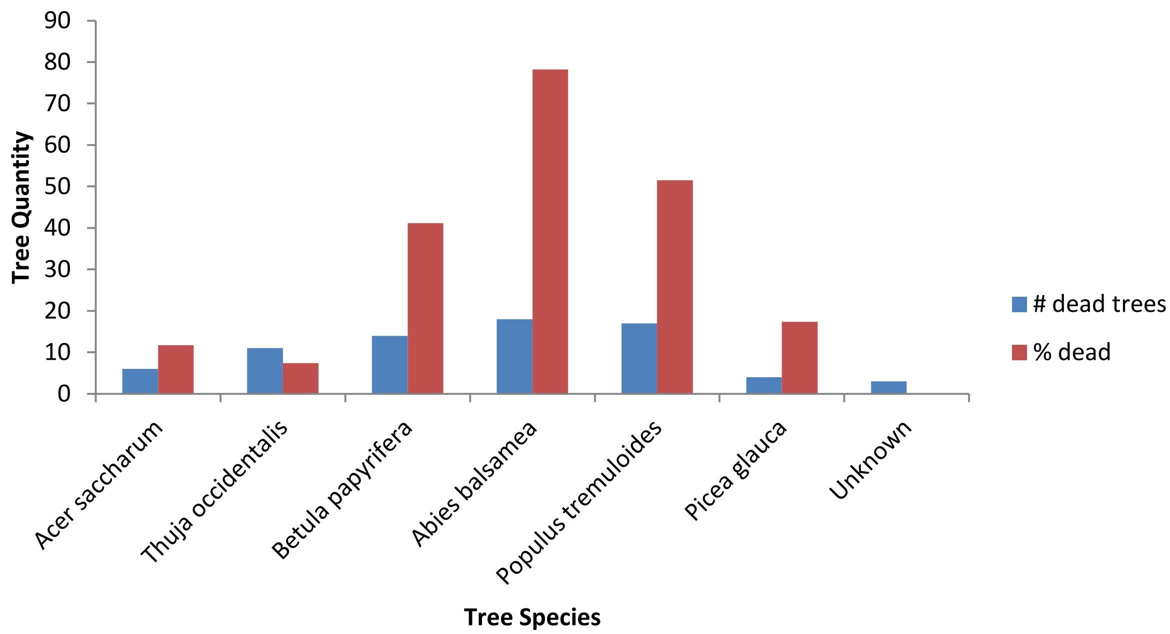


Figure 10: The number and percentage of dead trees by species

Figure 10 shows that for two species, *Abies balsamea* (78.3%) and *Populus tremuloides* (51.5%), were dead in more than 50% of the occurrences of the trees surveyed. *Thuja occidentalis* and *Acer saccharum* had the lowest percentage of dead trees, which is unsurprising given these species have the highest living abundance.

All trees surveyed were assigned a status, based on whether they were living or dead, standing, leaning, broken, or fallen. Among dead trees this status is important because the type of habitat provided by snags (standing deadwood) is significantly different from the habitat provided by fallen logs, though both are important to the system.

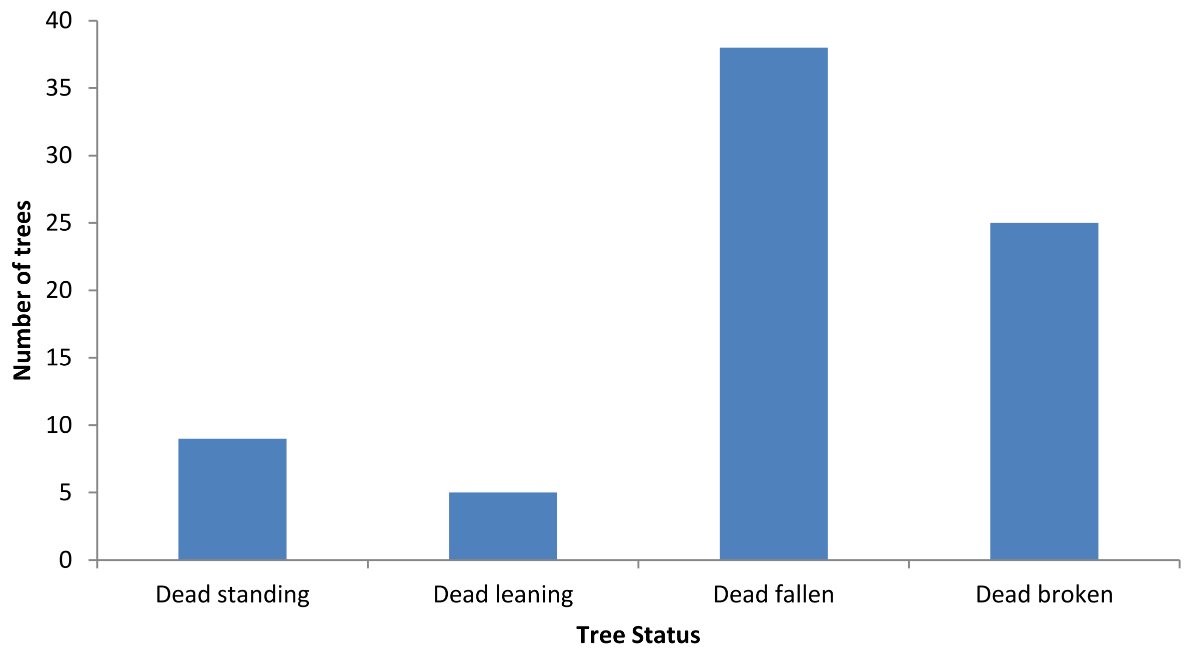


Figure 11: Tree status of surveyed dead trees combined from all six sites surveyed at BPNP

Close to 50% of the dead trees are fallen (38), whereas combined the standing (9) and leaning (5) trees account for less than 20% of the dead trees. Broken trees contain some standing component and some fallen component. A tree was considered broken, rather than fallen if more than 2 metres remained standing.

In addition to counting the number of trees dead explicitly in 2012, historical records of these sites were used to assess mortality. The *State of the Park Report* found an overall mortality rate of less than 0% in 2008 which is well below the 3% threshold. Since 2008 the annual mortality for the sites assessed can be seen in Table 2. While a higher mortality rate average was higher than was found in 2008, all values remain well below the 3% threshold meaning that for this indicator of Forest Health the status is “Good”. The three sites that show an increase in mortality area all coniferous sites, while all deciduous sites, though they do have fewer trees, show no mortality at all.

Going from a mortality rate below 0% to one at 0.45% shows the beginnings of a trend of increased mortality, particularly among deciduous sites, however with only two data points in less than 10 years this is not yet enough data to get a robust sense of a trend, as there could be one particularly anomalous year perhaps with a large storm accounting for above average mortality.

Table 2: Mortality of trees at sites with continuing data and the average compared to the mortality rate from the State of the Park report published in 2010. The * indicates that these sites have only been surveyed in 2011 and 2012 meaning only one year of mortality data and are thus not included in the 5 year average

Assessment	% Mortality	Status
State of the Park Report 2010	>0%	Good
Pendall Point	0.53%	Good
Horse Lake Trail	1.28%	Good
Emmett Lake	0%	Good
Cameron Lake Dunes	0%	Good
Average 2008-2012	0.45%	Good
***Cameron Trail**	1.75%	Good
***Bartley Lake**	0%	Good

The cross sectional area of downed woody debris for the 6 study sites in 2012 was 71.95m^2 . The downed woody debris measurements from previous years are reported only as a total area, so not comparable to this number because it is derived from a different set of sites, furthermore there has been inconsistency for this measurement even within Parks Canada's own records.

Annual growth rate is the third metric used BPNP to assess forest health. The growth rate is only assessed once every five years, and is assessed by individual site and then averaged. Cameron Trail was not included, because despite having been surveyed previously, it was only one year ago which is below the preferred five year interval for this measurement.

Table 3:Annual growth rate compared among sites measured in 2012 and in the 2010 State of the Park Report

Site	Annual Growth Rate	Rating
State of the Park 2010	2.21%	Good
Pendall Point	2.6%	Good
Horse Lake Trail	-0.96%	Poor
Cameron Lake Dunes	2.67%	Good
Emmett Lake	4.00%	Good
Average growth 2008-2012	2.10%	Fair

Regeneration was also measured at each site, counting seedlings and saplings that do not yet reach the 10cm DBH to be counted in the regular survey. The regeneration data gives an indication of which species are succeeding in the area. There are five 2m X 2m quadrats per survey site, one along each axis of the plot and one in the center. Figure 12 shows the number of seedlings in each size class at each of the survey sites.

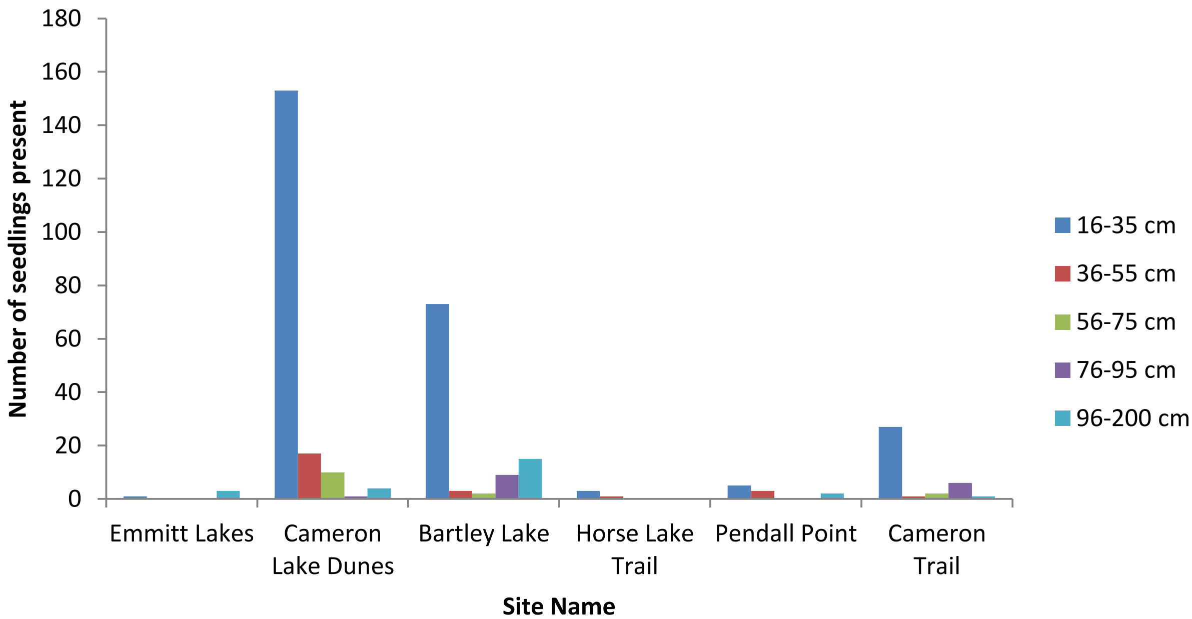


Figure 12: Number of seedlings present at each site divided into seedling classes by height in cm

Cameron Lake Dunes and Bartley Lake sites, both deciduous sites, have by far the highest levels of regeneration. Both sites have at least one seedling in each class had have a total number of seedlings of 207 and 102 respectively. The Emmitt lakes site had almost no regeneration, setting it apart from the other two hardwood sites. All three softwood sites had a lower level or regeneration but of those Cameron Trail had the most with all seedling classes represented and a total of 47 seedlings present.

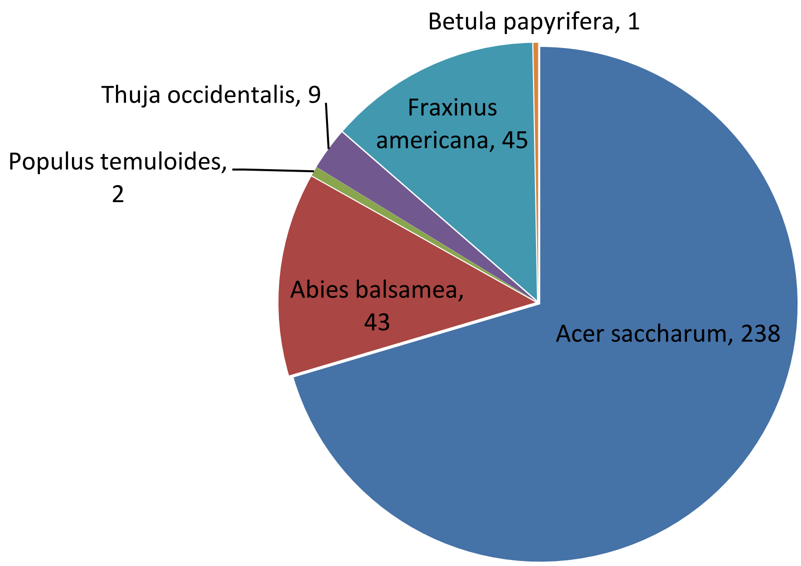


Figure 13: Comparison of seedlings (>200 cm) by species combined among all 6 sites surveyed in 2012 at BPNP

The majority of seedlings were found in deciduous sites, correspondingly the majority of seedlings were deciduous species (Figure 13). The most abundant seedling was *Acer saccharum* with 238 individuals, 185 of which were found at the Cameron Lakes site. Although only found at the Bartley Lake site the second most abundant species of seedling was *Fraxinus americana* L. (white ash) (45), closely followed by *Abies balsamea* (43) which was found at all of the coniferous sites and at the Emmitt Lake deciduous site. *Populus tremuloides*, *Thuja occidentalis*, and *Betula papyrifera* were also present in small numbers.

Saplings are young trees that are taller than 200 cm but have not yet reached 10cm DBH. There were many saplings within some of the sites, but only those in the regeneration plots were counted. Three of the sites, Cameron Lakes, Horse Lake Trail, and Cameron Lake Dunes did not have any saplings. Emmitt Lake had one *Abies balsamea*, Pendall Point had 4 *Abies balsamea*, and Bartley Lake had 7 *Fraxinus americana* and one *Acer saccharum* sapling.

2.4 Discussion

Tree monitoring indicates there currently is a healthy forest. There is a diversity of trees growing at the various sites and most trees have robust foliage, a highly rated crown class, and minimal trunk damage. Regeneration surveys showed that new trees are growing in the forest, though they may not be the exact proportion of composition of the currently mature trees in the forest.

