CLIMATE-CHANGE VULNERABILITY ASSESSMENT FOR SELECTED SPECIES IN THREE NATIONAL PARKS IN EASTERN CANADA

by

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Abstract

Canadian protected areas have been established with a premise of static distributions of different ecosystems, an assumption invalidated by climate change. In the Maritimes, there are few local case studies on how to consider and manage protected areas with potentially vulnerable ecosystems. Assuming two climate-change scenarios in the 2080s, we conducted climate-change vulnerability assessments (CCVAs) for a range of species in three national parks as case studies in the face of climate change. Specifically, we had two main goals: (1) to conduct CCVAs, including NatureServe's climate change vulnerability index, for terrestrial species in these areas, and (2) to explore adaptation opportunities. Our study then identified some of the most vulnerable species (e.g., American marten and brook trout) but also species that are adaptable to climate change. Identification of species' vulnerability to a changing climate is the first step in trying to identify potential adaptation opportunities for these species.

List of abbreviations used

CCVI: Climate Change Vulnerability Index

GDD: Growing-Degree Days

MVA: Modified Vulnerability Assessment

RCP: Representative Concentration Pathways

SRES: Special Report on Emissions Scenarios

CCVA: Climate Change Vulnerability Assessment

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Chapter 1. Introduction

(1) Background

Biodiversity and climate change

Biodiversity has been threatened due to various anthropogenic stressors. UNEP (2005) raised the following factors as key drivers changing ecosystems: increasing demands for ecosystem services, increasing pollution and waste, global trade and alien species, changing land use/cover, and changing climate. Sala et al. (2000) developed global scenarios of biodiversity in 2100 with various possible changes (e.g., changes in climate, land use, nitrogen deposition, and atmospheric CO_2 concentration) to rank their importance. As a result, although land use was the first key driver to change biodiversity globally, climate change was the most influential in arctic, alpine, and boreal ecosystems.

The latest full report of the Intergovernmental Panel on Climate Change (IPCC 2013) documented that the mean temperature of the Earth's surface increased by 0.89 °C between 1901 and 2012. Furthermore, the temperature may increase by 1.0-3.7 °C in 2081-2100 in comparison with 1986-2005 (IPCC 2013). A number of studies have reported that climate change has already had negative impacts on forest plant species, with elevated mortality and declining reproduction leading to regional decline and dieback events (Allen 2009; Jump et al. 2009). Moreover, climate change-induced modifications of frequency and intensity of forest fires, outbreaks of insects and pathogens, and strong winds are all considered to be more serious than the direct impact of higher temperatures and elevated CO_2 (Kirilenko and Sedjo 2007). According to Milad et al. (2011), however, the impacts can be both positive and negative on forests, depending on forest types, tree species, and/or regions. In the current thesis, positive and negative impacts of climate change on species/ecosystems are defined as the impacts of climate change that contribute to growth and decline of species/ecosystems. Note that some of the positive impacts, like the impacts leading to outbreaks of pathogens, could be negative from our socio-economic viewpoint. Indeed, temperature increase can be positive for thermophilic species of insects and pathogens, allowing them to expand their distributions (Milad et al. 2011). Disturbing ecosystems by climate change could also contribute to spreading pathogens as well as disease vectors (Dudley et al. 2010).

How to use protected areas to adapt to climate change

Considering its serious impact, many researchers have called for immediate actions against climate change (e.g., Stern 2006). To conserve biodiversity in the face of climate change, many researchers have given similar ideas focusing on adaptation. Hannah et al. (2002) advocated climate-change-integrated conservation strategies (CCS) centred on using protected areas, consisting of the following steps: (i) predicting ecological responses to climate change at regional scales, (ii) designing protected areas to protect biodiversity from the impacts of climate change, (iii) managing biodiversity around established protected areas, and (iv) coordinating such management at both regional and international levels. Because many species will change their distributions broadly under changing climates, consistent management of these species by multiple protected areas, regions, and/or countries may be necessary.

Hannah et al. (2007) and Araújo et al. (2011) assessed the necessity and effectiveness of protected areas in response to climate change by modelling species' range shifts in several sites. They found that protected areas in Europe were more effective at maintaining suitable habitats for species than were unprotected areas, likely because many protected areas are located in mountains, which can function as refugia for species under climate change (Araújo et al. 2011). Mawdsley et al. (2009) described 16 adaptation strategies, ranging from abiotic resource management, direct species management, monitoring and planning, and law and policy (Fig. 1.1). Commonly, these studies have regarded protected areas as the most crucial core for their strategies.

Regardless of the issue of climate change, protected areas can prevent or mitigate negative factors on wild species, increasing the likelihood of their survival (Margules and Pressey 2000). In other words, protected areas can diminish non-climatic factors and hence contribute to persistence of biodiversity even under climatic threats. Recently, specific methods of designing protected areas for persistence under a changing climate have been proposed (e.g., Beier and Brost 2010). Furthermore, linking multiple protected areas, known as connectivity, is meaningful because it allows species to move among different latitudes/elevations more freely and potentially avoid local extinction (Dobson et al. 1999). Hannah (2008) articulated the importance of protected area networks including connectivity as well as their spatially/temporarily flexible designs. Heller and Zavaleta (2009) collected 524 recommendations from 113 previous studies, finding that increasing connectivity was the most common recommendation globally for climate-change adaptation (Table 1.1). Groves et al. (2012) proposed five adaptation measures that were robust, regardless of actual climate change: (i) conserving the geophysical stage, (ii) protecting climatic refugia, (iii) increasing connectivity between habitats, (iv) protecting ecosystem processes and multiple functions (ecosystem service), and (v) capitalizing on conservation opportunities in response to climate change (e.g., REDD: Reducing Emissions from Deforestation and Forest Degradation).

In addition, according to Hannah (2008), assisted migration and/or *ex situ* protection (e.g., captive breeding) are helpful methods when climate change is so rapid that protected areas alone cannot address the negative influences on wild species. Likewise, Shoo et al. (2013) proposed a decision-making process about how to prioritize vulnerable species and measures to protect them. In their process, assisted migration at a genetic level has also been proposed as “genetic assisted colonization”, where certain genetic materials (e.g., alleles adaptive to a new climate) are introduced to wild populations artificially (Shoo et al., 2013).

Previous efforts to adapt to climate change in northern forested protected areas

Scott and Suffling (2000), Scott et al. (2002), and Suffling and Scott (2002) projected changes of temperature as well as precipitation due to doubled and tripled CO_2 concentrations in each Canadian national park. Lemieux and Scott (2005) conducted similar assessments for 2,979 Canadian protected areas including not only national parks but also provincial parks, national wildlife areas, etc. They then found that temperature increase would be pronounced during winter and that precipitation increase would be also observed in winter in most parks, concluding that northern biomes (tundra, taiga and boreal conifer forest) in particular would disappear.

Canadian protected areas have been established with a premise of static distributions of different ecosystems across Canada. This assumption will be invalidated by climate change (Scott et al. 2002; Suffling and Scott 2002; Lemieux and Scott 2005). Protected areas managers have four options in the face of climate change: (i) static management that keeps conventional goals and management that assume no impacts of climate change, (ii) passive management (*laissez faire* approach) that allows any changes caused by climate change, (iii) adaptive management to respond to climate change, and (iv) hybrid management (Suffling and Scott 2002; Scott and Lemieux 2005). The first option is just to keep initial conditions of protected areas, including species compositions and landscape beauty. For instance, if some new species invade from warm regions under climate change and they are devastating for native species, the first option will remove such harmful invasive species. In contrast, the second option allows such invasions into protected areas. The researchers proposed that the third option, adaptive management, would be the most effective, efficient and thus wise way to protect biotic legacies. It was defined as management that

> Maximise the capacity of species and ecological communities to adapt to climate change through active management (e.g., fire suppression, species translocation, invasive species suppression) (Suffling and Scott 2002: p132).

In other words, the third option is active and pro-active management. These efforts could possibly change species compositions and/or landscape beauty in part, but still they may be effective to minimize negative impacts of climate change on what society values. The last option is any combination of two of the three options.

Spittlehouse and Stewart (2004) proposed a framework for adaptation in Canadian forest ecosystems consisting of four steps: (i) defining the issue, (ii) evaluating the vulnerability to climate change, (iii) developing adaptation measures to be taken immediately, and (iv) developing future adaptation measures. The cited study then described the examples of applying this framework for both timber production and management of protected areas. Scott and Lemieux (2005) offered adaptation portfolios for protected areas consisting of system planning, management, research, and monitoring together with capacity-building and raising awareness. Similarly, Welch (2005) proposed five actions that should be taken immediately: raising public awareness, showing examples of environmentally friendly actions, active ecosystem management such as removing non-climatic stresses and redesigning park boundaries, research and monitoring. As well, CCFM (2009) and Gauthier et al. (2014) proposed some management options against climate change to protect commercial forests in Canada: reforestation and assisted migration, conservation of genetic variability, maintenance of species productivity, maintenance of forest health, and promotion of adaptive capacity.

In response to the aforementioned suggestions and ideas, climate change has been already considered in some conservation designs and activities. According to Nantel et al. (2014), some protected areas in Canada have been designed or expanded in consideration of climate change adaptation (e.g., Nahanni National Park Reserve and the Nááts'ihch'oh National Park Reserve). Canada also began addressing the issue of habitat connectivity to allow species to migrate under changing climates (e.g., protection of Chignecto Isthmus as well as the Ontario Ministry of Natural Resources 50 Million Tree program in Ontario) (Nantel et al. 2014). Moreover, short-distance assisted migrations have become common.

In Alberta, for instance, seed transfer zones were extended by up to 200 m in altitude and up to 2° north latitude, while British Columbia also allows upward seed/seedling transfers by 200 m (Nantel et al. 2014).

Challenges and problems of previous suggestions

There are various challenges in applying the aforementioned suggestions and ideas in the previous subsections (e.g., Suffling and Scott 2002; Scott and Lemieux 2005) to conservation and management. Some of them can be attributed to misunderstandings or poor knowledge about climate change among policymakers, managers, and conservation biologists. Lynch et al. (2008) suggested that the issue of climate change was misunderstood as just a global problem but that many adaptation measures are addressable at regional scales as well. Also, they proposed that measures against climate change were mistakenly regarded as special interests among policymakers, though in reality many adaptation measures can also offer benefits for non-climatic conservation issues. Consequently, although climate change is now taken into account for broad-scale conservation designs and rules, as aforementioned by Nantel et al. (2014), it is still often ignored or neglected in small-scale conservation in each protected area.