There is ample habitat for other species within all of the living, standing and fallen dead trees. Abstracting forest health from my dataset indicates that the state is consistent with the 2012 State of the Park. This is not surprising given the few years between samples.

2.4.1 Composition

Among the sites selected, there is a qualitative difference in composition between the three deciduous sites and the three coniferous sites. There was almost no overlap between species present from one type of site to the other. Among the three deciduous sites, Emmitt Lake, Bartley Lake, and Cameron Lake Dunes, only Emmitt Lake has any - 3 - *Thuja occidentalis* trees despite *Thuja occidentalis* being the most abundant tree overall. None of the three deciduous sites contain any *Abies balsamea* or *Picea glauca* (white spruce) and there was one *Pinus strobus* at Emmitt Lake. Of the coniferous sites none contained *Acer saccharum*, *Quercus rubra*, *Tilia americana*, *Fraxinus americana* or *Fagus grandifolia*, though other than *Acer saccharum* each of those species was only found at one site each, even among the deciduous plots. The deciduous plots had a greater diversity in number of species present however many of those species were represented by only one individual. Lower abundances are expected overall in deciduous sites, broad leaf trees take up much more area and canopy space than cedars and other coniferous trees, forcing a lower density of trees within the plots.

There were fewer overall species in the coniferous plots however those present were more likely to be present in all three of the coniferous plots as the composition was quite similar among the three. *Thuja occidentalis* was the most abundant tree in all three coniferous sites, but there were a larger number of each of the sub dominant species, *Betula papyrifera* (20), *Populus tremuloides* (16), *Abies balsamea* (5), and *Picea glauca* (19), than were present in the deciduous plots. Of the 6 species with the highest densities shown in Figure 7, five of them were species found in the coniferous plots. *Acer saccharum* was the only deciduous plot species among those trees with the highest relative density.

2.4.2 Forest age/Successional State

The six monitoring plots were all inhabited by mature trees with a well-developed canopy. There are few trees in the entire park that are older than 100 years. In 1908 there was a forest fire on the peninsula that not only burned the forests but also destroyed the organic layer of the soil and much of the seed bank (Kelly & Kischak, 1992; S.L. Ross Enviornmental Research Limited et al., 1989). As a result the current forests throughout the park are generally reflective of early successional forests. *Thuja occidentalis*, *Populus tremuloides*, and *Betula papyrifera* are all early colonizing species that are able to maximize the minimal competition or light and resources after a major disturbance (Burns & Honkala, 1990). *Acer saccharum* are also common in the deciduous forests despite being a shade tolerant species, which is often characteristic with later successional species (Burns & Honkala, 1990).

2.4.3 Regeneration

Two hundred thirty eight seedlings of *Acer saccharum* were sampled - far more than any other species. Next were *Quercus rubra* (45) and *Abies balsamea* (43). Where *Thuja occidentalis* is the most abundant mature tree, one might cavalierly expect there to be more seedlings but there were only 9 in my sample. This is actually what the life history of *Thuja occidentalis* would portend. It is a species that prefers a high light environment, hence few of them would grow the low light level regeneration plots within the thicker understory. This suggests that even though the forest currently is healthy, the composition of the forest may be changing slowly via succession. It will be difficult in the coming years to differentiate the changes in forest composition that are a result of succession as the forest continues to recover from the fires of the early 20th century, from the changes in composition that are a result of a changing climate that alters which species experience their most preferential climate within the park. Changes in composition over time are not necessarily indicative of poor or declining forest health, as long as the structure and functions of the forest are maintained.

It is acknowledged that the regeneration plots are only 2 m x 2 m, with 5 plots per site. This gives a total of 20 m^2 of regeneration survey area, quite small in comparison to the 400 m^2 for the mature tree plots. Despite the small size these 2 m x 2 m plots were used because they were already selected by the park and were consistent with the methods used by park staff for regeneration assessment allowing for comparison of results. In an ideal setting the park would fund additional personnel to increase the sample size and total sample area to better assess regeneration. This is important because there can be sampling errors arising from the size, density, and species of the trees in closest proximity, as well as plot aspect, and the amount of light the plot receives.

2.4.4 Comparison of 2012 State of the Park to the Formal 2010 State of the Park Report

Of the three sites assessed for mortality in 2012, the level of mortality was less than 3% and this is deemed to indicate "Good" health. As tree-fall is a normal part of succession and creates gaps in the canopy allowing for younger trees to take advantage of the sunlight. Comparison between the measurements of 2012 and the State of the Park Report were not possible for downed woody debris, but given that the mortality levels are similar it is likely that the downed woody debris levels are similar. Most downed woody debris measured at a site is from mortality/windfall from within that site, however sometimes it is trees adjacent to the sampling plot that fall over across the perimeter.

Annual growth rate was similar between the assessment in 2012 and the State of the Park report. There were two sites which were exceptions. The 2012 growth at Horse Lake Trail showed 0.96% growth in comparison to the state of the park average of 2.10%. In this site mortality was sufficient that it out weighed growth in net basal area. Where growth is small from year to year, this result could be from the death of only one large tree within the site. Conversely Emmitt Lake had a growth rate of 4.0% which is almost double the State of the Park average of 2.10%. It is possible that this large growth rate is due to the in-growth of a tree that was previously not of 10 cm DBH and could now be counted for the first time.

Overall the results of the 2012 survey were similar to the State of the Park Report published in 2010. This comparison is helpful, knowing that the results are similar between studies because the 2012 assessment uses fewer sampling points. Seeing the similarity suggests that the six sites selected for the 2012 assessment are representative of the park's forest system.

Chapter 3 Scenario Building

3.1 Intro to Scenario Building

Scenario building is a technique used to create a suite of possible future outcomes based on a set of drivers that are important to a system. Scenarios provide prospective and alternative projections to how that system may be affected by various drivers (Becker, 1983; Intergovernmental Panel on Climate Change, 2000). Examination of a suite of possible future outcomes can be used as a tool to assess risk and influence policy and planning.

Scenario building did not originate in the field of studying the natural environment. It was originally introduced to government and the private business sector in the early 1950s as military strategists from World War II returned to North America and returned to civilian careers (Becker, 1983). While at war, these military leaders had become adept at examining their situation and developing scenarios about the possible next move of their enemies and accounting for them with their own troop movements. This skill at incorporating many drivers to create strategies was translated back to the civilian workplace (Becker, 1983). In the business community during the 1970s, Royal Dutch/Shell Oil became an industry leader by accepting uncertainty to create scenarios rather than continuing to use traditional forecasting predicated on the notion that the future will look roughly the same as the past (Wack, 1985). The scenario technique allowed Shell to outperform its competitors through the government shifts and changing prices of the 1970s oil crisis and beyond (Peterson, Cumming, & Carpenter, 2003; Wack, 1985).

The first well known use of scenario building strategy in an environmental context was done by the Intergovernmental Panel on Climate Change (IPCC) in their Special Report on Emission Scenarios which was published in 2000 (Intergovernmental Panel on Climate Change, 2000). These scenarios focused on greenhouse gas (GHG) emissions and the influences of the socio-economic environment which lead to the development of a suite of scenarios that have been highly referenced in discussion of climate change mitigation efforts and emission targets. The Millennium Ecosystem Assessment, which was conducted from 2001-2005, also used scenarios to create a set of possible futures for dealing with ecosystem services (Raskin, Monks, Ribeiro, Vuuren, & Zurek, 2005; University of Washington Urban Ecology Research Lab, 2009b). Both of these examples are global in scope, a context much larger than the regional level scenario building championed by this research.

There are examples of ecological scenario building at a more regional scale that, while less prolific in the literature, are more directly comparable to the project at hand. The first is a case from the North Highlands Lake District in Wisconsin who used scenario building to look at the impacts of increasing population and environmental impacts on the ecosystem services provided by the lakes in the district (Peterson et al., 2003). The second example is a set of scenarios completed as a part of the Puget Sound Near Shore Restoration Project. Puget Sound is located at the south end of the Salish Sea in the Strait of Juan de Fuca, found along the coast of Washington State, near the British Colombia border. There, increasing development was putting extensive pressure on the health of the shoreline. The scientific and policy communities were in agreement that action needed to be taken, but could not come to a resolution about what that action should be, so a series of 6 scenarios were developed to assist in the decision making process (University of Washington Urban Ecology Research Lab, 2009a).

The six scenarios of the Puget Sound Near Shore Restoration Project are called: Forward, Order, Innovation, Barriers, Collapse, and Adaptation. Many driving forces were considered in the creation of these scenarios, considered forces include: climate change, human perception and behaviour demographics, development patterns, economy, governance, knowledge and information, natural hazards, technology and infrastructure, and public health (University of Washington Urban Ecology Research Lab, 2009a). While many driving forces are considered the logics of the six scenarios come down to where they fall on a hexagram that includes three general ideas for climate change: minor climate change, wet and hot, or dry and hot. The other three parts of the hexagram revolve around human perception and behaviour characterized as: me now, me later, or we later. How the climate change and human values and behaviours interact dictates the storyline of each scenario (University of Washington Urban Ecology Research Lab, 2009a). For example the "Forward" scenario is depicts minor climate change and the "we later" human behaviour, whereas the "Barriers" scenario depicts dry hot climate future and "me now" human behaviour.

When discussing scenario building, understanding what it is not, is just as important as understanding what it is. Scenarios are not predictions, projections, or forecasts. The future is not predicated on extrapolation of the past because that does not account for new ideas or technologies that have yet to be established (Becker, 1983). Unilateral prediction extrapolated from past trends is exactly what the scenario building technique avoids. By developing a suite of scenarios, each one representing a plausible future, fixation on a singular prediction of an ideal/catastrophic future can be avoided. Because they are not predictions, scenarios do not have probabilities attached to them. Different from other types of future assessments scenario building looks at drivers outside of the influence of the scenario planner, accounting for a type of uncertainty (University of Washington Urban Ecology Research Lab, 2009a). Scenario building is a technique that accounts for high levels of uncertainty, where other types of predictions are foiled by it.

The ideal situation for utilizing scenario building is when there is a high level of uncertainty and uncontrollability (Peterson et al., 2003). Managing for climate change in a National Park fits these conditions. There are currently high levels of uncertainty about the rate and magnitude of climate change at regional scales. At the park level, the management is subject to the extent of global climate related changes such as altered temperature and precipitation patterns. Unlike the bounded confines of a model, scenarios allow for creativity as well as the opportunity to explore the impacts of drivers that may not have otherwise been considered. Through exploring a wide range of drivers, a wide array of data may be incorporated.

The data and observations included in scenario building are qualitative and quantitative in nature. Various projects and papers have used and recommend a range of the number of scenarios in a given suite (Becker, 1983; Wack, 1985). The Puget Sound Near Shore Restoration Project uses 6 scenarios to accommodate the breadth of possibilities derived from the research, whereas Peterson et al (2003) suggest the ideal number is 3 or 4. The latter justify their number because they allow for multiple perspectives to be investigated, and avoids the potential trap of fixation on one scenario as either ideal or undesirable but also avoids a huge number that would lead to gridlock (Peterson et al., 2003).

The narrative nature of scenarios can facilitate efficient communication and public understanding. This is important for the development of management plans, documents that require those from different backgrounds, policy, science, economic development, as well as local citizens that may have none of these specializations to work together and collaborate for both the development of the management plan and its implementation. Adoption of a management plan may be easier if those involved in implementation have a solid understanding of the plan, its goals and objectives, and the rationale behind them.

3.2 Scenario Building for BPNP

Global circulation models (GCMs) are the most common tools used for predicting the impacts of climate at global and continental scale which included the highest level of complexity in accounting for atmospheric flow and radiative energy (McKenney et al., 2007). Several highly regarded climate research organizations have developed their own versions of GCMs weighting various factors of the models differently. Three of the most prominent GCMs including the Canadian Global Circulation Model, the Hadley Global Circulation Model developed in the United Kingdom, and the Australian based Commonwealth Scientific and Industrial Research Organization GCM.

The scenarios created for BPNP use the Canadian Global Circulation Model (CGCM). The climate prediction results used in this study were generated by the climate modeling project of the Canadian Forest Service through Natural Resources Canada. The CFS has a research program called Regional, National and International Climate Modeling, and on the website users are able to input GPS location. Two GPS point were selected (Lat 45.058001, Long -81.48422:Lat 45.307734, Long -81.264496), generating two sets of numbers, they were averaged to be representative of the broader area of the Bruce Peninsula National Park rather than being point specific.

Data could be generated based on several of the primary climate scenarios developed by the IPCC in the Special Report on Emission Scenarios. The SRES has six possible future climate scenarios A1T, A1FI, A1B, A2, B1 and B2 each representing a host of social and economic drivers. To maximize the divergence in representation for the BPNP scenario suite A2 and B1 were selected to be representative of the range of possible climate change. The A2 scenario assumes higher population, less forested land, greater pollution and higher CO_2 emissions. The B1 scenario assumes population growth has peaked by mid-century, and a change in economic structure with reduction of material intensity. Global solutions are being used to address major issues economic social and environmental sustainability (Intergovernmental Panel on Climate Change, 2000).

These two scenarios represent a conservative and dramatic picture for the future climate conditions resulting from the level of greenhouse gas emissions. Due to the method of collection for these data, it is not statistically appropriate to average the model outcomes to generate one median climate outlook on which to base the forest health management scenarios for the park, so the two primary scenarios will be considered separately. Results are compared to reference data from 1971-2000. The results are shown for three separate 30 year time periods, from 2011-2040, 2041-2070, and 2071-2100. These time periods (TPs) are labeled chronologically 1-3.