Although the degrees and/or manners of climate change are still uncertain, identifying adaptation strategies should be done as early as possible (Lemieux and Scott 2005; Scott and Lemieux 2005; Heller and Zavaleta, 2009). Scott and Lemieux (2005) pointed out that *laissez-faire* approaches would be ineffective and inefficient, possibly bringing about irreversible and serious impacts of climate change. In accordance with this, Welch (2005) called for considering adaptation strategies for Canadian national parks, because these parks already have some useful and available information. He also suggested that little has been provided as to practical guidance for managers of protected areas. A questionnaire survey revealed that Canadian protected area agencies especially wanted information on ecological consequences of climate change as well as strategies for climate change adaptation (Lemieux et al. 2011).

To respond to these challenges, climate change vulnerability assessments (CCVAs) have been developed. CCVAs for species/ecosystems can tell us the following two pieces of information: (i) which species/ecosystems are most likely to be influenced by climate change, and (ii) why they are so vulnerable (Glick et al. 2011; Pacifici et al. 2015; see the following chapters for details). Understanding reasons for species' vulnerability leads to identifying adaptation strategies.

However, *laissez-faire* approaches might be better than the other approaches, depending on the final goals of protected areas. A challenge in taking adaptation measures is to figure out what those societal values are (Suffling and Scott 2002). Someone may value specific species, while others might value landscape beauty and/or ecological functions (e.g., watershed conservation). Also, adaptation measures that interfere with habitats and ecosystems may have serious shortcomings (e.g., limited effectiveness, side effects, expensive costs). Therefore, besides CCVAs, it is crucial for each protected area to examine which option is the best among the four choices suggested by Suffling and Scott (2002) and Scott and Lemieux (2005).

(2) Research objectives

This study conducted climate-change vulnerability assessments for three forested protected areas in Nova Scotia and New Brunswick in Canada as case studies in the face of climate change. Specifically, we had three main goals:

(1) Conduct CCVAs for terrestrial species in these areas,
    · to compare the vulnerability of some species across the three protected areas
    · to describe the main features (strength or weakness) of each park in the context of climate change
(2) Explore adaptation opportunities,
    · to suggest adaptation opportunities for vulnerable species in each park,
    · to discuss possible roles of the parks in a more global context (i.e., for *ex-situ* conservation of vulnerable species from other parks); and,
(3) Discuss major technical challenges of previous CCVAs and to contribute to improving them (i.e., suggesting a modified method),
    · to compare species' vulnerability between a previous CCVA method (NatureServe's Climate Change Vulnerability Index) vs. a modified CCVA method (reasoned argumentation through the lens of the index).

All these goals are important in different respects. The first and second goals would be important for practical management and conservation in the three targeted protected areas, where similar CCVAs with comprehensive sets of species have not been performed. The second goal would be important even in the sense that most previous studies conducting CCVAs ended up just assessing species' vulnerability and did not discuss possible adaptation measures for vulnerable species. Even though we have limited scientific data and evidence to support each idea, figuring out ideas of adaptation measures is crucial for the future. The final goal is technically helpful for improving some species ranking systems, because addressing it sheds light on a couple of common challenges in many species ranking systems.

In the thesis, the second chapter introduces the background to CCVAs, while the third chapter outlines methods of our study. The fourth chapter presents the results of CCVAs in the three protected areas, exploring possible adaptation measures. Chapter 5 focuses on technical contrasts between a previous CCVA method vs. a modified CCVA method developed during our research. The sixth chapter then discusses the findings and draws conclusions from our study as a whole.

Table 1.1. List of recommendations for climate-change adaptation strategies for biodiversity management assembled by Heller and Zavaleta (2009) from 112 scholarly articles; 524 records were condensed into 113 recommendation categories and are ranked by frequency of times cited in different articles.

Rank/Recommendation	Number of articles
1. Increase connectivity (design corridors, remove barriers for dispersal, locate reserves close to each other, reforestation)	24
2. Integrate climate change into planning exercises (reserves, pest outbreaks, harvest schedules, grazing limits, incentive programs)	19
3. Mitigate other threats, e.g. invasive species, fragmentation, pollution	17
4. Study response of species to climate change-physiological, behavioural, demographic	15
4. Practice intensive management to secure populations	15
4. Translocate species	15
5. Increase number of reserves	13
6. Address scale problems to match modeling, management, and experimental spatial scales for improved predictive capacity	12
6. Improve inter-agency, regional coordination	12
7. Increase and maintain basic monitoring programs	11
7. Practice adaptive management	11
7. Protect large areas, increase reserve size	11
8. Create and manage buffer zones around reserves	10

Recommendations whose ranks were lower than eight were omitted.

Fig. 1.1. Climate-change adaptation strategies for wildlife management and biodiversity conservation (Mawdsley et al. 2009).

1. Increase extent of protected areas
2. Improve representation and replication within protected-area networks
3. Improve management and restoration of existing protected areas to facilitate resilience
4. Design new natural areas and restoration sites to maximize resilience
5. Protect movement corridors, stepping stones, and refugia
6. Manage and restore ecosystem function rather than focusing on specific components (species or assemblages)
7. Improve the matrix by increasing landscape permeability to species movement
8. Focus conservation resources on species that might become extinct
9. Translocate species at risk of extinction
10. Establish captive populations of species that would otherwise go extinct
11. Reduce pressures on species from sources other than climate change
12. Evaluate and enhance monitoring programs for wildlife and ecosystems
13. Incorporate predicted climate-change impacts on species and land-management plans, programs, and activities
14. Develop dynamic landscape conservation plans
15. Ensure wildlife and biodiversity needs are considered as part of the broader societal adaptation process
16. Review and modify existing laws, regulations, and policies regarding wildlife and natural resource management

Chapter 2. Background to climate change vulnerability assessment

(1) History of climate change vulnerability assessment

Climate change vulnerability assessment (CCVA) was proposed based on the concept of vulnerability, which is defined as

> the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC 2007, p883).

Historically, CCVA has evolved from “impact assessment”, aimed at finding mitigation measures, to “adaptation policy assessment”, aimed at finding adaptation measures (Füssel and Klein 2006). In the following, CCVA refers to the latter type, because our study explored adaptation measures, which control and reduce negative impacts of climate change on our environments without decreasing GHG emissions. Regardless of targets, however, basically CCVA consists of the following five steps: (i) defining assessment targets by reviewing previous relevant literature/plans etc., (ii) clarifying how and what components are vulnerable, (iii) assessing the degrees of vulnerability of chosen components to the current climate as well as socio-economic conditions, (iv) assessing the degrees of vulnerability to future change, and (v) relating the outputs from the previous four steps to adaptation policies (Downing and Patwardhan 2005).

There are a number of CCVA methods, and some guidelines have been published. For instance, CCVA has already been introduced as part of environmental impact assessments in some countries, trying to mitigate vulnerability of new projects to climate change (e.g., CCCEAC 2003). Subsequently, this method was modified to be applicable to a range of natural resources and ecosystem types. Essentially, CCVA for species/ecosystems can tell us the following two pieces of information: (i) which species/ecosystems are most likely to be influenced by climate change, and (ii) why they are so vulnerable (Glick et al. 2011). Final goals of such CCVAs are to allow managers to improve priorities for conservation action and to help them develop appropriate management and conservation actions in response to climate change (Glick et al. 2011; Pacifici et al. 2015).

Typical CCVAs differentiate vulnerability into several components, such as exposure, sensitivity and adaptive capacity, and assess these components separately (Williams et al. 2008; Glick et al. 2011; Gauthier et al. 2014). Here, exposure means the degree to which climate change takes place in certain species/systems' ranges (Williams et al. 2008). Sensitivity means the degrees to which certain species/systems are likely to be influenced by a changing climate, being determined by intrinsic biological characteristics like life-history traits (Glick et al. 2011). Finally, adaptive capacity is the ability of species/systems to cope with climate change, like plasticity or dispersal ability (Glick et al. 2011).

Examples of CCVAs:

i) Herman and Scott (1994) developed a scoring method for vertebrate species to assess sensitivity to climate change in Nova Scotia. They assumed nine geophysical consequences of climate change, like reduced summer soil moisture, and assessed sensitivity of the species to these nine.

ii) Chin et al. (2010) assessed vulnerability of sharks and rays to climate change in Australia's Great Barrier Reef by scoring their exposure, sensitivity, and rigidity with a component integration matrix. Herein, assessing rigidity is essentially the same as evaluating adaptive capacity, highlighting its negative aspect. The end result of Chin et al.'s (2010) approach is *high*, *moderate*, or *low* vulnerability.

iii) Young et al. (2011) developed a Climate Change Vulnerability Index (CCVI), which is evaluated by both the degrees of exposure and sensitivity based on species' traits. To do so, assessors answer up to 24 questions by choosing one or multiple factor values in each question (subfactor). Finally a calculated index is assigned to one of five categorical variables, which they call "index scores", such as "Extremely Vulnerable (EV)" or "Highly Vulnerable (HV)". The final goal of the CCVI is to increase the resilience of species to climate change by helping land managers develop and prioritize conservation strategies (Young et al. 2011).

iv) The System for Assessing Vulnerability of Species (SAVS) was developed by Bagne et al. (2011) for predicting species' responses to climate change. Like the CCVI, the SAVS assesses species' vulnerability through 22 criteria about species' habitat, physiology, phenology, and interspecific interactions. An overall vulnerability score is shown by the sum of positive scores (contribution to vulnerability) and negative scores (contribution to adaptability).

The main target of most CCVAs is the species rather than the ecosystem. On the other hand, the CCVI was expanded into the HCCVI (Habitat Climate Change Vulnerability Index), which can evaluate vulnerability of ecosystem/community to climate change (Comer et al. 2012). The final goal of the HCCVI is to offer stakeholders information for designing adaptation strategies, and output of the HCCVI is given at a four-level series of scores, *Very High*, *High*, *Moderate*, or *Low* vulnerability (Comer et al. 2012).

Recently, the CCVI has emerged as the dominant approach (e.g., Byers and Norris 2011; Dubois et al. 2011; Schlesinger et al. 2011; Brinker and Jones 2012; Shank et al. 2012; Ring et al. 2013; Pacifici et al. 2015). The CCVI has also been used in at least ten jurisdictions in the United States up to 2012 (Brinker and Jones 2012). It has been used to evaluate vulnerability of more than 1,700 species in the same country (Wright et al. 2015). In contrast, the HCCVI has been used by few researchers.

Regardless, no CCVA method is perfect (Pacifici et al. 2015). For instance, the CCVI takes into account effects of intra-population genetic variation on species' vulnerability, while the SAVS does not do so. In contrast, species that have temperature-dependent sex determination are judged to be more vulnerable to climate change than other species by the SAVS, but not the CCVI. Rannow et al. (2014) pointed out that CCVAs are still being developed. Acknowledging the value of currently available CCVAs, they emphasized the importance of accumulating trial case studies and repeating gradual improvements of such techniques.

As well, some of these CCVAs, such as the CCVI and the SAVS, do not consider species' demographic factors that could possible lead to extinction, such as population size and range size (Bagne et al. 2011; Young et al. 2011). Thus, users of the CCVI and SAVS are expected to consult species' general status or other ranks simultaneously to understand species' futures comprehensively.

(2) Other alternatives to CCVAs

Historically, one of the common ways to predict species' responses to climate change has been map-based simulations, which are often called species distribution models (SDMs) including a bioclimatic envelope model and an ecological niche model (Araújo and Peterson 2012). These models assume that current species' distributions are at equilibrium conditions determined by climate and predict future species' distributions based on projected climate-change scenarios (Araújo and Peterson 2012). For instance, MaxEnt (Maximum Entropy) is a popular method to predict future species' distributions by GIS using just presence-only species data (Elith et al. 2011). Vulnerability of 171 plant species in Mt. Lofty Ranges region in South Australia was assessed with this approach, and subsequently areas that should be protected were specified (Crossman et al. 2012). Such map-based approaches can reflect spatial heterogeneity precisely without the subjectivity of researchers' perceptions. However, they may still be imperfect. Map-based simulations are so precise that small changes in preconditions (e.g., climate-change scenarios and global climate models) could influence final outputs of the simulations (Wright et al. 2015). In other words, such approaches are hyper-sensitive to assumptions and simulation modes. Although many SDM studies predicted boreal tree species would move northwards and/or experience local extinction at fast speeds (in several decades or hundred years), in reality such changes will take much more time (from several hundreds to thousand years) (Loehle 2014). In this regard, such approaches tend to exaggerate responses of the tree species to climate change. As well, generally such spatial analyses do not take into account interspecific interactions and relevant factors.

Meanwhile, other simulation approaches have been proposed. For example, Steenberg et al. (2011) simulated likely changes of forested watersheds in Halifax in Canada (biomass change and species' presence change) under a warming climate scenario assuming three different harvesting approaches. Boreal species and late-successional species were then considered to be threatened, though harvesting measures could somewhat alter decline rates of these species (Steenberg et al. 2011). As well, Steenberg et al. (2013) addressed the combined effect of timber harvest and climate change on these forests using a simulation approach. Under a drastic climate change with no timber harvest, balsam fir and black spruce in particular were forecast to decline remarkably. In contrast, red maple and white pine were predicted to increase in the landscape. If timber harvest is also assumed in addition to a warming climate, then declines of some other mid-/late- successional species would be concerning (e.g., red spruce, and yellow birch) (Steenberg et al. 2013). Yet, Steenberg et al. (2011 and 2013) noted that they could not consider climate-change impacts on disturbance regimes and also that they assumed just one climate-change scenario, the SRES-A2 scenario.

Qualitative studies about future species' responses to climate change are conducted by not only literature review but also by interviews and workshops. For instance, Gomer (1999) explored species' sensitivity to climate change in Kejimkujik National Park by consulting the park's experts. According to her result, populations of red maple, poplar, grey squirrel, and brown-headed cowbird were supposed to grow under a warming scenario. Red spruce, striped maple, sugar maple, hemlock, American beech, several disjunct coastal plain plants, and American marten were identified, in contrast, as being threatened by climate change. Furthermore, exotic and pest species that were armed with high adaptability and ability to expand rapidly were judged to increase under future climate change (Gomer 1999). After activities including workshops over five years, C-CIARN (2007) finally proposed that Atlantic Canada could be characterized with long coastlines, exposure to extreme weather events, vulnerable communities and infrastructure (e.g., transportation in lowlands), and many resource-dependent communities (e.g., forestry communities). All these characteristics may make this region vulnerable to climate change.

As well, scenario planning was conducted in a few case studies through expert consultation. Fisichelli et al. (2013) developed future scenarios of forests and wolf and moose populations in Isle Royale National Park in the United States by holding a workshop, while assuming four climate-change scenarios. In the Landes region of south-western France, Mora et al. (2014) conducted scenario planning using expert panels and interviews to understand adaptation measures of forestry in this region. Cross et al. (2012) introduced a framework of Adaptation for Conservation Targets (ACT). This method consists of making conceptual diagrams between causes and effects, consulting experts (including stakeholders), and prioritizing adaptation options in consideration of socio-economic constraints (Cross et al. 2012). They then applied this framework to five cases in the southwestern United States (Cross et al. 2012; 2013).

All the methods described above, such as map-based predictions and scenario planning, are included in CCVAs in a broad sense. However, some researchers of the methods may use them without being aware of this fact. Furthermore, complementary approaches of CCVAs are gradually becoming more popular nowadays. For instance, Goff and Bergeron (2014) conducted both literature-based CCVA and expert-based CCVA for three ecosystem-based forest management projects in Quebec. Interestingly, they consulted not only experts but also resource persons who were responsible for the CCVA. As a whole, literature-based CCVA showed possible vulnerability and adaptation opportunity more exhaustively than expert-based CCVA, while resource persons mentioned other vulnerability and/or opportunity in terms of socio-economic aspects. Furthermore, Hameed et al. (2013) proposed a similar combination, "a multifaceted CCVA", which consisted of expert judgment, map-based predictions of vegetation, and geophysical properties and species-level CCVA (using Young et al.'s (2011) index). However, such expert-opinion-based CCVAs have rarely documented rationales and backgrounds of each expert's opinion in detail. Therefore, although expert-opinion-based CCVAs could cover vulnerability-related factors, which have rarely been documented in the literature, it is often difficult for other persons to understand their thinking processes (i.e., why each expert judged a species vulnerable or not vulnerable). Even expert opinions are subjective, but we cannot examine such possibilities without reading/listening to sufficient rationales.

Chapter 3. Methods

(1) Study areas and species

Three protected areas in the Maritime region of Canada were targeted in our study: Kejimkujik National Park and National Historic Site of Canada (hereafter Kejimkujik National Park); Cape Breton Highlands National Park of Canada (hereafter Cape Breton Highlands National Park); and Fundy National Park of Canada (hereafter Fundy National Park). CCVAs with exhaustive sets of species have never been conducted in these parks (but see Gomer (1999)). Although they are located in the same Maritime region, they have some unique biogeophysical features respectively (see later for detail). Thus, studying them enabled us to undertake an interesting comparison in terms of species' vulnerability to climate change. All these protected areas are managed by Parks Canada, whose mandate is as follows.

> On behalf of the people of Canada, we protect and present nationally significant examples of Canada's natural and cultural heritage, and foster public understanding, appreciation and enjoyment in ways that ensure the ecological and commemorative integrity of these places for present and future generations (Parks Canada 2011a).

However, ecological integrity is particularly important to sustain in national parks (Parks Canada, 2000). Ecological integrity is defined as follows:

> A condition that is determined to be characteristic of its natural region and likely to persist, including abiotic components and the composition and abundance of native species and biological communities, rates of change and supporting processes. (Canada National Parks Act, Article 2(1))

National parks have different geophysical conditions and/or aims. In the next four paragraphs, we briefly introduce the three protected areas for this study based on key aspects of their management plans (Parks Canada 2010a; 2010b; 2011b).

Kejimkujik National Park

According to Parks Canada (2010a), Kejimkujik National Park was designated in 1974, and Kejimkujik Seaside area was added to this park in 1988. Furthermore, the inland area of this park was designated as a National Historic Site in 1995. In this respect, this protected area has a dual designation, protecting both ecological and commemorative integrities. The inland area is 381 km^2, whereas the seaside area is 22 km^2. The provincial Tobeatic Wilderness Area is adjacent to this national park, thereby comprising the largest contiguous protected area in the Maritimes. This area also functions as a core site of the UNESCO Southwest Nova Scotia Biosphere Reserve (Parks Canada 2010a). From an ecological viewpoint, the forests are Acadian, which are a mixture of southern deciduous forests and northern coniferous forests (Loo and Ives 2003). White pine and red oak have been heavily deforested within the park in the past (Parks Canada 2010a). There are 46 lakes and 30 streams, with cold-tolerant fish species (e.g., brook trout).

Cape Breton Highlands National Park

Cape Breton Highlands National Park was established in 1936, covering 950 km^2 (Parks Canada 2010b). Near this park, there are multiple provincial wilderness areas protecting the Northern Cape Breton region. This region harbours Acadian, boreal forests, and Taiga ecosystems. As well, wetland and coastal ecosystems are included in the park. Among these, the boreal ecosystem is the most predominant component, corresponding to half of the area of the park. Additionally, a wide range of elevations has accommodated both northern species and temperate species. Parks Canada (2010b) mentioned improving the condition of forest ecosystems by controlling the number of moose and developing a fire management plan as future action plans.