		Comparison to reference					
Climate variable	**Reference**	**A2 TP1**	**B1 TP1**	**A2 TP2**	**B1 TP2**	**A2 TP3**	**B1 TP3**
Annual Mean Temperature °C	6.03	1.8	1.06	3.16	2.47	4.79	2.82
Annual Min Temperature °C	1.74	1.97	1.21	3.42	2.69	5.12	3.08
Annual Max Temperature °C	10.32	1.63	0.91	2.89	2.25	4.45	2.56
Mean Diurnal Variation °C	8.55	-0.3	-0.25	-0.5	-0.4	-0.65	-0.5
Max temp in warmest period °C	23.45	2.4	1.75	3.45	2.95	5.2	3.25
Min temp in coldest period °C	-11.4	2.25	1.65	4.7	4.05	6.65	4.05
Annual Precipitation mm	924	10.5	-24.5	33	26	111.5	46
Precip in wettest period mm	97	21	9.5	17.5	9.5	41.5	12.5
Precip in driest period mm	59	-5.5	-8.5	-8	-2.5	-9.5	-2
Precip in warmest quarter mm	211	-11	-12.5	-20	-9.5	3	-13.5
Precip in coolest quarter mm	256.5	30	4.5	37	30	95	30
Julian day start of growing season	111.5	-10	-5	-12	-12.5	-21.5	-14
Julian day end of growing season	323.5	8.5	4	14	9.5	18.5	11.5
# of days of growing season	213	18.6	9	24	22	40	25.5

Table 4: Comparison to reference of changes to key climate variables for A2 and B1 climate scenarios across three time periods

Table 4 shows the differences between the reference levels (taken from 1971-2000) for key climate variables and the levels expected for each primary climate scenario (A2 or B1) over the three time periods. In the comparison columns a negative number indicates a predicted decrease, and a positive number indicated a predicted increase. For both A2 and B1 the Mean Annual Temperature, Annual Minimum Temperature, and Annual Maximum Temperature are all expected to progressively increase with each TP, however in A2 the increases are much more dramatic with a prediction of a 4.79°C increase for Mean Annual Temp. Mean Diurnal variation is expected to progressively decrease over each time period, meaning there will be less of a temperature difference between day and night.

Changes in precipitation are less consistent than the steady increases expected for temperature. For the A2 primary climate scenario with each time period increases in precipitation were predicted, but in the B1 primary climate scenario a decrease is predicted TP1 then increases for the following two TPs. Although the magnitudes are inconsistent, both A2 and B1 suggest it will be progressively wetter during the wet/colder season and progressively dryer during the dry/warm season. The monthly changes in precipitation are where the predictions are the most erratic. Below in Figure 14 the predicted monthly precipitation is shown for both A2 and B1 in all three TP as well as the reference. Figure 14 shows that over the varying TP and primary climate scenarios there is little consistency with predictions. This inconstancy in prediction is, in itself, consistent with the literature which states that overall changes to precipitation resulting from climate change are more uncertain that the impending changes to temperature (IPCC, 2007).

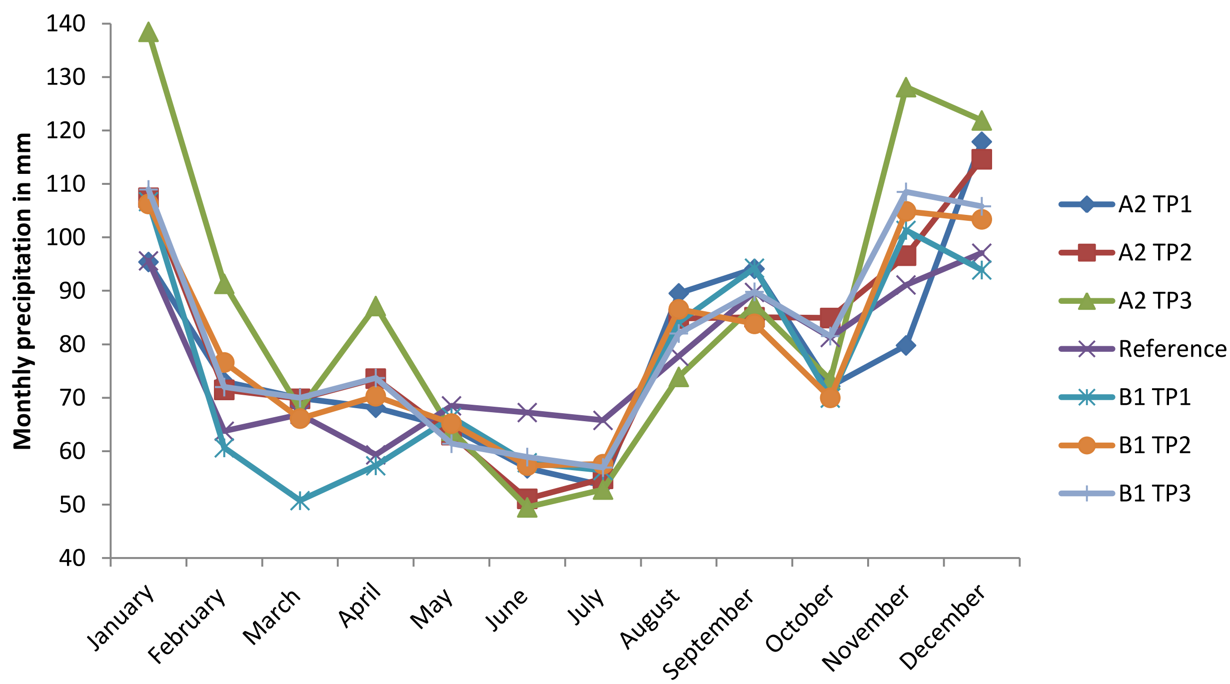


Figure 14: Predictions of monthly precipitation (in mm) for the BPNP region using scenarios A2 and B1 compared to reference precipitation levels

Comparisons of monthly maximum and monthly minimum temperatures to the reference levels are shown in Figures 15 and 16. With the exception of the January monthly maximum, all predictions across primary climate scenario and TP show increases from the reference. The largest increase is seen in A2 TP3 where an increase of over 7 degrees is predicted for the minimum in the month of February. As is consistent with the above climate variables listed above, the A2 predictions continue to show a larger increase compared to the reference for a given time period than does B1. Despite being substantially lower than A2, the B1 predicted increases still have the potential to have dramatic ecological influences according to the IPCC (Intergovernmental Panel on Climate Change, 2000).

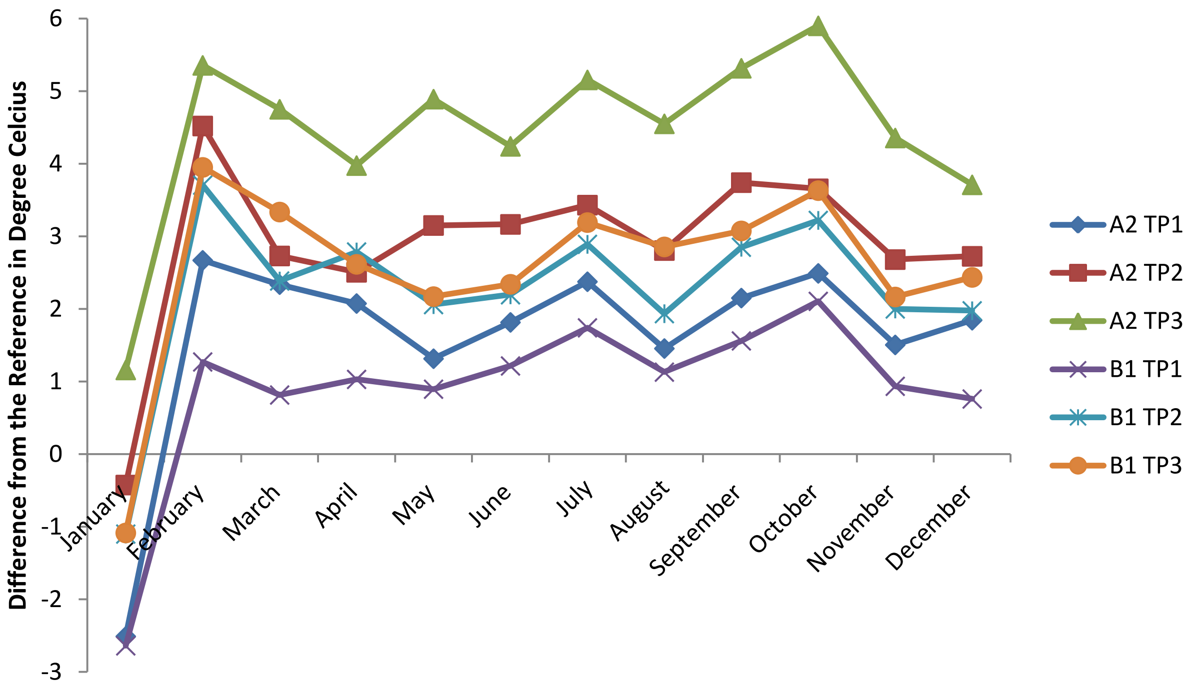


Figure 15: Difference between predictions of monthly maximum temperature (in degrees C) to the reference level for the BPNP region using scenarios A2 and B1

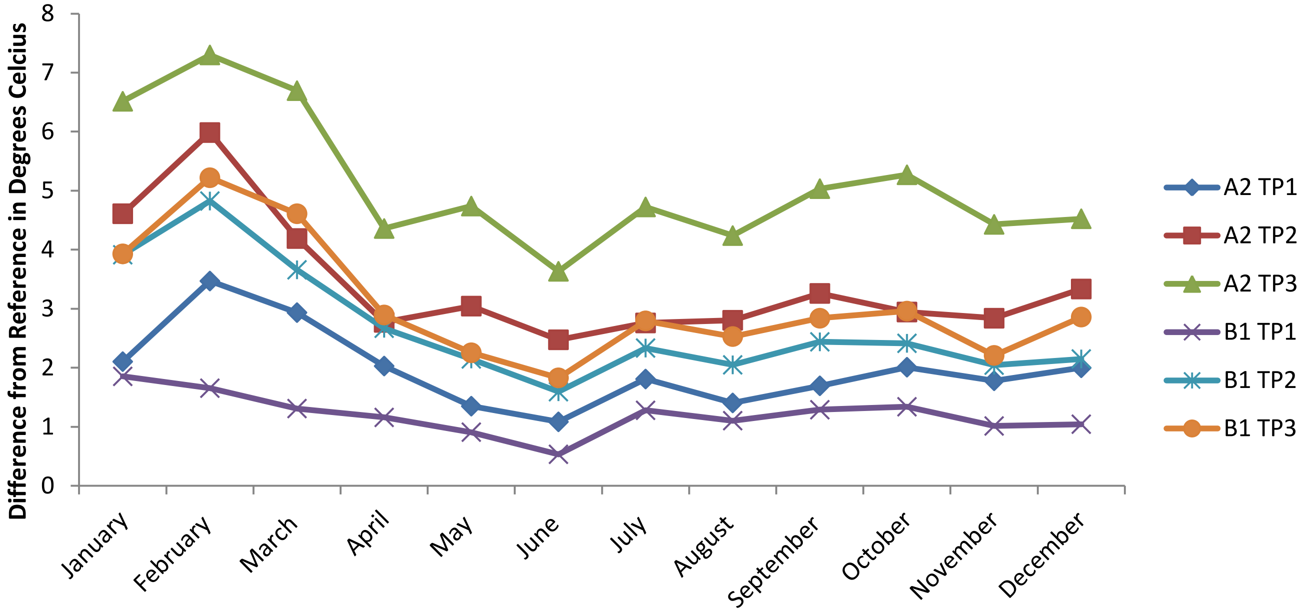


Figure 16: Difference between predictions of monthly minimum temperature (in degrees C) to the reference level for the BPNP region using scenarios A2 and B1

Table 5: Summary of life history preferences of tree species within Bruce Peninsula National Park

Tree species	Common name	Present in study site	Location in range	Soil preferences	Temperature preferences	Moisture preferences	Competition
Thuja canadensis	Eastern Cedar	yes	Near south end	No extreme- wet or dry. Likes rich swamps or fens. Likes limestone cool moist nutrient rich sites	Annual mean temp 10-16ºC Jan mean (-12)-(-4)ºC July mean 16-22ºC	Common 710-1170mm Extremes 570-1400mm 1/3-1/2 in warm season	Vegetative reproduction on poor sites - vegetative reproduction more shade tolerant and has better roots. Rot and termite resistant wood
Acer saccharum	Sugar Maple	yes	Central	Best on well drained loams. Not dry shallow soil. pH range 3.7-7.3	Typical temp range (-40)- 38ºC	Range 570-2-3-mm 1270mm is ideal. Well distributed through year. Can handle much as snow	Shade tolerant, late successional
Betula papyrifera	White Birch	yes	Most widely distributed tree in North America - mostly in Canada - near the south end	Best on well drained sandy loams on cool moist sites. High nutrient requirement but will grow anywhere	Mean July temp 13-21ºC	Tolerates a wide range 300-1520 mm/yr	Medium size, fast growing, shade intolerant, short lived. Pioneer after forest fires but only last one generation then replaced by more shade tolerant species. Important for browsing species
Abies balsamea	Balsam Fir	yes	Near south end	Tolerates pH range 5.1-6.0 optimum is 6.5-7.1. Cool temperature and abundant moisture preferred.	Mean annual 2-4ºC optimum Jan mean (-18)- (-12)ºC July mean 16-18ºC Range mean annual (-4)-7ºC	Optimum mean annual precip 760-1100mm Range is 390-1400mm Moisture a key driver	Shade tolerant, second generation post disturbance

Populus tremuloides	Trembling Aspen	yes	Central	Sandy or gravelly slopes well drained loamy. Best in high silt and clay with high organic moisture	Temp extremes of (-57) - 41°C Grows in warm permafrost free areas of permafrost zones	Water surplus a bigger constraint than a particular temperature	Grows singly or in multi-stem clones. Fast growing, natural pruning, high mortality for seedlings and saplings. Shade intolerant, quick to pioneer, short lived
Pinus strobus	White Pine	yes	Central	Generalist but prefers well drained sandy soil	Largely coincides with eastern North America where mean July temp is 18-23°C	Needs moisture surplus in all seasons. 510-2030 mm Half up to 2/3 in warm season	Not a strong competitor. Fast growing for a northern tree. Intermediate shade tolerance
Tsuga canadensis	Eastern Hemlock	No	North-central	Peat and muck of swamps must be shallow. Mount on rocky ridges, ravines and hillsides, moist to very moist	At north end of range mean Jan temp is -12 - (-6)°C and mean July temp is 16°C	740-1270 mm up 50% in summer	Very long lived and slow growing 250-300 years to maturity may live to 800. Shade tolerant
Larix larcinia	Tamarack	No	Southern end	Prefers wet to moist organic soils. Texture is a limiting factor. Can withstand acidity	Extremes from (-29)-(-62) - 29-43C July mean 13-24C Jan mean (-31)-(-1)C	Growing season 75-355mm Range 180-1400mm	Can handle shade when young but must become dominant-in over-story- to survive. First species to colonized filled lake bogs. Doesn't grown in its own shade.
Tilia americana	Basswood	yes	Near north end	Deep moist soil of finer texture, doesn't like acidity	Best in mean July temp of 18-27 °C Northern limit at the -18°C Jan mean min temp	Best is 250-380mm in summer growing season 530-1140mm annually. Likes humid to sub humid	Fast growing. Shade tolerant but less than *Acer saccharum*