Fundy National Park

According to Parks Canada (2011b), Fundy National Park was designated in 1948, and is located in southern New Brunswick adjacent the Bay of Fundy. It covers 206 km^2 of the Fundy Coast (20%) and Southern Uplands (80%) ecoregions. This park has been designated as the core site of the UNESCO Fundy Biosphere Reserve since 2007 (Parks Canada 2011b). The park includes multiple types of forests in the Southern Uplands ecoregion, though most of the forests are covered with young, regenerating trees due to previous logging (Parks Canada 2011b). The main tree species are red spruce and balsam fir. There are 111 wetlands in the park, functioning as biodiversity hotspots. Aquatic ecosystems are the most prioritized challenge for restoring ecological integrity in the park, such as restoration of the Bay of Fundy population of Atlantic salmon and populations of the American eel (Parks Canada 2011b).

In terms of climate, there are some southern relic populations since the Hypsi-thermal period, due to a warm condition in Kejimkujik National Park (e.g., southern flying squirrel; Lavers 2004; Petersen and Stewart 2006). Clayden et al. (2011) documented that the interior of southern Nova Scotia is one of the warmest regions in Eastern Canada with ample precipitation in summer. In contrast, Cape Breton Highlands National Park is situated at a latitudinally and elevationally high position, therefore in a relatively cool condition. Coastal fog in combination with a local cooling effect from the Bay of Fundy have created local refugia for some species (e.g., red spruce) around Fundy National Park during the mid-Holecene, and even now such microclimates maintain distinctive forest vegetation (Cox et al. 1996; Schauffler and Jacobson 2002; Clayden et al. 2011). Details of current and future climates in the park are mentioned in Chapter 4 (and Appendices 4.3-4.10).

Identifying target species

To conduct CCVAs for species that are important in terms of park management, species of trees, mammals, birds and freshwater fish mentioned in management plans of each national park were extracted. However, the plans do not necessarily cover all the important species. Relatively many tree and bird species were documented in the management plans, while few mammal species were mentioned. To supplement this imbalance, mammal species mentioned on official websites of each park were also selected (Parks Canada 2012). This is because only a few mammal species were highlighted in the management plans despite the fact that some mammals are important as top-level predators and herbivores in ecosystems (Terborgh et al. 1999). As well, regardless of species documentation in the management plans, for every park we assessed vulnerability of all key tree species of Acadian forests that were listed in Table 2 of Steenberg et al. (2013) and documented in any of the three park management plans. This is because Steenberg et al. (2013) showed data on suitable Growing Degree Days (GDD) for these species based on several sources, and such GDD data are helpful to understand vulnerability of tree species. In total, 31 species in Kejimkujik National Park, 43 species in Cape Breton Highlands National Park, and 39 species in Fundy National Park were targeted in the following assessment (Table 3.1.). Among them, vulnerability of 19 species were commonly assessed in all the three parks (Table 3.1.).

(2) NatureServe's climate change vulnerability index

Considering the popularity as well as the comprehensive frame of the CCVI developed by Young et al. (2011) (c.f., Chapter 2), we decided to employ it in our study. The CCVI looks at various aspects of the vulnerability of species and is widely used regardless of taxa (Brinker and Jones 2012; Anacker et al. 2013; Young et al. 2015) (Fig. 3.1; see also Appendix 4.12 in Chapter 4 for details). There are four categories of considerations for which assessors input information to the CCVI program (Young et al.

2011). Herein, category A represents exposure to local climate change, which is used as climate-change scenario information in the program. Assessors are supposed to choose one or multiple options from five given choices of thermal and hydrological changes respectively. Actual selections in the three parks are explained in the following chapter (Chapter 4). Category B (subfactors: B1-B3) represents indirect exposure to climate change, while category C (subfactors: C1-C6) is about species' sensitivity. Note that there are several subfactors (C4a-e) that consider vulnerability of associated species. Category D (subfactors: D1-D4) is about documented and/or modeled responses of assessed species to climate change (e.g., McKenney et al. 2007). The last category is optional in the program. When information for category D is available, the CCVI is calculated in consideration of such information.

To calculate the CCVI, Young et al.'s (2011) protocol gave examples of each factor value of each subfactor. In other words, assessors can compare these examples and available information on each of the assessed species to determine the most appropriate factor value(s) from GI (Greatly Increase Vulnerability), Inc (Increase Vulnerability), SI (Somewhat Increase Vulnerability), N (Neutral), SD (Somewhat Decrease Vulnerability), or Dec (Decrease Vulnerability). When choosing only one specific factor value is difficult, multiple values can be chosen.

Subscores are the product of multiplying categorical factor values (3.0, 2.0, 1.0, 0, -1.0, or -2.0) with exposure weighting (by temperature and/or moisture changes), and subsequently these subscores are summed to calculate the CCVI (Young et al., 2012). The program finally gives a vulnerability index, the CCVI, which is one of EV (Extremely Vulnerable), HV (Highly Vulnerable), MV (Moderately Vulnerable), PS (Not

Vulnerable/Presumed Stable), or IL (Increase Likely) (Table 3.2.). This calculation is done by discretizing continuous variables of the CCVI based on specific thresholds. The confidence of assessment results is also given by 1,000 iterations of a Monte Carlo simulation by using every marked factor value (Young et al., 2011). If an assessor assigns several values to each subfactor due to lack of definitive information, the simulation would judge a given result (the CCVI) highly uncertain.

Information about species' traits that are relevant to factors in the CCVI was then obtained from the following species sources: Roland (1945), Fowells (1965), Burzynski et al. (1986), Farrar (1995), Saunders (1996), and Hinds (2000) for plant species; Banfield (1976) and Feldhamer et al. (2003) for mammals; Godfrey (1986) and Erskine (1992) for bird species; and Livingstone (1951) and Scott (1967) for fish species.

As well, considering the importance of recent and/or local studies, we searched for relevant studies by using Google Scholar. We also consulted State of the Park and Site Reports of the three parks (Parks Canada 2010c; 2010d; 2011c) together with the forest ecosystem guideline for the Greater Fundy Ecosystem by Betts and Forbes (2005). Telfer (2004) as well as MTRI and Parks Canada (2014) were used to grasp recent changes in the main species in southwestern Nova Scotia.

In particular, subfactors for indirect exposure to climate change (B1, B2a, B2b, B3), some subfactors of species' sensitivity (C2ai, C2aii, C2bi, C2bii, C5a, C5b, C6), and subfactors about documented or modeled response to climate change (D1-D4) (see Appendix 4.12 in Chapter 4 for details) are location-specific. In contrast, the other subfactors (C1, C2c, C2d, C3, C4a, C4b, C4c, C4d, and C4e) are likely to be consistent across locations.

Consequently, the necessary information related to factors in the CCVA was collected from 6-25 references for each species (around 14 references on average). Assessments on the same species in different parks often consulted the same references, but sometimes we could find a few different references, which included local information as well. By doing so, the literature survey could cover almost all relevant documents to vulnerability of targeted species to climate change and took the information into the assessment.

Meanwhile, Master et al. (2012) developed several “NatureServe conservation status ranks” for evaluating such non-climatic extinction risk based on species’ rarity, threats, and trends. Therefore, Young et al. (2011) recommended consideration of two indexes, Global Conservation Status Rank (G-rank; Table 3.4.) as well as Subnational Conservation Status Rank (S-rank; Table 3.5.) to interpret results. In our study, we obtained general status ranks of the assessed species at two geographic scales (i.e., Canada and a specific province) from the Canadian wild species database (http://www.wildspecies.ca/home.cfm?lang=e), which tells us the general status of 21,352 species in and around 2010. Because of the large geographic extent of Canada and the Canadian provinces, ranks for Canada and each province were treated as ranks for global and subnational scales in our study. Hence, the obtained ranks from the database were converted into G-rank and S-rank respectively. Yet, these ranks were not directly incorporated into the CCVI calculation, and they were just references for interpreting the calculated CCVI.

(3) Modified vulnerability assessment

Although the CCVI and similar methods are popular, such methods may not always give robust conclusions about species' vulnerability for several reasons. A few studies that examined the effectiveness of the CCVI have reported that the CCVI produced different results from those of other CCVAs (Anacker et al. 2013; Lankford et al. 2014). Although these gaps are partly attributable to shortcomings of the other CCVAs, these studies also mentioned possibility of limitations of quantifying species' vulnerability by scoring methods. Furthermore, the CCVI was designed to emphasize the negative influences of climate change rather than the positive ones. Indeed, there are three available categories to show species' negative responses to climate change (EV, HV, and MV) but only one category to show species' positive responses to climate change (IL). Previous studies using the CCVI concluded that just a few of the assessed species could gain benefits from climate change (e.g., Byers and Norris 2011), but some of their conclusions may be due to the skewed assessment viewpoint of the CCVI. Warmer climates may be more favourable for species that suffer from severe winters, for instance (e.g., Garroway and Broders 2005). There are already many studies that have reported positive impacts of climate change on forest species (as reviewed by Milad et al. 2011).

To compensate for such shortcomings of the CCVI, we developed an alternative approach called the Modified Vulnerability Assessment (MVA). Herein, while avoiding quantifications, species' responses to climate change are determined again by qualitative reasoned argumentation through the lens of the subfactors of the CCVI. In other words, the viewpoints of the CCVI were taken into account in the MVA as well, because the CCVI covers most of the important aspects of species' responses to climate change.

However, each subfactor of the MVA has just five selectable scores, which include two negative scores, a neutral score, and two positive scores (Inc, SI, N, SD, Dec) so that negative and positive contributions of each subfactor to vulnerability could be equally considered and evaluated. Finally, collected insights could be expressed in five categorical classes that could describe both a decline and a flourishing of species (i.e., vulnerability and adaptability) equally (Table 3.6). Thus, the final output is given in this approach as HV (Highly Vulnerable), MV (Moderately Vulnerable), PS (Presumed Stable), MA (Moderately Adaptable), or HA (Highly Adaptable).

Importantly, rerating each factor value, which was previously rated by the CCVI assessment, in the MVA based on the modified style is not used for determining a final conclusion of the assessment. This is because the MVA has no calculation processes, and in this regard no factor values are used as numerical values. However, the rerated factor values are useful to clarify which subfactors are relevant to vulnerability/adaptability of each assessed species and also to clarify which values of the CCVI need to be revised. Rather than these factor values, rationales are more important for each assessment. These rationales should be documented in each assessment so that readers could understand how and which attributes contribute to the determination of a conclusion. However, determining a single class as each species' vulnerability/adaptability by qualitative thinking is still frequently difficult, and hence giving two mutually adjacent classes may be necessary in some cases. In other words, precise evaluation of species' vulnerability/adaptability might be difficult in the MVA, though it will still be useful for practical conservation and management.

In the thesis study, we used both the CCVI and the MVA to assess species' vulnerability to compensate for the shortcomings of each approach. Technical detail and comparison of them are elaborated in Chapter 5.

(4) Expert consultation

To assist in making assessments of the CCVI as well as the MVA, a one-day expert consultation meeting was held in each park in autumn 2014 (Tables 3.7 and 3.8). The consulted experts included mainly park staff from each national park but also a few external experts (Table 3.8). Each consultation meeting began with a brief explanation about our research, and then we decided which species we would discuss in each meeting. Thereafter, intensive discussion ensued about the vulnerability of a few species, and we also obtained some advice on adaptation opportunities of the vulnerable species. Because additional consultation with extra experts was suggested in the Kejimkujik consultation meeting, we also consulted additional experts by email or in person (Table 3.7).

All insights provided in these consultations were reflected in our assessments as well as suggestions of adaptation measures for specific species, unless the insights were judged by us to be inconsistent with the scoring system of the CCVI. For instance, because most of the consulted experts were not familiar with the CCVI protocol, occasionally they gave us suggestions of factor values without consideration of the nuances and requirements of the protocol. In such cases, we adjusted their suggestions so that scoring could be consistent with the protocol. All our responses (follow-up) to experts’ advice were documented in species-specific assessment sheets (electronic supplementary materials).

By conducting the same assessments for three parks, we tried to clarify unique features of each park in the context of climate change but also to explore what kind of adaptation measures could be considered for them (Chapter 4). As elaborated in Chapter 4, for this moment, identifying adaptation measures is still challenging due to insufficient scientific information. Thus, after all, we tried to discuss what kinds of research and work would be needed to identify the measures. Furthermore, based on comparison between the CCVI and the MVA results, we argued the importance of challenging algorithmic approaches as well as skewed viewpoints commonly seen in many species ranking systems including the CCVI (Chapter 5).

Table 3.1. Assessed species list by climate change vulnerability assessments in three national parks in the Maritime Provinces of Canada.

Taxon	Scientific name	English name	S-rank in park(s)*		
			K	C	F
Bird	*Ardea herodias herodias*	Great blue heron			S4S5
Bird	*Bonasa umbellus togata*	Ruffed grouse			S4S5
Bird	*Catharus bicknelli*	Bicknell's thrush		S1S2	
Bird	*Catharus guttatus faxoni*	Hermit thrush		S4S5	S4S5
Bird	*Chaetura pelagica*	Chimney swift		S1S2	
Bird	*Charadrius semipalmatus*	Semi-palmated plover			S4S5
Bird	*Contopus borealis/cooperi*	Olive-sided flycatcher		S1S2	
Bird	*Cyanocitta cristata bromia*	Blue jay		S4S5	
Bird	*Dendragapus/Falcipennis canadensis canace*	Spruce grouse		S4S5	
Bird	*Dryocopus pileatus abieticola*	Pileated wood-pecker			S4S5
Bird	*Euphagus carolinus nigrans*	Rusty blackbird	S2S3		
Bird	*Falco peregrinus anatum*	Peregrine falcon			S1S2
Bird	*Gavia immer*	Common loon	S2S3		
Bird	*Junco hyemalis hyemalis*	Dark-eyed junco			S4S5
Bird	*Loxia leucoptera*	White-winged crossbill			S4S5
Bird	*Parus/Poecile hudsonicus*	Boreal chickadee		S3S4	
Bird	*Perisoreus canadensis*	Gray jay		S3S4	
Bird	*Setophaga ruticilla*	American redstart		S4S5	
Bird	*Strix varia varia*	Eastern barred owl	S4S5		
Bird	*Tringa melanoleuca*	Greater yellowlegs		S3S4	
Bird	*Turdus migratorius migratorius*	American robin		S4S5	
Bird	*Vireo olivaceus*	Red-eyed vireo		S4S5	
Bird	*Wilsonia canadensis*	Canada warbler		S1S2	
Fish	*Ameiurus nebulosus*	Brown bullhead	S4S5		
Fish	*Anguilla rostrata*	American eel		S2S3	S4S5
Fish	*Morone americana*	White perch	S4S5		
Fish	*Perca flavescens*	Yellow perch	S4S5		
Fish	*Salmo salar*	Atlantic salmon		S2S3	S3S4
Fish	*Salvelinus fontinalis*	Brook trout	S3S4		S4S5
Mammal	*Alces alces*	American/Western moose	S1S2	S1S2	S4S5
Mammal	*Canis latrans*	Coyote	S4S5	S4S5	S4S5
Mammal	*Castor canadensis acadicus*	Beaver	S4S5		S4S5
Mammal	*Erethizon dorsatum dorsatum*	Porcupine	S4S5		
Mammal	*Glaucomys sabrinus gouldi*	Northern flying squirrel			S4S5
Mammal	*Glaucomys volans*	Southern flying squirrel	S3S4		
Mammal	*Lepus americanus struthopus*	Snowshoe hare		S4S5	S4S5

Taxon	Scientific name	English name	S-rank in park(s)*		
			K	C	F
Mammal	*Lynx canadensis*	Canada lynx		S1S2	S1S2
Mammal	*Lynx rufus gigas*	Bobcat		S4S5	
Mammal	*Martes americana americana*	American marten	S1S2	S1S2	S4S5
Mammal	*Martes pennanti*	Fisher	S3S4		
Mammal	*Myotis lucifugus lucifugus*	Little brown bat			S3S4
Mammal	*Odocoileus virginianus borealis*	white-tailed deer	S4S5	S4S5	S4S5
Mammal	*Peromyscus maniculatus abietorum*	Deer mouse		S4S5	
Mammal	*Procyon lotor lotor*	Raccoon			S4S5
Mammal	*Sorex cinereus acadicus*	Masked shrew		S4S5	
Mammal	*Tamias striatus lysteri*	Eastern chipmunk			S4S5
Mammal	*Tamiasciurus hudsonicus gymnicus*	Red squirrel/Pine squirrel		S4S5	S4S5
Mammal	*Ursus americanus americanus*	Black bear	S4S5	S4S5	S4S5
Mammal	*Vulpes vulpes rubicosa*	Red fox		S4S5	
Tree	*Abies balsamea*	Balsam fir	S4S5	S4S5	S4S5
Tree	*Acer pensylvanicum*	Striped maple		S4S5	
Tree	*Acer rubrum*	Red maple	S4S5	S4S5	S4S5
Tree	*Acer saccharum*	Sugar maple	S4S5	S4S5	S4S5
Tree	*Betula alleghaniensis*	Yellow birch	S4S5	S4S5	S4S5
Tree	*Betula cordifolia*	Mountain paper birch/Heart-leaved birch			S4S5
Tree	*Betula papyrifera*	White birch	S4S5	S4S5	S4S5
Tree	*Fagus grandifolia / Fagus americana*	American beech	S4S5	S4S5	S4S5
Tree	*Larix laricina*	Eastern larch/American larch/Tamarack	S4S5	S4S5	S4S5
Tree	*Ostrya virginiana*	Ironwood	S4S5		
Tree	*Picea glauca*	White spruce	S4S5	S4S5	S4S5
Tree	*Picea mariana*	Black spruce	S4S5	S4S5	S4S5
Tree	*Picea rubens*	Red spruce	S4S5	S4S5	S4S5
Tree	*Pinus resinosa*	Red pine	S4S5	S4S5	S4S5
Tree	*Pinus strobus*	White pine	S4S5	S4S5	S4S5
Tree	*Quercus rubra*	Red oak	S4S5	S4S5	S4S5
Tree	*Tsuga canadensis*	Eastern hemlock	S4S5	S4S5	S4S5
Tree	*Ulmus americana*	American elm		S4S5	

* S-rank refers to Subnational Conservation Status Rank (c.f., Table 3.5.). Species marked with S-rank were targeted for climate change vulnerability assessments in the indicated park(s) (K, Kejimkujik National Park; C, Cape Breton Highlands National Park; F, Fundy National Park).

Table 3.2. Definitions of Index scores by the CCVI (Young et al. 2011; 2012).

Index score	Score	Note
EV	+10 to +23	“Extremely Vulnerable: Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050s.”
HV	+7 to +10	“Highly Vulnerable: Abundance and/or range extent within geographical area assessed likely to decrease significantly by 2050s.”
MV	+4 to +7	“Moderately Vulnerable: Abundance and/or range extent within geographical area assessed likely to decrease by 2050s.”
PS	-2 to +4	“Not Vulnerable/Presumed Stable: Available evidence does not suggest that abundance and/or range extent within the geographical area assessed will change (increase/decrease) substantially by 2050s. Actual range boundaries may change.”
IL	-6 to -2	“Not Vulnerable/Increase Likely: Available evidence suggests that abundance and/or range extent within geographical area assessed is likely to increase by 2050s.”
IE	n.a.	“Insufficient Evidence: Available information about a species' vulnerability is inadequate to calculate an Index score.”

Note that in this study, the climate change assessment/model year is 2080s but not 2050s.

Table 3.3. Literature survey steps in climate change vulnerability assessments.

Step no.	Method
1	Searching and scanning up to 50 documents published since 2000 by the keyword combination of “species name” + “national park name”.
2	Searching and scanning up to 50 documents published since 2000 by the keyword combination of “species name” + “region name (Nova Scotia, Cape Breton, or New Brunswick)”.
3	Searching and scanning up to 50 documents published since 2000 by the keyword combination of “species name” + “climate change”.
4	Searching and scanning up to 50 documents published since 2000 by the keyword combination of “species name” + “temperature/thermal”.
5*	If no or few documents were available in the first four searches, similar documents published before 2000 were additionally searched.
6*	To supplement relevant information, searching and scanning additional documents by keyword combinations of “species name” + specific terms (e.g., snow/ice, fire/wind, genetic).

* The last two searches were done only if necessary/applicable.