Fraxinus americana	White Ash	yes	Near north end	pH 5.0-7.5 High N and Ca levels. Rich, moist, well drained soils, high nutrient requirement	Mean Jan temp (-14)-12°C Mean annual minimum (-34)-(-5)°C Mean July tem 18-27°C Wide range of temperatures between Ontario and Florida	Needs high soil moisture. The average annual precip is 760-1520mm and snowfall is from 0-250cm	Never dominant species in the forest. A pioneer species, after some protective species have established. Seedlings are quite hade tolerant. At risk from Emerald Ash Borer
Quercus rubra	Red Oak	yes	Near north end	Northerly or middle slope N or E aspect in coves or ravines and well drained valley floors. Thick A horizon, loam-silt loam	Mean annual temp range from 4-16°C	Mean annual precipitation ranges from 760-2030mm	Intermediate shade tolerance
Fagus grandifolia	American Beech	yes	Northern tip	Corse texture, high organic, acidic	Mean annual temp range from 4-21°C. Beech can exist under temp extremes between (-42)- 38°C. Higher than average summer temps may be unfavorable for growth	Uses large amounts of water. 250-460mm in growing season. 580-1270mm of rain a year - a very drought intolerant species	Usually very shade tolerant but less tolerant on cold or poor soil sites. Very responsive stomata. Slow growing, may attain age of 300-400years.
Picea glauca	White Spruce	yes	Southern edge	Importance of good soil moisture and nutrients all equal and compensatory. No stagnant water. Gets pickier about site further north	July average 10-18°C Capable of enduring extreme variations in temp/climate	250-1270mm In moist conditions a moss layer is developed which affects soil but also traps moisture. Can handle a wide range of moisture but does not like to sit in standing water	Intermediate shade tolerance, slow growing. Can associate with pioneers or late successional species. Will benefit from release at any age. Remains in understory 50-70 years

3.3 Conceptual framework for scenario building

The scenarios built for the present study at Bruce Peninsula National Park are a mix of exploratory and normative scenarios (Becker, 1983). The scenarios start with two pillars, one for each of the primary climate scenarios of A2 and B1, then the assessment of forest health is applied. This assessment is based on the fieldwork completed and the historical data collected by the Parks Canada staff at BPNP. One of the things that distinguish scenarios from mere predictions is that they account for more than one level of uncertainty; therefore the scenarios have a second branch based on various levels of management and intervention by the park staff.

There are many possible combinations and permutations of climate and management, and it would be both confusing and impractical to try to build a scenario for every possible outcome. In addition to a thorough investigation of potential futures for Bruce Peninsula National Park, the objectives of this project include attempting to develop a strategy that will be both accessible and adaptable for other protected areas so that they may develop a climate change management plan for their own parks. For this reason and for financial and logistical practicality the number of scenarios for the BPNP suite was capped at four.

This is this point at which the normative scenario technique was used. Based on the research of Becker et al (1983) four scenarios was decided as an ideal number and then the scenario was built normatively down to what had already been established during the exploratory phase. Each primary climate scenario trunk bifurcates after the application of the assessment of forest health. There are now two branches for management type on each primary climate trunk to accumulate the desired suite of four scenarios.

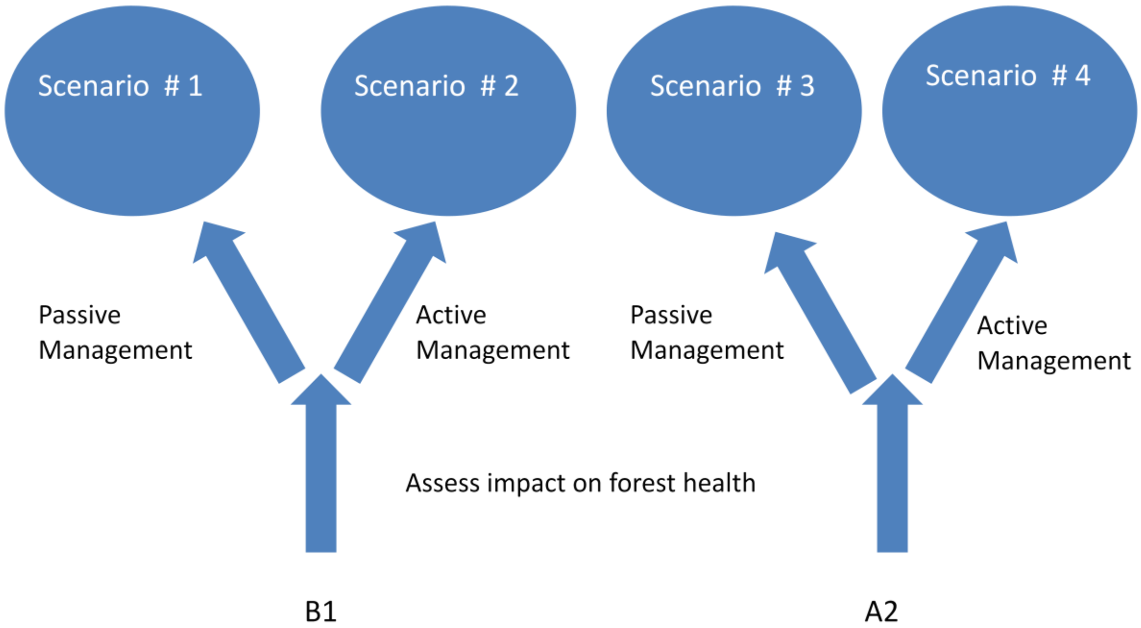


Figure 17: Format and steps for Scenario Building with a mix of exploratory and normative techniques

The levels of management and intervention options are binary, and the same for both primary climate scenarios. The first option is passive management, and the second option is active management. There are many possible metrics for dividing these two categories, including but not limited to, actual management techniques, hours of labour, and dollars spent. Dollars spent on management was the metric ultimately chosen because it could be easily transferred from park to park for easy adaptation of the scenario building tool. Dollars spent also encapsulates hours of labour by parks employees, as staff salary is one of the biggest costs in an active management budget. Classifying management in dollars spent is appropriate because it is the metric with which management of national parks in Canada are actually recorded.

The threshold for passive management was set at 0 dollars. This means that time and effort would be put in by the park staff for their regular monitoring activities and report writing, but no time or money would be spent on actions in the park such as tree planting, selective harvesting, removal of dams, and breeding assistance programs. Passive management is the path of minimal intervention, it means letting the environment run its own course. A 0 dollar passive management plan is also a realistic possibility to consider for national parks in Canada at the moment. After the budget cuts to Parks Canada made through the Growth, Jobs, and Long-term Prosperity Act, bill C-38 in April 2012, National parks have fewer employees, shorter seasons, and less money to work with than they have in the past. This means that managers have less time for active management pursuits. Although it is unlikely that this number would ever be reduced entirely to $0, it provides an appropriate baseline, a metric, and a useful management binary for the purposes of developing scenarios with the most divergent possible futures.

Setting the dollar amount for the active management scenario is difficult. It is important that this number be large enough to allow adequate management to provide a contrast from the passive management scenario. However, it would be unrealistic to set the amount so high that BPNP would ever reasonably be able to achieve that level of management. To provide a reference for this decision BPNP provided their actual budget for management in 2013 as well as an ideal management budget for the park.

Table 6 : Comparison of actual and ideal budget for active management in Bruce Peninsula National Park for the 2013 season

Actual costs		Ideal Budget	
Expense	**Amount**	**Expense**	**Amount**
Vehicle and supplies	$6000	Two technicians invasive species control for 4 month	
Staff time	$20,000	Salary	$35,000
		Vehicle and supplies	$10,000
		Two resource technicians other management and monitoring for 6 months	
		Salary	$50,000
		Vehicle and supplies	$10,000
		Full time ecologist to work and manage	$80,000
Total	**$26,000**	**Total**	**$185,000**

The information provided by BPNP shows a large difference between their actual budget and the ideal budget. Actual budget for 2013 was $26,000 and the ideal budget is $185,000. Of the ideal budget of $185,000, the majority is spent on salary. Including the ideal budget figures is important in the context of the recent cutbacks to Parks Canada. The cutbacks mean that the numbers in the actual budget may be too low to show a major difference in outcome from the passive scenario. Currently, government spending on conservation and protected areas is experiencing a trough; therefore using the actual budget from 2013 is a low floor. In the past, there have been periods of greater financial support for parks and their management. For this reason and for the purpose of building scenarios that are different enough to provide management options, the $185,000 value from the ideal budget was used as the upper cap for the active management scenario.

3.4 BPNP Scenario Suite

In addition to the conceptual model of figure 17, which is configured like a tree to demonstrate the development of the scenarios, it is common to visualise scenarios in a quadrant diagram. Each side of the axis is a discrete area, as these axes are not a continueum. Figure 18 shows the BPNP scenario suite in this format which is often effective at communicating the possible futures.

Figure 18: BPNP Scenario suite depicted in quadrant format

3.4.1 Scenario 1 B1 Passive Management: Status Quo

According to Parks Canada documents, the forests of Bruce Peninsula National Park are inhabited by 24 species of tree. Of those, eleven were found within the six sites surveyed for forest health to be used in this project in 2012. Of the more widespread species discussed in Chapter 2: The State of Forest Health, many have large geographic ranges and can tolerate a wide array of temperature and moisture conditions. *Betula papyrifera* is the most widely distributed tree in North America. *Acer saccharum*, *Populus tremuloides,* and *Larix laricina* also have large home ranges.

As would be expected, most of the coniferous trees prefer more northerly habitats and BPNP is positioned centrally or near the southern edge of home range. Among deciduous trees, many (*Acer saccharum, Quercus rubra, Fagus grandifolia, Fraxinus americana, Ostrya virginiana, Tilia americana*) had much more southerly home ranges and BPNP was often located near the northern edge of that range. As dictated by the research on northward shifting biomes, those trees for which BPNP is near the south end of their range, may experience some difficulty - from a lack of regeneration and health, right up to local extirpation - as a result of the biome shifting northward. Therefore trees in the north or central parts of their range are unlikely to see changes to their distribution within the small geographic area that is BPNP.

Because of the wide ranges of some tree species found in BPNP and the smaller magnitude of climate changes associated with the B1 scenario, it is possible that the forest health and structure will not change much over the next 100 years. *Abies balsamea* and *Thuja occidentalis* are the only two trees species among those found at the six sites that may decline as a result of temperature and precipitation changes with *Abies balsamea* being affected sooner than *Thuja occidentalis* (Table 5).

Under this scenario the future of the park forest structure is likely to be dictated by regeneration and succession influences. Because the current forest is young and dominated by early colonizing and shade intolerant species, it is likely that any changes in dominance over the next 100 years will be a result of light dynamics and regeneration - as opposed to changing climate.

Regardless of the driver, the essential aspect of this scenario is that any changes in the forest structure are not likely to be a threat to ecological integrity of the Park. Any changes in dominance of species will happen slowly enough over time for the local wildlife to adjust. This scenario is the "Status Quo", i.e. it is what is currently the management plans of BPNP and potentially other national parks use. Management plans currently expect that the needs for and results of, management for the next 10-15 years will look similar to the needs for and results of management for the last 10-15 years. This scenario also represents the status quo in the lack of funding for management activities. Although some management remains in place after the budget cuts of 2012, at BPNP the actual spending budget of $26,000 is closer to $0 spent than it is to $185,000.

It is important to be aware that while $26, 000 is closer to $0 than it is to $185,000, the current level of active management spending is not 0. Currently BPNP is spending a large portion of t his funding on staff time to work on the removal of invasive species. Regardless of the lack of changes to the forest composition structure resulting from climate change, these invasive species continue to pose a threat to the ecological integrity of the park, outside of the forest health indicator being used as a proxy for ecological integrity of the system. Of the $26,000 currently being spent, some is also targeted toward programs for species at risk protection in the park. Reducing the active management budget to $0 includes the possibility of negative impacts on these at risk species despite a healthy forest structure. These examples of invasive species and species at risk demonstrate that while forest health is a good indicator for overall ecological integrity of the BPNP system, it is not all inclusive and there are other factors to consider when planning for the entire system.

While this scenario suggests that even with no management the park forest system will likely remain healthy indicating an overall high level of ecological integrity in the system, this scenario is clearly predicated on the assumption that there will be effective reduced GHG emissions and less dramatic impacts of climate change. The drivers for global GHG levels and major climate change impacts are beyond the control of Parks Canada, despite their own best mitigation efforts, so there is a risk in blindly following this scenario plan. Although it may seem a waste of resources to go through the scenario building process and then choose the scenario that most closely represents what is already happening, at least then there would be an understanding of alternatives and the potential risks associated with assuming minimal climate change and not investing in managing for that.

3.4.2 Scenario 2 B1 Active Management: Regional Resilience

The large geographic range of many of the trees that inhabit BPNP, and the minimal negative impacts predicted by the B1 primary climate scenario result in expectations for minimal negative impact to the tree health in BPNP. With an active management budget and few expected negative impacts there is a real opportunity in this scenario to go beyond the Status Quo represented by Scenario 1 to make improvements to ecological integrity within the park and build regional resilience (Gunderson, 2000; Holling, 1973).

The proposed $185,000 budget covers cost for two additional staff members for four months through the summer, two additional staff for six months from spring until October, and one full time year round ecologist to manage them. With this level of human resources, there is an opportunity to increase species and perhaps functional redundancy to promote ecological integrity in the forest ecosystems. A generalist forest means minimal impact is predicted to result from climate change. Management can therefore, be targeted toward completing backlogged management actions recommended at the time of park establishment as well as removing invasive species and supporting those species that are ecologically important and/or threatened.