Table 3.4. Definitions of Global Conservation Status Ranks (G-rank) (Master et al. 2012).

Rank	Score	Note*
G1	n.a.	"Critically Imperiled - At very high risk of extinction or elimination due to extreme rarity, very steep declines, or other factors."
G2	n.a.	"Imperiled - At high risk of extinction or elimination due to very restricted range, very few populations or occurrences, steep declines, or other factors."
G3	n.a.	"Vulnerable - At moderate risk of extinction or elimination due to a restricted range, relatively few populations or occurrences, recent and widespread declines, or other factors."
G4	n.a.	"Apparently Secure - Uncommon but not rare; some cause for long-term concern due to declines or other factors."
G5	n.a.	"Secure - Common; widespread and abundant."

*, The note was cited from the explanation written on page 43 of Master et al. (2012).

Table 3.5. Definitions of Subnational Conservation Status Ranks (S-rank) (Master et al. 2012).

Rank	Score	Note*
S1	n.a.	"Critically Imperiled - Critically imperiled in the jurisdiction because of extreme rarity or because of some factor(s) such as very steep declines, making it especially vulnerable to extirpation from the jurisdiction."
S2	n.a.	"Imperiled - Imperiled in the jurisdiction because of rarity due to very restricted range, very few populations or occurrences, steep declines, or other factors making it very vulnerable to extirpation from the jurisdiction."
S3	n.a.	"Vulnerable - Vulnerable in the jurisdiction due to a restricted range, relatively few populations or occurrences, recent and widespread declines, or other factors making it vulnerable to extirpation."
S4	n.a.	"Apparently Secure - Uncommon but not rare; some cause for long-term concern due to declines or other factors."
S5	n.a.	"Secure - Common; widespread and abundant in the jurisdiction."

*, The note was cited from the explanation written on page 46 of Master et al. (2012).

Table 3.6. Definitions of classes by the MVA.

Class	Score	Note
HV	n.a.	Highly Vulnerable: Abundance and/or range extent within geographical area assessed likely to decrease significantly by 2080s.
MV	n.a.	Moderately Vulnerable: Abundance and/or range extent within geographical area assessed likely to decrease by 2080s.
PS	n.a.	Not Vulnerable/Presumed Stable: Available evidence does not suggest that abundance and/or range extent within the geographical area assessed will change (increase/decrease) substantially by 2080. Actual range boundaries may change.
MA	n.a.	Moderately Adaptable: Available evidence suggests that abundance and/or range extent within geographical area assessed is likely to adapt to climate change and moderately increase by 2080s.
HA	n.a.	Highly Adaptable: Abundance and/or range extent within geographical area assessed likely to increase significantly by 2080s. Some of them could be important species that maintain ecosystem functions, and some of them could be devastating for other pre-existing species.
IE	n.a.	Insufficient Evidence: Available information about a species' vulnerability is inadequate to judge species' vulnerability.

Table 3.7. Outline of expert consultations in three Maritime National Parks.

	Kejimkujik*	Cape Breton Highlands	Fundy
Date	Nov 20th 2014	Oct 16th 2014	Sep 25th 2014
Consulted experts	Gabrielle Beaulieu (GB) Darren Reed (DR) Megan Crowley (MC) Chris McCarthy (CM) Stephanie Walsh (SW) Donna Crossland (DC) Amanda Lavers (AM)	James Bridgeland (JB) Derek Quann (DQ) Matthew Smith (MS) Michée Lemieux (MG) Clayton d'Orsay (CO) Erich Muntz (EM) Alana Plumber (AP) (via phone)	Gilles Seutin (GS) Marie-Josée Laberge (ML) Denis Doucet (DD) Shirley Butland (ShB) Alain Caissie (AC) Dan Mazerolle (AC) Alana Plummer (AP) Karel Allard (KA) Sean Blaney (SB) Ben Phillips (BP) Edouard Daigle (ED) Bruce Persaud (BrP)
Other participants (committee members and students)	Peter Duinker (PD) Dan Kehler (DK) Takafumi Osawa (TO) Melissa Lesko	Peter Duinker (PD) Takafumi Osawa (TO) Sydney Toni	Peter Duinker (PD) Karen Beazley (KB) Takafumi Osawa (TO) Lara Slapcoff

*, Because additional consultation with extra experts was suggested in Kejimkujik consultation meeting, we consulted the following experts by emails or in person communication: Alex Mosseler (Canadian Forest Service), Art Lynds (Nova Scotia Department of Natural Resources), Cindy Staicer (Dalhousie University), and Trevor Avery (Acadia University).

Table 3.8. Timetable of each consultation meeting.

Time	Agenda
0900-0930 hr	opening, welcome, presentation
0930-1000 hr	discussion on the overall project and approach
1000-1015 hr	selection of species for further discussion
1015-1030 hr	break
1030-1200 hr	detailed discussions by species - CCVI and MVA
1200-1300 hr	lunch
1300-1400 hr	cont’d detailed discussions by species
1400-1445 hr	discussion on adaptation measures - what is possible, what is feasible
1445-1500 hr	break
1500-1600 hr	discussion on management implications; next steps

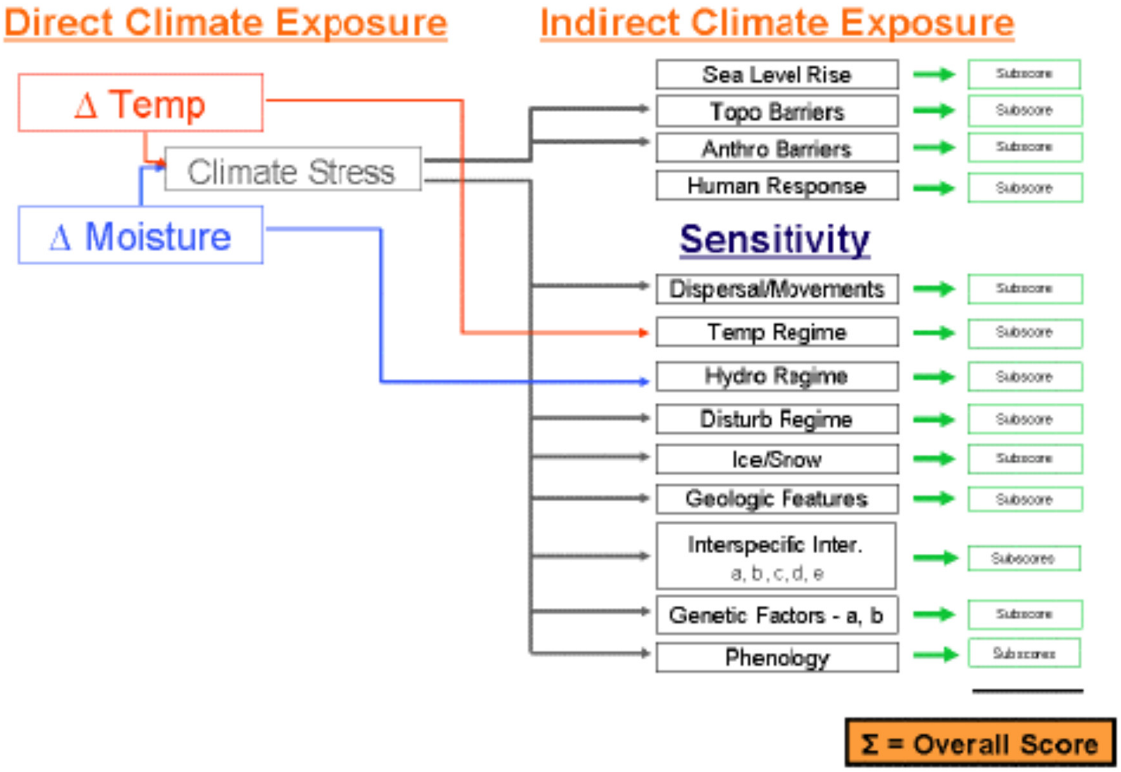

Fig. 3.1. Relation between exposure to local climate change and sensitivity factors (Young et al. 2011; p46).

Chapter 4. Climate-Change Vulnerability Assessment for Selected Species in Three National Parks in Eastern Canada

Note: this chapter will be submitted to "Journal of Environmental Management", with authorship as follows: Ohsawa, Duinker, Beazley, Kehler

(1) Introduction

Protected areas are established to conserve ecological values (i.e., to prevent or mitigate negative effects of anthropogenic factors; represent certain ecoregions persistently) (Margules and Pressey 2000; Mawdsley et al. 2009; Araújo et al. 2011). Most protected areas have been set up under a premise of static distributions of different ecosystems and species, though this assumption is no longer valid due to shifting species' distributions under changing climates (Scott et al. 2002; Suffling and Scott 2002; Lemieux and Scott 2005; Reid 2006). Regardless, a number of studies have still regarded protected areas as crucial core areas for conserving species and ecosystems in a climate change context (Hannah et al. 2007; Mawdsley et al. 2009; Araújo et al. 2011). There are four possible options for managing protected areas under climate change: (i) static management which maintains current goals and management, (ii) passive management (a *laissez faire* approach) which allows any changes caused by climate change, (iii) adaptive management to climate change, and (iv) hybrid management (Suffling and Scott 2002; Scott and Lemieux 2005).

The aforementioned researchers proposed the third option – adaptive management – as the most effective, efficient and thus wise way to protect biotic legacies. For instance, Canadian Parks Council Climate Change Working Group (CPCCCWG) (2013) emphasized the importance of strengthening resilience of existing protected areas and expanding and/or linking protected areas in Canada. Indeed, broad-scale conservation designs and rules (e.g., protected area designs and seed transfer zoning) have been increasingly paying attention to climate change in the country (Nantel et al. 2014). Yet, Welch (2005) advocated that parks should not be moved following the future distributions of certain biomes. This is because existing parks were the products of previous conservation efforts and also because establishing new parks is realistically difficult (Welch 2005). Furthermore, even when habitats in different protected areas are disconnected from each other due to climate change, each protected area may accommodate species and serve as a refugium site for the time being. Thus, strengthening resilience of existing protected areas may be the most feasible approach.

Canada has observed an increase of annual average temperature of 1.5 °C over the past 60 years (Environment Canada 2013), higher than the global temperature increase of 0.89 °C (IPCC 2013). In the next 100 years, further temperature increases (2.2-11.5 °C) are expected, with potentially significant implications for Canadian national parks (Parks Canada 2009). Because of concerns about the impacts of climate change on biodiversity, a number of studies have been conducted in an attempt to predict specific species' responses to climate change in and around Canada. For instance, Lawler et al. (2009) projected climate-induced faunal change in the western hemisphere. Cheung et al. (2009) projected global marine biodiversity impacts under climate change scenarios. McKenney et al. (2007) used a species distribution model (SDM) to predict future distributions of 130 tree species in North America. For southeastern Canada, their results indicate increases in temperate species and decreases in boreal species. Bourque et al. (2010)

predicted future distributions of twelve native tree species in Nova Scotia, reporting that many of these species would move northwards and/or locally disappear. Kanno and Beazley (2004) rated the relative vulnerability of groups (coldwater, coolwater, and warmwater) of freshwater fish in Nova Scotia. Herman and Scott (1994) offered an approach for analyzing vulnerability to climatic warming of terrestrial and aquatic vertebrates in the same region. Stortini et al. (2015) assessed climate-change vulnerability of Nova Scotian marine species.

Despite these previous studies, partially due to a lack of specific information, park managers and conservationists may still have difficulty coming up with concrete ideas and taking appropriate actions for each area, even if they are concerned with the climate-change issue. A recent survey revealed that Canadian protected-area agencies especially wanted information on ecological consequences of climate change as well as strategies for climate-change adaptation (Lemieux et al. 2011).

There are several challenges when applying the aforementioned studies' insights to protected area conservation. First, most of these studies focus on a few species of specific taxa. Second, because many species are interrelated with other species (e.g., important prey species, landscape modifiers, etc.), assessing species' responses to climate change or any other stressors should take into account information about these other species' responses. Consequently, conservation and management measures need to be based on consideration of sets of the species, if not all species, in a region.

The studies using SDMs, such as McKenney et al. (2007) and Bourque et al. (2010), are valuable as objective and precise predictions of future species' distributions, but they generally do not take into account key factors such as interspecific competition, forest succession, and invasive alien species. Assessing such species' responses with sets of species enables us to consider such biotic factors and to predict species' responses to climate change more rigorously. Further, SDMs are so precise that small changes in preconditions (e.g., climate-change scenarios and global climate models) could influence the final outputs of the simulations (Wright et al. 2015). These models also assume that current species' distributions are at equilibrium conditions determined by climate and they predict future species' distributions based on projected climate-change scenarios (Araújo and Peterson 2012). However, these assumptions could be also wrong (Araújo and Peterson 2012). Furthermore, the target sites of previous studies often differ from each other and are generally large (e.g., province scale) and at coarse resolutions.

To address such challenges, climate change vulnerability assessments (CCVA) have been developed and applied (e.g., Glick et al. 2011; Young et al. 2011; Stortini et al. 2015). CCVA for species/ecosystems can tell us the following two pieces of information: (i) which species/ecosystems are most likely to be influenced by climate change, and (ii) why they are so vulnerable (Glick et al. 2011). The final goals of such CCVAs are to allow managers to improve priorities for conservation action and to help them develop appropriate management and conservation actions in response to climate change (Glick et al. 2011). For instance, a Climate Change Vulnerability Index (CCVI) developed by NatureServe (Young et al. 2011) has been used in many CCVAs recently (e.g., Byers and Norris 2011; Dubois et al. 2011; Schlesinger et al. 2011; Brinker and Jones 2012; Shank et al. 2012; Ring et al. 2013). The CCVI has also been used in at least ten jurisdictions in the United States up to 2012 (Brinker and Jones 2012). It has been used to evaluate vulnerability of more than 1,700 species in the same country (Wright et al. 2015). The

CCVI looks at various aspects of the vulnerability of species, and is widely used regardless of taxa (Brinker and Jones 2012; Anacker et al. 2013; Wright et al. 2015).

Despite the popularity of the CCVI, such methods may not give robust conclusions about species vulnerability. A few studies that examined the effectiveness of the CCVI have reported that the CCVI produced different results from those of other CCVAs (Anacker et al. 2013; Lankford et al. 2014). Although these gaps are partly attributable to shortcomings of the other CCVAs, these studies also mentioned the possiblity of limitations of quantifying species' vulnerability by scoring methods. As well, most previous studies using such CCVAs assess species' vulnerability without addressing possible adaptation measures for vulnerable species (Keenan 2015). Even though a few studies give recommendations for practical conservation (e.g., Byers and Norris 2011; Brinker and Jones 2012), these recommendations are usually too generic (e.g., monitoring) and not specific to each vulnerable species. Most conservation biologists have been interested in data collection, analysis, and publication, while they have been insufficiently involved in implementing conservation actions, in part because such action is rarely acknowledged as a scholarly contribution (Arlettaz et al. 2010). As a consequence, park managers have not harnessed academic insights for climate-change adaptations (Janowiak et al. 2014), and little is known about the feasibility and effectiveness of adaptation measures (Geyer et al. 2015). In other words, there is a need to explore species-specific adaptation measures and identify further research and data required to support implementation of such measures by dialogue among stakeholders (Keenan 2015).

We assessed climate-change vulnerability of selected terrestrial and freshwater species of birds, mammals, fish and trees in three protected areas in Nova Scotia and New Brunswick in Canada: Kejimkujik National Park and National Historic Site of Canada (hereafter Kejimkujik National Park); Cape Breton Highlands National Park of Canada (hereafter Cape Breton Highlands National Park); and Fundy National Park of Canada (hereafter Fundy National Park) (Fig. 4.1). To do so, we applied both a CCVI (semi-quantitative approach) and a Modified Vulnerability Assessment (MVA) (qualitative approach; see later for details). By conducting the same two assessments for all three parks, we aimed to clarify unique features of each park in the context of climate change, and explore adaptation measures that could be considered for specific vulnerable species in specific parks.

(2) Methods

Canadian national parks aim to represent nature in 39 natural regions in Canada (Environment Canada 2011). This means that the full suite of Canadian national parks represents the full diversity of ecosystems across the country. In relation to such diversity of protected areas, there are few case studies regarding how to conserve and manage each protected area in consideration of its setting within a unique natural region. Suffling and Scott (2002) together with the Canadian Climate Impacts and Adaptation Research Network (C-CIARN) (2007) described likely impacts of climate change in the Atlantic region (Appendix 4.1). The authors acknowledged the necessity of analyzing individual parks within each natural region in the context of climate change, because each region contains a wide range of variation.

Kejimkujik National Park (inland area: 381 km^2), established in 1974 in Nova Scotia, harbours Acadian forests, which are a mixture of southern deciduous and northern coniferous forests (Loo and Ives 2003; Parks Canada 2010a). Cape Breton Highlands National Park was established in 1936 in the same province, covering 950 km^2 (Parks Canada 2010b). This region harbours Acadian and boreal forests as well as taiga ecosystems. Fundy National Park was designated in 1948, located in southern New Brunswick adjacent the Bay of Fundy. It covers 206 km^2 of the Fundy Coast (20%) and Southern Uplands (80%) ecoregions, where red spruce and balsam fir dominate (Parks Canada 2011b).

To conduct CCVAs for species that are important in terms of park management, every species of tree, mammal, bird and freshwater fish mentioned in the management plans of each national park was identified. To supplement such lists, mammal species profiled on the official website of each park were also selected (Parks Canada 2012). This is because only a few mammal species were highlighted in the management plans despite the fact that some mammals are important as top-level predators or herbivores in ecosystems (Terborgh et al. 1999). As well, for every park we assessed vulnerability of all species that were listed in Table 2 of Steenberg et al. (2013). This is because Steenberg et al. (2013) showed data on suitable Growing Degree Days (GDD) for these species, as key tree species of Acadian forests, based on several sources, and such GDD data are helpful to understand vulnerability of tree species. Four tree species (e.g., Striped maple (*Acer pensylvanicum*) and American elm (*Ulmus americana*)) were found in the official websites but none of the three management plans, and these species were added to our assessment target species.

In contrast, herbaceous plants, amphibians, reptiles, insects, and other taxa were not targeted in this study. A few taxa without specific species names were documented in the management plans and the official websites, and such taxa were precluded from our target (e.g., "various mice and shrews" in Fundy National Park (Parks Canada 2011b)). Consequently, 31 species in Kejimkujik National Park, 43 species in Cape Breton Highlands National Park, and 39 species in Fundy National Park were targeted in the following assessment (Appendix 4.2). Among them, 19 species were common to all three parks.

Following the World Meteorological Organization (n.d.), we assumed the climate during the period 1961 and 1990 as the baseline climate (present climate). We estimated the current climate data of each park by using Climate Wizard Custom (http://climatewizardcustom.org/; Girvetz et al. 2009) (Appendix 4.3). Furthermore, as supplemental data, climate data of centroids of these parks were calculated by using the program New LocClim ver 1.10, which is a tool for spatial interpolation of agroclimatic data (Grieser et al. 2006). We then assumed two scenarios for each park in the 2080s (Appendices 4.3-4.10): "moderate climate change scenario" and "severe climate change scenario". To obtain data about moisture changes, we estimated data by using Climate Wizard Custom (Girvetz et al. 2009) again. In Young et al. (2011)'s program, users are supposed to select one or multiple choices of temperature change and the Hamon AET:PET moisture metric. The AET:PET metric is a ratio of actual evapotranspiration (AET) to potential evapotranspiration (PET) reflecting moisture availability (Young et al. 2011). Therefore, we did so in this program so that we could approximately reflect future climate scenarios (Appendices 4.4-4.6).

More specifically, for the moderate climate change scenario, we assumed a relatively limited temperature increase (~ +2.2-2.5℃) with no change of snow accumulation, whereas for the severe climate change scenario we assumed a greater temperature increase (~ +4.2℃) with decline of snow accumulation considering such a drastic temperature increase. In support of this, Richards and Daigle (2011) estimated a slight increase of snow days until the 2050s in comparison with that of the 1980s, but they predicted a decrease in number of snow days and an increase in number of rain days in winter in the 2080s around the parks. Dalton et al. (2009) projected that a decrease in number of snow days but an increase in number of rain days in winter in the 2080s in towns around Fundy National Park. Thus, we assumed that snow accumulation amount would decline in the long term due to increasing temperature, but not in the short term.