There are several management actions that were suggested in 1998 in the initial park management plan that had still not be acted upon as recently as the State of the Park report published in 2010 (Parks Canada, 1998). An evaluation of the continued relevance of these management actions is necessary in order to determine if their implementation would still be useful. The State of the Park Report cites habitat connectivity as one of the lower rated measures of ecological integrity in the park. BPNP is small compared to many national parks and was only recently established, there are many roads and private properties surrounding and interwoven through the park. BPNP continues to try to acquire these properties on a willing seller willing buyer basis. Once acquired, extensive restoration is required, including the decommissioning of roads and buildings before planting of trees and shrubs. While the availability or resources for increased property acquisition are not present in this scenario, there is increased capacity for an accelerated restoration process once a piece of land has been acquired.

According to the 2010 State of the Park Report, there are 14 SARA listed species that inhabit BPNP for at least part of their life cycle. This list includes several plants and reptiles, two birds and the monarch butterfly (*Danaus plexippus* L.). *Sistrurus catenatus* Rafinsque (Massasauga rattle snake), *Regina septemvittata* Say (Queen snake), *Clemmys guttata* Schneider (Spotted turtle) are threatened reptiles which all rely on health habitat within the park for their survival. Species at risk was a new measure for the last state of the park report so at this point most of those species have been inventoried but there is no information published yet on the trends they are experiencing. This is an area where management could have a positive impact but without the supporting documents stating the problems and trends, it is currently difficult to plan the specific management actions. BPNP is in the process of producing a report with a set of programs and protocol for SAR monitoring, upon publication this will serve as a useful management tool for this scenario.

Invasive species management is another important way to increase the resilience of the BPNP region. The 2010 State of the Park Report does not include a report on the number, severity, or species of invasions within the park ecosystem; however, invasive species are present (SD Murphy, pers. comm; S Parker, pers comm.). For example, in the summer of 2013 a large portion of the $26,000 spent on active management was salaries for staff activities related to invasive species control. Invasive species present in BPNP include: *Alliaria petiolata* (M. Beib.) Cavara & Grande (garlic mustard), *Heracleum mantegazzianum* Sommier & Levier (giant hogweed), and *Lythrum salicaria* L. (purple loosestrife) and several aquatic invasive species (McCanny et al., 2012).

The Bruce Peninsula has an advantage in terrestrial invasive species management. The geographic landform of a peninsula means there is a bottleneck and, for plant species, they may be interdicted if detected down-peninsula before their arrival in the park. Due to the inherent quality of excellent dispersal ability invasive species, the geographic landform advantage of the peninsula will not enough to prevent the establishment of new invasive species, but it is an advantage. This can be important also for preventing, slowing, or reducing the impact pests that are damaging to forest health such as *Agrilus planipennus* (emerald ash borer), which may find the Northern Bruce Peninsula climate more hospitable with even the small climate changes predicted by B1. *Fraxinius americana* (white ash, the species most negatively affected by *Agrilus planipennus*) was one of the tree species found at the monitoring sites within the park. It was not one of the most abundant in the adult cohort, however it was prevalent as a seedling meaning that the impacts of *Agrilus planipennus* may be more substantially felt in the future as these seedlings mature.

Managing invasive species means not only eliminating those species through mechanical removal or spraying, but also, in the case of herbaceous invasives, seeding or planting to ensure that it is native species that fill the niche left behind. Without planting or seeding native species, the in situ seedbank or new propagules from nearby populations of invasive species will allow them to quickly re-colonize the area left barren, pre-empting native species (Hellmann et al., 2008).

3.4.3 Scenario 3 A2 Passive Management: Novelized Forests

The A2 primary climate scenario predicts changes in temperature and precipitation that, over time, are increasingly more severe than those predicted in B1. At this level of change, despite the generalist nature of many of the inhabiting trees, it can be expected that there will be more negative impacts on forest health (Table 5). With a passive management strategy it can be expected that there will be changes in relative abundance in the forests, as less suitable trees are not regenerating concurrent with the impacts of succession and light dynamics in the forest. As a result of these changes it is possible that the composition of the forest will be unlike any previous assemblage leading to the label of a novel ecosystem (Hobbs et al., 2009). Under this scenario, in the BPNP ecosystem, changes in temperature will continue to have an impact, but they will not be the primary driver, as has been predicted in many other ecosystems. Due to the underlying geology and soil conditions, changes in precipitation patterns will have the biggest influence on the future distribution of tree species within the park.

According to the North American Silvics Manual (Burns & Holonka, 1990), and the results of the climate predictions through the Canadian GCM (Table 4) the species that will be most affected by temperature are those species that are more associated with the Boreal Forests (Burns & Honkala, 1990). Based on the predicted increase in temperature for the Bruce Peninsula region, *Abies balsamea* will be the first species to no longer be in its preferred habitat range. As the temperature continues to rise, *Abies balsamea*, *Pinus strobus*, and *Picea glauca* will be the next species outside of their preferred range (Burns & Honkala, 1990). Although not a coniferous species, *Betula papyrifera* will also be affected. *Thuja occidenalis* is currently the most abundant and most dominant species (Figure 8) in the forest at BPNP, a decline in the regeneration or success of this species will definitely affect the overall structure an ecosystem of the park's forest.

Even under this more dramatic prediction of changing climate, the prediction for overall change moisture in precipitation is only under 50mm even after 100 years - not large. However, there are major changes predicted for the time of year in which that precipitation arrives. It is predicted that there will be more winter precipitation and less summer precipitation (Table 4 and Figure 14), the wet season will be wetter, and the dry season will be drier, resulting in several implications. There are several trees in the region that require high moisture levels. Moisture is a limiting factor for *Fagus grandifolia*, *Fraxinus americana, Tsuga canadensis, Pinus strobus,* *Abies balsamea*, and *Populus tremuloides*, they are particularly drought intolerant (Burns & Honkala, 1990). *Pinus strobus* and *Populus tremuloides* in particular require a moisture surplus year round. Changes in annual moisture distribution will be a problem for these species in several ways. The first is that evapotranspiration will be increased in the summer, when the temperatures are already high and predicted to be rising. So even if precipitation remained steady, the effective moisture availability would be reduced as a result of higher evaporation and evapotranspiration rates.

With the predicted rising winter temperatures and precipitation, more of the precipitation will fall as rain rather than snow over several decades. A reduction in the size of the snow pack and earlier thaw dates mean less water available in the spring melt, and that it will happen sooner, compounding the issues associated with a dryer summer (Barnett, Adam, & Lettenmaier, 2005). It is also predicted that although the precipitation will overall experience a slight increase, it is more likely that more of it will arrive if the form of storm events. This causes a third challenge because in major rain storm events, once the soil is saturated and no more water can be absorbed, it instead runs off as overland flow, often causing problematic soil erosion in the process. There would be times of heavy rain where not all the water can be optimized, and then periods of dry in between (Michael, Schmidt, Enke, Deutschländer, & Malitz, 2005).

Erosion potential is collinear with the soil and underlying geology of the region. The Bruce Peninsula is formed by the Niagara Escarpment and the area of BPNP is known for having shallow soil, e.g. alvars, are prevalent (exact areas of alvar uncertain they were included with open pasture land in the biophysical survey and in Figure 2). Shallow soil risks more runoff and more drought with more extreme precipitation events. The depth of the soil can also be a limiting factor in the distribution of some species within the park such as *Acer saccharum*, *Quercus rubra*, *Tilia americana,* and *Fraxinius americana* (Burns & Honkala, 1990). For both reasons of moisture requirement as well as size and stability these deciduous trees require moderate to deep soil to form a healthy root system and achieve preferred crown class (Burns & Honkala, 1990).

Without the effects of climate change, succession and light dynamics indicate that BPNP forest system could expect a shift over the next 100 years to a more maple, beech dominated forest with more late successional and shade tolerant species (Burns & Honkala, 1990). However it is unlikely that any of the above mentioned late successional species requiring deep root systems will achieve maturity in the areas with shallow soil (Table 5). Currently many of the areas with deeper soil are already the locations of the more deciduous dominated sections of forest versus the more boreal coniferous sections that require less depth (Kelly & Kischak, 1992). Otherwise most of the soil rich areas in the region have previously been converted to field for use as cropland, hayfield or pasture land.

If coniferous and boreal trees are going to be adversely affected by rising temperatures pushing them out of their preferred habitat range, but minimal soil depth and moisture retention is preventing later successional deciduous trees from reaching maturity what is to become of the large amount of coniferous dominated forest (Burns & Honkala, 1990)? One possibility is that the *Thuja occidentalis* will adjust to temperature changes better than expected and continue to be the dominant tree in the forest. It is also possible that *Abies balsamea*, *Pinus strobus* and *Picea glauca* will be replaced by shrubbier *Sambucus canadensis* L. (elderberry), *Rhus typhina* L. (staghorn sumac), *Acer pensylvancium* L. (striped maple), rather than by large deciduous trees with large soil and moisture requirements (Burns & Honkala, 1990).

Shrub dominated forest in lieu of coniferous forest has several implications for overall ecological integrity of the park. Tree like shrubs do not never establish the height or the diameter of a mature tree. This means they provide fewer habitats for wildlife that make their homes in sturdy upper branches or in hollowed out trunks of trees. Their downed woody debris provides less area for ground nesting habitat compared to the log or stump of a tree as well. *Thuja occidentalis* currently dominates the forest in BPNP but the other coniferous species, *Abies balsamea*, *Picea glauca*, *Pinus strobus*, *Tsuga canadensis*, *Larix laricina*, all contribute as important food sources for much of the local wildlife (Burns & Honkala, 1990; Nelson, 1951). Squirrels, porcupines, deer, and many birds depend on these food sources over the winter months. Any major changes to the health of these species would have a cascading impact on ecological integrity across multiple trophic levels (Urban et al., 2012).

In addition to the threats to forest health discussed in this scenario, ecological integrity of the system will continue to be impacted by other parts of the system, including invasive species and species at risk. As discussed in Scenario 1 and 2, there are already vulnerabilities in the system resulting from invasive species and species at risk within the park. Although the implications for climate change were assessed only for the main indicator, forest health, and not for these other components of the system, that does not mean that they would not be impacted by a changing climate and that they would not continue to contribute to considerations of overall ecological integrity of the BPNP system.

3.4.4 Scenario 4 A2 Active Management: Anticipating Restoration

Under the A2 primary climate scenario there are several changes predicted to influence the health of the forest. As discussed in Scenario 3, over time changes in temperature will cause problems for the more boreal coniferous species, and in the future it will be the soil profile and moisture availability that drive the composition and distribution of forests more so than temperature. In the passive management scenario there was no way to avoid or mitigate the results of the dramatic change in climate that could reduce the biodiversity of the forest and the ecological integrity of the system. In this scenario of active management, there is an opportunity to get ahead of the changes. It is possible not only to react to declines in forest health and then restore the areas, but to anticipate the changes and manage for them with the goal of minimizing the requirement for reactive restoration. For this reason, scenario 4 is called Anticipatory Restoration.

It is understood that there is an inherent level of uncertainty when managing for climate change. When performing acts of anticipatory restoration it is important to ask the question of whether or not this action would be hurtful if the impacts of climate change are different than what has been predicted by the A2 primary climate scenario. Assisted migration or assisted colonization in particular are an emerging field with a growing body of literature weighing the ecological benefits of the chance having a more complete system that maintains levels of biodiversity, and the possibility that newly incorporated species will become invasive and further degrade the system (Hoegh-Guldberg et al., 2008; Kreyling et al., 2011; Willis et al., 2009).

Changes to GHG levels and climate have the potential to be different from anything that has been predicted under any scenario thus far, despite scientists' best efforts. This means that any anticipatory restoration steps taken as part of this scenario must consider whether this action would be good for the ecological integrity of the park even if the climate does not change at the anticipated rate. It is also important to consider the alternative question, would park management regret not taking this action now, if the impacts of climate change are more severe and dramatic than predicted by the A2 primary climate scenario.

Possible management actions to be considered as anticipatory restoration include, planting preferred species filling a similar ecological role, removal of invasive species, selective tree harvesting to promote understory growth and addition of mulch or soil to prevent erosion. Selective removal of trees eg. *Abies balsamea* allowing more sunlight penetration may allow increased success of other species in a particular area that are more likely to be successful long term (Burns & Honkala, 1990). By pre-emptively removing the trees most likely to decline in the future the surrounding trees are given the benefit of additional sunlight and nutrient availability early. Despite being a non-traditional, and possibly controversial technique, selective harvesting has the potential to allow released trees to flourish so that they may increase their root system and provides more soil stability and habitat for wildlife by the time that the removed tree would have died.

Per scenario 3, changes to precipitation patters have the potential to create more change in BPNP than changes in temperature. Increased frequency and severity of storm events, as well as a reduction in time of year the ground is protected by snowpack and/or being frozen lead to the potential for serious erosion problems in an area where soil is already thin and at a premium (Barnett et al., 2005; Michael et al., 2005; S.L. Ross Enviornmental Research Limited et al., 1989). Ensuring healthy forests with a strong root network is one important way to minimize the effects of erosion. With a large budget to maintain ecological integrity, other options to prevent soil erosion might include planting specific herbaceous species, adding soil or mulch to particular areas, or building structures such as ditches or culverts to minimize damage.

In addition to removing trees which are least likely to survive, it is conversely possible to plant trees or plants that are more likely to thrive under the new conditions. Planting for new conditions may mean selecting more suitable species that are already present within the park but are present in low numbers, such as *Ostrya virginiana* (ironwood) or *Fagus grandifolia*. It could also mean planting species that are currently prevalent south of the park but not yet established within the park boundaries. For the undertaking of either variation of this action, monitoring would be crucial to ensure that the plants established properly and were successful, but not so successful as to become invasive in the area becoming an additional threat to the community (Kreyling et al., 2011).

3.5 Implications and Recommendations for Park Management at BPNP

As discussed in Chapter 2, the current state of forest health in Bruce Peninsula National Park is good. This is used as an indicator of overall ecological integrity, while incomplete and not accounting for issues of established invasive species or vulnerability of species at risk, which directly impact on a result of current ecological integrity, it remains a useful indicator and proxy. Compared to areas outside of the protection of the park, the ecological integrity of the system is in good condition. Due to the forest composition, and location within its eco-zone, BPNP is in a good position to handle impending climate change with minimal negative impact to the forest health in the park. Context is also important to consider including the actions being undertaken to mitigate climate change, as well as the political climate and support for parks and protected areas management and research.

When considering the future actions or inactions necessary in park management there are a few important considerations. The first is that Scenarios 1 and 2 are both highly unlikely as they are based on the optimistic primary scenario B1. The primary climate scenarios designed by the IPCC were originally written in 1997. At that time immediate action would have made that scenario not only possible but likely, however as time passes the window for action that will lead to this scenario is decreasing in size. It is not that a B1 outcome is no longer possible, just that as time passes and the window for change gets smaller, a larger and more drastic change becomes more necessary.

As of 2014 there has been no evidence that drastic efforts are being made either nationally in Canada, or globally to reduce greenhouse gas emissions enough for this scenario to be representative of Earth's ecological future. Scenarios 1 and 2 are best case scenarios in the climate impact aspect, so relying on them exclusively for decisions gives an unrealistic expectation of environmental change to come. While it is unlikely that the future will look exactly like any one of the IPCC primary climate scenarios, the magnitude of climate change described by the A2 scenario is a more realistic expectation than B1 at this point in time. This should factor into the decision making about park management. It becomes an important question to ask: Is managing for a lower magnitude of climate change more useful than not managing for climate change at all?

The positive projection for future ecological integrity at BPNP is a fortunate situation for a National Park in a political climate where the financial support to implement the recommendations of either active management scenario (Scenarios 2 - Regional Resilience and 4 - Anticipatory Restoration) is not available. This is important to consider when making recommendations for future management of the Park. While the active restoration condition of

$185, 000 seems large at the moment in comparison to what BPNP is receiving, it is not an outrageously large number.

Despite being in an overall positive position, the most important recommendation for the managers at BPNP is to do as much active management as possible with the budget that they have. Removal or prevention of invasive species is a top priority as well as efforts in soil conservation and erosion management. Although on a separate budget line for the park, the continued acquisition and restoration of lands in the North Bruce Peninsula region will be important for the future. Increased area and contiguous habitat reduces edge effect and allows for larger healthier populations of wildlife that require a larger home range, such as black bears. More continuous habitat will also make it easier for organisms that are trying to shift their ranges to keep pace with their preferential biome.

The financial figures in the scenarios were exclusively associated with active management, which is important for maintaining the highest possible level of ecological integrity within the park. Regular monitoring of forest health or other ecological indicators within the park was not considered to be part of the active management portfolio since it is not an action that directly changes the environment in the park. Monitoring is, however, essential to maintaining an understanding of the health of various components of the park ecosystem and how those components are related to one another. Effective regular monitoring allows decisions to be made about what the best and most efficient active management strategies should be. While the recommendations for managing for climate change have focused on active management items and the importance of allocating funds for these activities in order to maintain forest health and maximize ecological integrity in a changing climate, it is important to note that these actions should not come at the expense of effective and regular monitoring of park systems.

BPNP remains a relatively young park, and is still in the land acquisition phase on a willing seller willing buyer basis. As some of the local farmer's fields are being decommissioned there is a possibility that they could be bought by the park. The Johnston Fields are an excellent example of this transaction. The land acquisition is paid for separately, as is public consultation about the objectives and restoration plan for the land. But once decided upon, there is still a large resource requirement for the actual implementation of management and restoration on the property. Despite the cost and the management requirements of this type of acquisition, it remains important, and supportive of the ecological integrity mandate to return the area to as much contiguous forest as possible.

3.6 Recommendations for Further Research

The third objective of this research is that, from this initial case study at BPNP improvements and adaptations can be made to the research program and scenario building technique. Ideally it will be taken and implemented, at BPNP, but also adapted for use at other national parks in Canada. The most direct application would be for other forest dominated parks that could also use forest health as a primary indicator. This would be an important first step toward ensuring that all Canadian national parks are dutifully considering and making choices around managing for EI in a changing climate.

A larger, and more historic data set would be the most direct way to improve the scenario building technique. The short time span of the data at BPNP was unavoidable as it is such a recently established park. It would also be ideal to be able to consider more than one system indicator. In a forested system, the health of the forest certainly plays a vital role, structurally and functionally and is the closest proxy for ecological integrity in one indicator. Systems are complex and the more of that complexity that can be accounted for, the more inter-trophic interaction that can be considered the clearer a picture that can be obtained about the impacts of the various primary climate scenarios on the ecological integrity of the park. Incorporating many indicators would give a more complete picture about the system for assessing ecological integrity and future possibilities. At some point however the number of indicators would pass a threshold where it is no longer time or resource efficient to complete the scenario building process, or that the amount of additional understanding would not be sufficiently justified by the additional resources required.

In the case of a park having extensive monitoring data sets that are both historic and up to date, it would be beneficial to include a few additional indicators in the analysis. For the BPNP system I would select migratory birds, invasive species, and *Sistrurus catenatus* Rafinsque (Massasauga rattle snake) as indicators. These additional indicators would allow for a more complete picture of system ecological integrity, potential impacts of a changing climate, and consequently, what active management techniques should be considered.

Another way to add redundancy and make the scenario building more robust would be to assess the regional climate predictions based on multiple GCMs. My research was based exclusively on the most accessible information, i.e. IPCC primary climate scenarios and regional climate predictions of the Canadian GCM. Evaluating multiple GCM outputs would ensure that the scenario suite being developed is not based on climate predictions that extreme or outliers such that the resulting management suggestions are unlikely to be helpful.

While it is useful to consider adding multiple indicators, and using multiple GCMs in the scenario building technique, time and financial resources will constrain any employee of Parks Canada looking to use, adapt and improve the scenario building technique. While each of the aforementioned suggestions would certainly add value to the scenario building process, it would also require more time on the part of the analyst. This technique was developed based on the premise that park managers and employees have many demands on their time and few available hours and dollars to dedicate to developing a climate change management plan. The time and financial restrictions at a particular park would have to be weighed against the benefits of including additional data.

3.7 Conclusions

Despite being a disturbed system, Bruce Peninsula National Park currently shows good forest health; the mortality is low, the growth rate is healthy, there is a good diversity of species, and there are varying ages as well as downed woody debris to provide habitat for other wildlife. The location of the park, both geographically within the province and on a peninsula, and in relation to the boundaries of its ecozone, situates it well for the forest to adapt to impending climate change. For both the milder B1, and the more aggressive A2 primary climate change scenarios, the forecasted impacts for the park forests are manageable, nothing that appears devastating. The impacts under the A2 scenario, are, unsurprisingly more severe than those of B1, and if following Scenario 3 with only passive management, changes in precipitation could cause problem to forest health and, consequently, ecological integrity 50 to 100 years in the future. Scenarios 1 and 2 are both positive futures for the forests of BPNP but the likeliness of curbing emissions for such minimal increase in CO_2 is becoming more unlikely as time passes without any major changes to policies globally and in Canada.

While this research presents possible positive outlooks on the forest health at BPNP and uses that as a positive indicator of ecological integrity and that is good news in a changing climate, in addition to the unlikelihood of B1 scenario there are other factors important to remember. 1. Forest health is the best single indicator to serve as a proxy for system ecological integrity, but it is not the complete picture. 2. This is the first iteration of this approach for parks, as it is used it will be adapted and approved to give a more complete and accurate picture. The imperfection of this method, however is not reason to discount its usefulness. Any technique that is logistically and financially accessible to national parks to begin considering and taking action in managing for climate change is worth investigating and incorporating into the existing adaptive management strategies.

Active management is a proactive way of supporting the ecosystem, preventing invasive species and anticipating restoration needs for the park. By taking a proactive approach managers can avoid the impacts, stress, and cost of serious degradation and associated restoration needs. Even if the suggested $185, 000 active management threshold cannot be met at this time it is important that parks invest as much into active management and anticipatory restoration as possible, so long as it is not done at the expense of monitoring practices.

Uncertainty is inherent when planning and forecasting for the future, but the scenario technique accepts and accounts for the uncertainty by providing four options, none a direct prediction and with no probabilities attached. It is understood that it is extremely unlikely the actual future will look exactly like any of the four scenarios, but they give a place to start, an idea about what the possibilities look like. Through the use of scenarios park managers can make more informed decisions about how to spend the little time and money they have so that they choose the management actions that are the most important for maintaining ecological integrity.

The most important conclusion to come out of this research is the importance that national parks in Canada start planning for a changing climate. Managing the next 15 years the same as the last 15 and expecting to yield the same result is no longer viable. The scenario building technique demonstrates that it is possible to take climate into account without expensive and time consuming models or research programs. As climate change is considered and various parks, the iterative nature of scenario building will offer managers the opportunity to improve the process leading to improved decision making. With the resources that are currently open access, the historical data of the park and basic ecological understanding, it is possible to shift management thinking into a proactive approach that takes a changing climate into account.

References

Alo, C. A., & Wang, G. (2008). Potential future changes of the terrestrial ecosystem based on climate projections by eight general circulation models. *Journal of Geophysical Research*, *113*(G1), G01004. doi:10.1029/2007JG000528

Barnett, T. P., Adam, J. C., & Lettenmaier, D. P. (2005). Potential impacts of a warming climate on water availability in snow-dominated regions. *Nature*, *438*(7066), 303–9. doi:10.1038/nature04141

Bartlein, P. J., Whitlock, C., & Shafer, S. L. (1997). Future Climate in the Yellowstone National Park Region and Its Potential Impact on Vegetation. Clima Futuro en la Region del Parque Nacional de Yellowstone y su Potencial Impacto Sobre la Vegetacion. *Conservation Biology*, *11*(3), 782–792. doi:10.1046/j.1523-1739.1997.95383.x

Becker, H. S. (1983). Scenarios A Tool of Growing Importance to Policy Analysts in Government and Industry. *|technological Forcasting and Social Change*, *120*, 95–120.

Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W., & Courchamp, F. (2012). Impacts of climate change on the future of biodiversity. *Ecology Letters*, 365–377. doi:10.1111/j.1461-0248.2011.01736.x

Bradford, L. (2004). Progress in Integration of Social Science in the Parks Canada Science Strategy. In *Parks Research Forum of Ontario* (pp. 241–250).

Burns, C. E., Johnston, K. M., & Schmitz, O. J. (2003). Global climate change and mammalian species diversity in U.S. national parks. *PNAS*, *100*(20), 11474–11477.

Burns, R., & Honkala, B. (1990). *Silvics of North America 1. Conifers 2. Hardwoods* (Vol. 1). Washington, DC.

Canada, G. of. (1987). Federal-Provincial Agreement for the establishment of a national park and a national marine park in the township of St. Edmonds. Tobermory, ON.

Charmantier, A., McCleery, R. H., Cole, L. R., Perrins, C., Kruuk, L. E. B., & Sheldon, B. C. (2008). Adaptive phenotypic plasticity in response to climate change in a wild bird population. *Science (New York, N.Y.)*, *320*(5877), 800–3. doi:10.1126/science.1157174

Dale, V. H., Joyce, L. a., Mcnulty, S., Neilson, R. P., Ayres, M. P., Flannigan, M. D., … Michael Wotton, B. (2001). Climate Change and Forest Disturbances. *BioScience*, *51*(9), 723. doi:10.1641/0006-3568(2001)051[0723:CCAFD]2.0.CO;2

Davis, M. B., & Shaw, R. G. (2001). Range shifts and adaptive responses to Quaternary climate change. *Science (New York, N.Y.)*, *292*(5517), 673–9. doi:10.1126/science.292.5517.673

Davis, M. B., Shaw, R. G., & Etterson, J. R. (2005). Evolutionary responses to changing climate. *Ecology*, *86*(7), 1704–1714.

Dawson, T. P., Jackson, S. T., House, J. I., Prentice, I. C., & Mace, G. M. (2011). Beyond predictions: biodiversity conservation in a changing climate. *Science (New York, N.Y.)*, *332*(6025), 53–8. doi:10.1126/science.1200303

Dukes, J. S., Pontius, J., Orwig, D., Garnas, J. R., Rodgers, V. L., Brazee, N., … Ayres, M. (2009). Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: What can we predict?This article is one of a selection of papers from NE Forests 2100: A Synthesis of Climate Change Impacts o. *Canadian Journal of Forest Research*, *39*(2), 231–248. doi:10.1139/X08-171

Gibson, R. B., & Hassan, S. (2005). *Sustainability Assessment: Criteria and Processes*. *London Earthscan Government of Western Australia* (p. 254). Earthscan. Retrieved from http://mcgill.worldcat.org/title/sustainability-assessment-criteria-and-processes/oclc/60767046&referer=brief_results

Gunderson, L. H. (2000). Ecological resilience — In theory and application. *Annual Review of Ecology and Systematics*, *31*, 425–39.

Hellmann, J. J., Byers, J. E., Bierwagen, B. G., & Dukes, J. S. (2008). Five potential consequences of climate change for invasive species. *Conservation Biology : The Journal of the Society for Conservation Biology*, *22*(3), 534–43. doi:10.1111/j.1523-1739.2008.00951.x

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

Hoegh-Guldberg, O., Hughes, L., Mcintyre, S., Lindenmayer, D. B., Parmesan, C., Possingham, H. P., & Thomas, C. D. (2008). Assisted Colonization and Rapid. *Science*, *321*, 345–346.

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

Holling, C. S. (2001). Understanding the Complexity of Economic, Ecological, and Social Systems. *Ecosystems*, *4*(5), 390–405. doi:10.1007/s10021-001-0101-5

Intergovernmental Panel on Climate Change. (2000). *IPCC Special Report: Emission Scenarios*.

Intergovernmental Panel on Climate Change. (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability, 1–44.

International Panel on Climate Change. (2007). *Climate Change 2007 : An Assessment of the Intergovernmental Panel on Climate Change*. *Change* (pp. 12–17).

Jump, A. S., & Penuelas, J. (2005). Running to stand still: adaptation and the response of plants to rapid climate change. *Ecology Letters*, *8*(9), 1010–1020. doi:10.1111/j.1461-0248.2005.00796.x

Kelly, C., & Kischak, V. (1992). A land use study of the Bruce Peninsula with emphasis on St Edmunds Township.

Kreyling, J., Bittner, T., Jaeschke, A., Jentsch, A., Jonas Steinbauer, M., Thiel, D., & Beierkuhnlein, C. (2011). Assisted Colonization: A Question of Focal Units and Recipient Localities. *Restoration Ecology*, *19*(4), 433–440. doi:10.1111/j.1526-100X.2011.00777.x

Lafleur, B., Paré, D., Munson, A. D., & Bergeron, Y. (2010). Response of northeastern North American forests to climate change: Will soil conditions constrain tree species migration? *Environmental Reviews*, *18*(NA), 279–289. doi:10.1139/A10-013

Lemieux, C. J., Beechey, T. J., & Gray, P. a. (2011). Prospects for Canada's protected areas in an era of rapid climate change. *Land Use Policy*, *28*(4), 928–941. doi:10.1016/j.landusepol.2011.03.008

Lemieux, C. J., Beechey, T. J., Scott, D. J., & Gray, P. a. (2011). The state of climate change adaptation in Canada's protected areas sector. *Canadian Geographer / Le Géographe Canadien*, *55*(3), 301–317. doi:10.1111/j.1541-0064.2010.00336.x

Loarie, S. R., Duffy, P. B., Hamilton, H., Asner, G. P., Field, C. B., & Ackerly, D. D. (2009). The velocity of climate change. *Nature*, *462*(7276), 1052–5. doi:10.1038/nature08649

McCanny, S., Gonzales, E. K., Vis, C., Patrikeev, M., Keitel, J., Wolonski, M., … Parker, S. (2012). *Scientific Rationale for the Bruce Peninsula National Park ' s 2010 State of the Park Report*.

McFarlane, B. L., Stumpf-Allen, R. C. G., & Watson, D. O. (2006). Public perceptions of natural disturbance in Canada's national parks: The case of the mountain pine beetle (Dendroctonus ponderosae Hopkins). *Biological Conservation*, *130*(3), 340–348. doi:10.1016/j.biocon.2005.12.029

McKenney, D., Pedlar, J. H., Lawrence, K., Campbell, K., & Hutchinson, M. F. (2007). Potential Impacts of Climate Change on the Distribution of North American Trees. *BioScience*, *57*(11), 939–948.

McKenney, D. W., Pedlar, J. H., Rood, R. B., & Price, D. (2011). Revisiting projected shifts in the climate envelopes of North American trees using updated general circulation models. *Global Change Biology*, *17*(8), 2720–2730. doi:10.1111/j.1365-2486.2011.02413.x

Mclennan, D. S., Bell, T., Berteaux, D., Chen, W., Copland, L., & Fraser, R. (2012). Recent climate-related terrestrial biodiversity research in Canada ' s Arctic national parks : review , summary , and management implications. *Biodiversity*, *13*(3-4), 157–173.

Michael, a., Schmidt, J., Enke, W., Deutschländer, T., & Malitz, G. (2005). Impact of expected increase in precipitation intensities on soil loss—results of comparative model simulations. *Catena*, *61*(2-3), 155–164. doi:10.1016/j.catena.2005.03.002

Opdam, P., & Wascher, D. (2004). Climate change meets habitat fragmentation: linking landscape and biogeographical scale levels in research and conservation. *Biological Conservation*, *117*(3), 285–297. doi:10.1016/j.biocon.2003.12.008

Parks Canada. (1997). *National Park System Plan* (p. 106). Retrieved from http://www.pc.gc.ca/progs/np-pn/pr-sp/index_e.asp

Parks Canada. (1998). *Bruce Peninsula National Park Management Plan*.

Parks Canada. (2008). National Parks of Canada: National Parks List. Retrieved April 02, 2012, from http://www.pc.gc.ca/progs/np-pn/recherche-search_e.asp?p=1

Parks Canada. (2009). Ecological Integrity: What is Ecological Integrity? Retrieved April 02, 2012, from http://www.pc.gc.ca/eng/progs/np-pn/ie-ei.aspx

Parmesan, C. (2006). Ecological and Evolutionary Responses to Recent Climate Change. *Annual Review of Ecology, Evolution, and Systematics*, *37*(1), 637–669. doi:10.1146/annurev.ecolsys.37.091305.110100

Pearson, R. G. (2006). Climate change and the migration capacity of species. *Trends in Ecology & Evolution*, *21*(3), 111–3. doi:10.1016/j.tree.2005.11.022

Pearson, R. G., & Dawson, T. P. (2003). Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? *Global Ecology and Biogeography*, *12*(5), 361–371. doi:10.1046/j.1466-822X.2003.00042.x

Pearson, R. G., & Dawson, T. P. (2005). Long-distance plant dispersal and habitat fragmentation: identifying conservation targets for spatial landscape planning under climate change. *Biological Conservation*, *123*(3), 389–401. doi:10.1016/j.biocon.2004.12.006

Peterson, G. D., Cumming, G. S., & Carpenter, S. R. (2003). Scenario Planning: a Tool for Conservation in an Uncertain World. *Conservation Biology*, *17*(2), 358–366. doi:10.1046/j.1523-1739.2003.01491.x

Price, T. D., Qvarnström, A., & Irwin, D. E. (2003). The role of phenotypic plasticity in driving genetic evolution. *Proceedings. Biological Sciences / The Royal Society*, *270*(1523), 1433–40. doi:10.1098/rspb.2003.2372

Raskin, P., Monks, F., Ribeiro, T., Vuuren, D. Van, & Zurek, M. (2005). *Global Scenarios in Historical Perspective* (p. Chapter 2).

S.L. Ross Enviornmental Research Limited, Mosquin Bio-Information Ltd., & Horler Information Inc. (1989). *Bruce Peninsula Biophysical Survey*.

Scheller, R., & Mladenoff, D. (2008). Simulated effects of climate change, fragmentation, and inter-specific competition on tree species migration in northern Wisconsin, USA. *Climate Research*, *36*, 191–202. doi:10.3354/cr00745

Scott, D., Malcolm, J. A. Y. R., & Lemieux, C. (2002). Climate change and modelled biome representation in Canada ' s national park system : implications for system planning and park mandates. *Ecology*, *25*, 475–484.

Society for Ecological Restoration International Science & Policy Working Group. (2004). The SER International Primer on Ecological Restoration (Vol. 2, pp. 206–207). Tucson: Society for Ecological Restoration International. Retrieved from www.ser.org

University of Washington Urban Ecology Research Lab. Puget Sound Future Scenarios (2009).

University of Washington Urban Ecology Research Lab. (2009b). *Puget Sound Future Scenarios: Appendecies A-I.*

Urban, M. C., Tewksbury, J. J., & Sheldon, K. S. (2012). On a collision course: competition and dispersal differences create no-analogue communities and cause extinctions during climate change. *Proceedings. Biological Sciences / The Royal Society*. doi:10.1098/rspb.2011.2367

Van der Putten, W. H., Macel, M., & Visser, M. E. (2010). Predicting species distribution and abundance responses to climate change: why it is essential to include biotic interactions across trophic levels. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *365*(1549), 2025–34. doi:10.1098/rstb.2010.0037

Van Grunsven, R. H. a., Van Der Putten, W. H., Martijn Bezemer, T., Berendse, F., & Veenendaal, E. M. (2010). Plantâ□"soil interactions in the expansion and native range of a poleward shifting plant species. *Global Change Biology*, *16*(1), 380–385. doi:10.1111/j.1365-2486.2009.01996.x

Wack, P. (1985). Scenarios : uncharted waters ahead. *Harvard Business Review*, *63*, 73–89.

Walther, G.-R. (2010). Community and ecosystem responses to recent climate change. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *365*(1549), 2019–24. doi:10.1098/rstb.2010.0021

Wildlands League. (2005). Human History - People and the Peninsula. In *Norther Bruce Peninsula Ecosystem Community Atlas* (pp. 11–16). Retrieved from www.wildlandsleague.org

Willis, S. G., Hill, J. K., Thomas, C. D., Roy, D. B., Fox, R., Blakeley, D. S., & Huntley, B. (2009). Assisted colonization in a changing climate: a test-study using two U.K. butterflies. *Conservation Letters*, *2*(1), 46–52. doi:10.1111/j.1755-263X.2008.00043.x

Yang, L. H., & Rudolf, V. H. W. (2010). Phenology, ontogeny and the effects of climate change on the timing of species interactions. *Ecology Letters*, *13*(1), 1–10. doi:10.1111/j.1461-0248.2009.01402.x

Zhu, K., Woodall, C. W., Ghosh, S., Gelfand, A. E., & Clark, J. S. (2014). Dual impacts of climate change: forest migration and turnover through life history. *Global Change Biology*, *20*(1), 251–64. doi:10.1111/gcb.12382

Appendix 1 - Forest Health monitoring protocol

Introduction

This protocol is based upon the Ecological Monitoring and Assessment Network (EMAN). This protocol is intended for assessing forest health of coniferous stands only.

Information will be collected of the following: tree condition, regeneration and downed woody debris.

Trees

The trees element involves the collection of tree attribute data for each tree inside the growth plots. Some tree attributes change through time and need to be assessed during each and every visit. The dynamic attributes are: tree status, diameter at breast height (DBH), type and location of stem defects, and crown class. The static attributes (tree species and age) are determined during the first visit.

Regeneration

Seedlings and saplings will be measured during each visit. Seedling height classes and total number of saplings are assessed during each and every visit. Because seedlings and saplings are not marked with tags, the identification to species is required during each visit.

Downed Woody Debris

The down woody debris element involves the collection of data on the amount of dead coarse woody biomass that has fallen to the forest floor. During each and every visit the following attributes will be recorded: species (if possible), location on the transect, diameter, decomposition class, and type (log or stump).

Plot layout

Canopy-tree stratum monitoring plot

To survey a 20m x 20m plot, choose a starting point with a good northward line of sight. Mark the starting point with a flagged stake. Using a compass and a 30m measuring tape, stand directly over the pin, align the compass with true north and measure out the first baseline. Mark the 20m point with another flagged stake.

Once the corner has been staked, keep the measuring tape in place and mark the two points where the 2m x 2m seedling and sapling monitoring quadrat will be established, adjacent to the line – insert one metal pigtail pin at 9m and another at 11m.

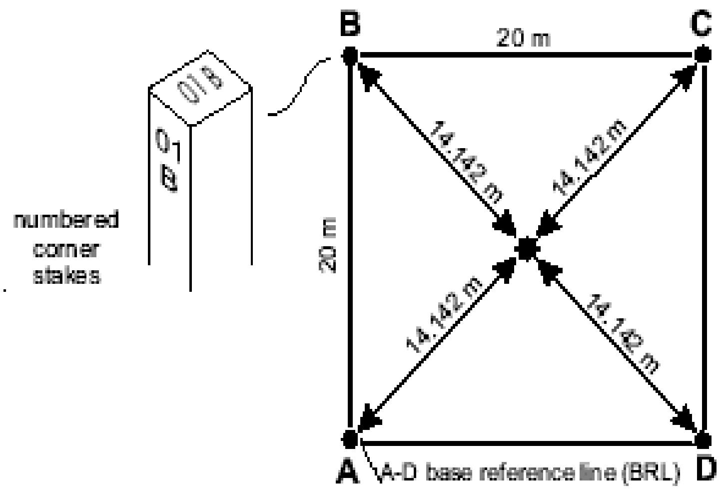


Figure 2. Plan of the 20m x 20m tree biodiversity monitoring plot and method of labeling stakes.

Using the same procedure measure the other three 20m baselines along east, south and west bearings and insert one metal pigtail pin at 9m and 11m on each side.

The maximum error when measuring the plot should be no more than 4% of the baseline measurement (i.e. the plot should not be out more than 80cm).

Measure the diagonal of the plot to ensure accurate surveying. The diagonal should measure 28.28m. An error of less than 2% (56cm) is considered acceptable.

Tie a string to the stakes of the surveyed plot to facilitate orientation during tagging and mapping and to make quadrat boundaries clear. Remove the string when all measurements have been taken.

<u>Seedling and sapling regeneration monitoring quadrats</u>

From the metal pigtails marked at 9m and 11m on each of side of the 20m x 20m monitoring plot, measure 2m at right angles to the line outside of the plot. Measure the diagonal of the quadrat to ensure accurate surveying. The diagonal should measure 2.83m.

From the centre stake of the 20m x 20m canopy-tree stratum monitoring plot, measure 1.41m diagonally out from the centre pin towards the corners of the plot. Stake each corner with a metal pigtail pin. Again, ensure that the diagonal of the quadrat is 2.83m.
Attach a piece of flagging tape to each pin.

Tie a string to the metal pigtails of the 2m x 2m regeneration quadrat to facilitate orientation in order to minimize impacts of the surveyor on ground vegetation. Leave the string attached to the pins because regeneration plots may be difficult to locate after five year intervals, and string may facilitate in finding the corners.

<u>Downed Woody Debris</u>

The Downed Woody Debris transect consists of two edges of the 20 x 20 meter forest plot and then an additional 5.14m in order to make a 45.14m transect. Start the transect at the south-west corner (A) of the 20 x 20 m plot, then proceed to B, then C, and 5.14 m from C to D.

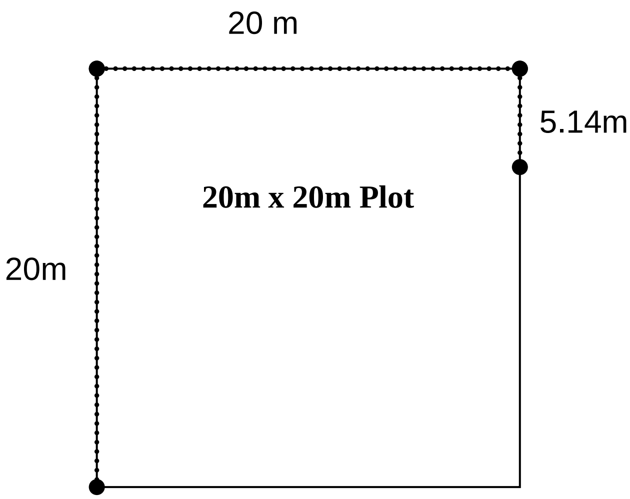


Figure 3. Example of 45.14 meters transect for down woody debris.

Plot Marking

Use tube paint or spray paint of different colors to make the following markings:

Component	Markings
Plot centre post	Red
Plot corner posts	Yellow
DBH height (on each tree with DBH > or = 10 cm)	Blue line (spray or tube paint) at 1.3 m above the ground
Dead trees in growth plot	Yellow ring or line

Tree Identification

Trees must be correctly identified to species. Since errors in species identification can occur even among trained observers, an observer who has any doubt whatsoever should collect a specimen (a twig with leaves preferably). A piece of the bark may be useful. Each specimen should be labeled with the tree's identification number, placed in a plant press, or if the storage is temporary, in a plastic bag which is kept in the shade. Always have a field guide to trees in the field for making identifications.

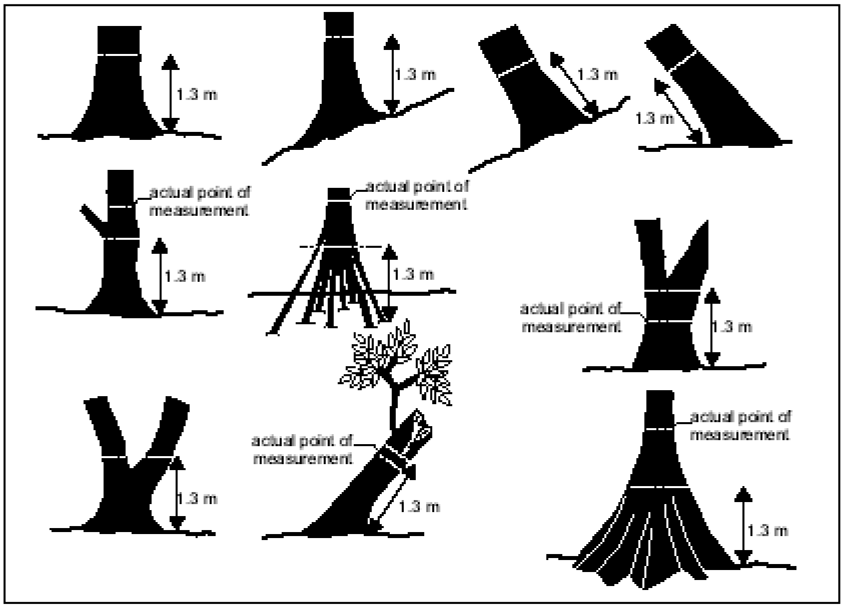
Use seven-letter species codes from Table 4 to fill out survey forms. Recommended guides or tree and shrub identification include “Trees in Canada” (Farrar 1995), “Forest plants of Central Ontario” (Chambers et al. 1996), and “Shrubs of Ontario” (Soper and Heimburger 1982).

Measuring Diameter at Breast Height (DBH), and Tree Tagging/Numbering

Measure DBH of all trees within the quadrat by wrapping a metric DBH tape around each tree 1.3 m up from the ground. Use a 1.3 m pole or a measuring tape to determine the exact spot where DBH should be measured. Make sure the tape is taut and correctly placed around the tree at right angles to the stem axis and not over an atypical part of the stem. Mark each tree with DBH ≥10 cm with a small daub of lead free blue paint (spray or tube paint) at 1.3 m above the ground. This is a permanent mark (DBH line) to ensure that all DBH measurements will be taken at the same place.

Many trees are irregular in form (e.g. leaning, branch at 1.3 m, windswept, buttressed etc.) and therefore require special handling when measuring the DBH (Figure 4). If the DBH is not taken at 1.3 m, record the height at which it is taken. When a tree has multiple-stems or the branches that separate below 1.3 m, number/tag and measure each stem with ≥10 cm (i.e., 1A, 1B, 1C, etc.). If the tree is on an outside line, only tag and measure it if at least half the stem is inside the quadrat, otherwise ignore it.

Start numbering eligible trees (DBH ≥10 cm) at the south-west corner of the plot, proceed in a clockwise spiral from the periphery to the centre of the quadrat. Tag all living and dead trees



within the quadrat with an aluminum tree tag secured by a steel or galvanized nail (number tags 1, 2, 3, etc. with no other numbers or symbols added). Hummer the nail at ca. 130^{o} to the tree trunk to prevent water from entering the wound. Also use tube paint to draw a corresponding number on the bark, above the DBH line. Both the tag and the number should be facing the south side of the plot.

Figure 4. Measuring positions for diameter at breast height (DBH).

Tree Mapping

From 2010 the field crew will map trees using a handheld GPS unit. The staff will collect tree location information from one plot, and map it using Map GIS.
Include both plot number and tree number when entering individual trees in GPS. For example, trees from plot 02-04 should be labeled 02-04-1, 02-04-2, 02-04-3, etc. If this technique works then trees in all subsequent plots will be mapped with GPS; if GPs mapping is infeasible then the field crew will resort to technique described below, and map trees with BIOMON.

Each numbered tree is mapped in relation to two adjacent, precisely located quadrat corner stakes. Each quadrat is bounded by four lines, the one parallel with and closest to the base reference line (A-D) is Line 1 (Figure 5). For example, Line 1 goes from corner A to D, Line 2 from corner A to B, Line 3 from corner B to C and Line 4 from
corner from C to D. Getting these lines correctly identified is essential for the BIOMON mapping software.

Use measuring tape to measure distances from each numbered tree to the two nearest corner stakes. Measurements are made to the nearest centimeter. The sum of the A and B distances must be equal to or greater than 20 m.

On the data sheet, record the tree number, the A distance, the B distance, and the line number (1, 2, 3, or 4). The two most common errors in mapping are switching A and B distances and incorrectly recording the line number.

In the office enter the data into the computer using the BIOMON software. This program calculates by triangulation the X and Y coordinates of the tree (taking into account the DBH) and generates a map of each quadrat showing the exact location of each tree. If necessary correct any mistakes by remeasuring distances to corner stakes.

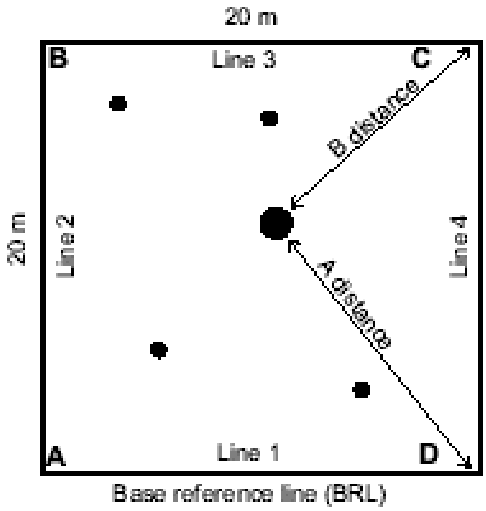


Figure 5. Set-up for mapping trees.

Tree Height

Field crews are no longer required to collect tree height information. It has been determined that correctly locating a top of each tree in a closed canopy forest is inaccurate and impractical. Although information on tree heights was collected in previous years, this measurement has been discontinued.

Tree Age

Identify the species of trees that together represent the largest and most common canopy trees in the monitoring plot.

From the stand surrounding the plot, select five specimens of each species for age determination making sure that they mirror the range of sizes on the plot, and record their DBH. **<u>Do not take cores of the trees on the plot!</u>**

Tag the cored trees for future reference (e.g., Core-1, Core-2, etc.).

To give accurate ring widths, take the core on the <u>north-facing side of the tree</u> (if deformed, core the stem outside the deformed area) and at an angle to the stem axis to allow for an easy reading. If the tree has a definite lean, core from the upper side.

Take the core at 30 cm above the ground - just above the swelling (butt swell) where the roots originate. Insert the bit of the increment borer in the handle and remove the extractor. Punch the bit through the bark and turn it gently until the end is beyond the centre of the tree. Insert the extractor, lifting it slightly to make sure it goes under the core, and then back off the borer about one turn to break contact between the core and the tree tissue. The notch on the extractor should be up so that if the core breaks, it will still rest in the extractor. Pull out the extractor with the core.

Carefully transfer a core into a milk shake drinking straw, and seal the ends (alternatively place the straw in a Ziploc bag). Use permanent marker to label each core (record core number, e.g., Core-1, species, plot number, and date).

Count the rings in the core samples in the lab (use microscope or a good loupe), and record determined ages.

Tree Status

Note the condition or status of all tagged trees in the quadrat. Record observations on the data sheet using the following symbols:

Standing alive (AS)	Standing dead (DS)
Broken alive (AB)	Broken dead (DB)
Leaning alive (AL)	Leaning dead (DL)
Fallen/prone alive (AF)	Fallen/prone dead (DF)
Standing alive dead top (AD)	

Use Figure 6 for guidance.

Figure 6. Tree status.

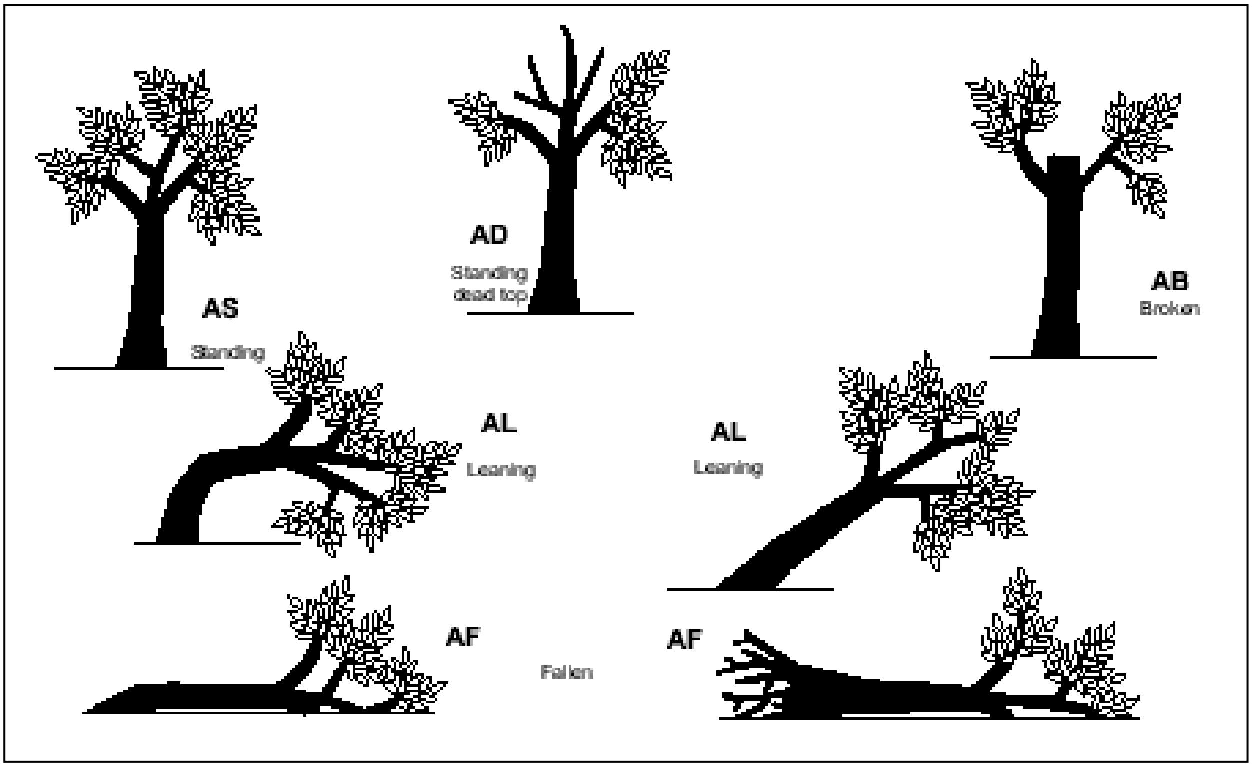
At each subsequent re-measurement period, record the condition of all tagged trees (alive or dead) that have fallen since the first data were collected. In addition, measure the length, diameter and orientation of all tagged fallen dead trees.

When re-assessing the plot on the next visit (e.g. after a five year interval):

- Look for missing tags or numbers. While tags and numbers do not normally "fall" off of trees, time, wind, wildlife, and vandalism can all contribute to tag or number loss. Where metal tags have been used, search the forest floor in the vicinity of any tree missing its tag.
- Repaint any "out" trees near the growth plot border if the paint is fading
- Repaint any dead trees that are tagged and standing if the paint is fading

In-Growth Trees

Crews must look for in-growth during visits. These are trees that were non-existent or too small



during the last visit to be assessed but have since grown to meet minimum requirements for inclusion in the assessment. Only trees with DBH equal to 10 cm or greater will be assessed.

Every effort should be made to number in-growth by continuing from where the sequence ended during the last measure. It is very important, however, to ensure that every tree number is unique for the growth plot. Never recycle tree numbers, even when a tree dies and falls down.

Missed Trees

If a crew finds a tree that was clearly large enough during the last measure to be sampled but it was not included for any reason, it must be recorded as a missed tree, and marked and numbered. As with in-growth trees, missed trees should be numbered by continuing from where the sequence ended during the last measure, ensuring that the number used is unique for the growth plot.

Plot monitoring

A team of four might be able to establish and survey one plot on the same day. However, a team of two will likely need an extra visit to survey the plot. Plots shall be surveyed every fifth year.

Crown condition assessment

1. Evaluate each tree for Crown Class.

Two observers rate each tree, simultaneously, from opposite sides of the tree. Good communication between the observers will result in more accurate data being collected. The observers walk around under the crown of the tree until they find the location from which they have the best, unobstructed view.

2. Record Stem Damage. The entire stem of all trees in the plot greater than 10 cm in diameter are examined for the presence of biotic or abiotic damage (see Appendix 1 for definitions). The location and type of the defects are recorded on the Crown Condition data sheet (Appendix 3).

Regeneration and sapling survey

Count the number of each species within the 2 x 2 m regeneration quadrats, and use the measuring stick to categorize each individual into 16-35cm, 36-55cm, 56-75cm, 76-95cm, 96-200cm, and >200cm height classes.

Seedling:
Height class 1 = 16-35 cm
Height class 2 = 36-55 cm
Height class 3 = 56-75 cm
Height class 4 = 76-95 cm
Height class 5 = 96-200 cm

Sapling = >200 cm in height and <10cm DBH.

Downed Woody Debris

Survey a transect following two edges of the 20 x 20 meter forest plot (A to B, and then B to C), and then an additional 5.14 m (on the line C-D) in order to make a 45.14m transect.

Record species, type of debris (log/stump), diameter (where possible) and log decomposition class for every piece of downed woody debris that intersects the transect and has a diameter of 7.5cm or greater at the point of intersection (see Appendix 2 for log decomposition class definitions). If you cannot identify the species, record a “0”. If a single piece of woody debris crosses a down woody debris line in more than one place, or more than one down woody debris line, assess each crossing that meets the criteria as if they were a different and independent piece.

Record the location of the downed woody debris along the transect line.