To assess species' vulnerability, we utilized Young et al.'s (2011) CCVI. The CCVI looks at various aspects of the vulnerability of species, including exposure to local climate change, indirect exposure to climate change, species' sensitivity, and documented or modeled response of assessed species to climate change (optional) (Young et al. 2011) (Appendix 4.12). Each aspect is incorporated into the calculation of species' vulnerability as subscores. They are the product of multiplying categorical factor values (+3 (Greatly Increase Vulnerability: GI), +2 (Increase Vulnerability: Inc), +1 (Somewhat Increase Vulnerability: SI), 0 (Neutral: N), -1 (Somewhat Decrease Vulnerability: SD), and/or -2 (Decrease Vulnerability: Dec)) with exposure weighting (by temperature and/or moisture changes), and subsequently these subscores are summed to calculate the CCVI (Young et al. 2012). The program finally gives a vulnerability index, the CCVI, which is one of EV

(Extremely Vulnerable), HV (Highly Vulnerable), MV (Moderately Vulnerable), PS (Not Vulnerable/Presumed Stable), or IL (Increase Likely) (Young et al. 2011).

Note that some factor values are to be determined in consideration of vulnerability of associated species. Thus, when judging vulnerability of species that are dependent on other species, we took into account vulnerability (i.e., vulnerable or adaptable) of the associated species that we or other studies assessed. When choosing only one specific factor value was difficult given various uncertainties, multiple scores were chosen. The consequent range of assessment results is generated by the CCVI program using 1,000 iterations in a Monte Carlo simulation (Young et al. 2011). If an assessor assigns several factor values to each subfactor due to lack of and/or inconsistent information, the simulation indicates the result (the CCVI) as highly uncertain. In our study, we regarded the index that was supported most frequently (>50%) by the Monte Carlo simulations as the final vulnerability index. Sometimes two adjacent indices were supported by the simulation equally (e.g., 50% and 50%), and we expressed such results by the two contiguous indices (e.g., HV/MV).

Because we assessed vulnerability based on some rationales that are peculiar to our study (the Maritimes), as shown in the Appendix 4.12, our assessment is a comparative assessment among the three parks, but not an absolute assessment. In other words, our results cannot be directly compared to results of other studies conducted in other regions.

As aforementioned, the CCVI may not always give robust conclusions about species vulnerability due to limitations associated with quantifying species' vulnerability by scoring methods. Furthermore, the CCVI was designed to emphasize the negative influences of climate change rather than the positive ones. Indeed, there are three available categories to show species' negative responses to climate change (EV, HV, and MV) but only one category to show species' positive responses to climate change (IL). Previous studies using the CCVI concluded that just a few of the assessed species could gain benefits from climate change (e.g., Byers and Norris 2011), but some of their conclusions may be due to the skewed assessment viewpoint of the CCVI.

To compensate for such shortcomings of the CCVI, we developed and applied a more qualitative approach, the MVA. While avoiding quantifications, species' responses to climate change were determined by qualitative reasoned argumentation through the lens of the subfactors of the CCVI. In other words, the viewpoints (i.e., the subfactors) of the CCVI were taken into account in the MVA as well, because the CCVI covers most of the important aspects of species' responses to climate change. The final output was then given as HV (Highly Vulnerable), MV (Moderately Vulnerable), PS (Presumed Stable), MA (Moderately Adaptable), or HA (Highly Adaptable). Determining a single class as each species' vulnerability/adaptability by qualitative thinking is frequently difficult, however, and hence giving two mutually adjacent classes was necessary in some cases. Herein, we refrained from assessing vulnerability of species whose physiological thermal niche (CCVI subfactor: C2aii) was unclear due to poor or inconsistent information. This is because the C2aii is likely the most relevant subfactor to species' vulnerability to climate change in the Maritime region, which will be unlikely to experience significant hydrological changes (Wang et al. 2014). Details of the contrasting methods of the CCVI and the MVA are described in Chapter 5.

The assessments based on the CCVI and the MVA were conducted with information from six to 25 references for each species' assessment (around 14 references on average) (c.f., Appendix 4.12). Information about species' traits relevant to factors in the CCVI was obtained from species sources: Roland (1945), Fowells (1965), Burzynski et al. (1986), Farrar (1995), Saunders (1996), and Hinds (2000) for plants; Banfield (1976) and Feldhamer et al. (2003) for mammals; Godfrey (1986) and Erskine (1992) for birds; and Livingstone (1951) and Scott (1967) for fish.

Considering the importance of recent and/or local studies, we searched for relevant studies by using Google Scholar by the steps written in Appendix 4.13. We also consulted State of the Park and Site Reports for the three parks (Parks Canada 2010c; 2010d; 2011c) together with the forest ecosystem guideline for the Greater Fundy Ecosystem (Betts and Forbes 2005). Telfer (2004) and Mersey Tobeatic research Group (MTRI) and Parks Canada (2014) were used to identify recent changes in the main species in southwestern Nova Scotia. Thus, assessments on the same species in different parks were often based on the same references, but occasionally we were able to find references specific to the local contexts.

Our CCVAs did not fully consider demographic factors that could possible lead to extinction, such as population size and range size (Young et al. 2011). Master et al. (2012) developed several "NatureServe conservation status ranks" for evaluating such non-climatic extinction risk based on species' rarity, threats, and trends. For such cases, Young et al. (2011) recommend consideration of two indexes, Global Conservation Status Rank (G-rank) and Subnational Conservation Status Rank (S-rank) to interpret results. Thus, we obtained general status ranks of the assessed species at two geographic scales (i.e., Canada and the specific province) from the Canadian wild species database (http://www.wildspecies.ca/home.cfm?lang=e), which provides the general status of

21,352 species in and around 2010. Because of the large geographic extent of Canada and the Canadian provinces and the relatively small geographic area of our study sites, ranks for Canada and each province were treated as ranks for global and subnational scales in our study. Hence, the obtained ranks from the database were converted into G-rank and S-rank respectively.

Given that we were focusing on adaptation within a protected area, the species that should be prioritized for protection could be extracted by looking at S-rank in combination with CCVA judgments. To do so, we focused on the species that are ranked as "S3/S4" (i.e., between Vulnerable and Apparently Secure) or a more serious rank (S1/S2) by S-rank evaluation and as HV/MV or more seriously vulnerable (HV) by our CCVAs (CCVI and MVA) under climate change. We then suggested possible adaptation measures for these species based on a wide range of literature that documents reasons for species' vulnerability and/or adaptation opportunities and measures that counteract such reasons.

Following these assessments, a one-day expert consultation meeting was held in each park in autumn 2014. Eight, seven and 12 experts respectively participated in meetings in Kejimkujik, Cape Breton Highlands, and Fundy National Parks. The consulted experts included mainly park staff from each national park but also a few external experts. Each consultation meeting began with a brief explanation about our research. Subsequently, intensive discussion ensued about the vulnerability of a subset of species, and potential adaptation opportunities for the threatened species. Because consultation with additional experts was recommended by participants in the Kejimkujik meeting, we consulted with four more experts by email or in person.

All insights provided in these consultations were reflected in our assessments and suggestions of adaptation measures for specific species, unless the suggestions were judged by us to be inconsistent with the scoring system of the CCVI. For instance, because most of the consulted experts were not familiar with the CCVI protocol, occasionally they gave us suggestions of factor values without consideration of the nuances and requirements of the protocol. In such cases, we adjusted their suggestions so that scoring could be consistent with the protocol.

(3) Results

Details of our CCVA results assuming two climate-change scenarios are provided in Appendices 4.14-4.25. Hereafter, we focus on the results generated for the severe climate change scenario, because CCVAs assuming more-severe climate changes are more likely to highlight species' responses in both positive and negative ways. Moreover, there are few contrasting results (i.e., vulnerable vs. adaptable) between the assessments under the two climate-change scenarios, and results for the severe scenario represent almost all results. A few species for which results were contrasting between the two scenarios are documented specifically below. Also, species that were judged in contrasting ways between the CCVI and the MVA are briefly mentioned below, but details about gaps in the results between the two methods are described in Chapter 5.

Species in Kejimkujik National Park

Under the CCVI, brook trout (*Salvelinus fontinalis*), American marten (*Martes americana americana*), and yellow birch (*Betula alleghaniensis*) were judged as HV (Table 4.1). American moose (*Alces alces americana*), balsam fir (*Abies balsamea*), and black spruce (*Picea mariana*) were assessed as HV/MV. Eight species were predicted to increase: brown bullhead (*Ameiurus nebulosus*), white perch (*Morone americana*), coyote (*Canis latrans*), fisher (*Martes pennanti*), white-tailed deer (*Odocoileus virginianus borealis*), red maple (*Acer rubrum*), ironwood (*Ostrya virginiana*), and red oak (*Quercus rubra*).

According to the MVA, eight species (brook trout, American moose, balsam fir, white birch, eastern larch (*Tsuga canadensis*), white spruce (*Picea glauca*), black spruce, and red pine (*Pinus resinosa*)) were HV. Red spruce (*Picea rubens*) was HV/MV. Brown bullhead, white perch, red maple, and ironwood were HA. Yellow perch (*Perca flavescens*), southern flying squirrel (*Glaucomys volans*), white-tailed deer, and red oak were judged as MA/HA. American beaver (*Castor canadensis acadicus*), sugar maple, and eastern hemlock (*Tsuga canadensis*) were adaptable (and presumably stable) to the moderate climate change scenario but vulnerable (and presumably stable) to the severe climate change scenario.

Yellow perch and American beech (*Fagus grandifolia/americana*) were judged possibly vulnerable according to the CCVI but adaptable according to the MVA.

Species in Cape Breton Highlands National Park

In the CCVI, under the severe climate change scenario, six species (American marten, balsam fir, yellow birch, eastern larch, black spruce, and red spruce) were judged as HV (Table 4.2). Bicknell's thrush (*Catharus bicknelli*), white birch, and white spruce were HV/MV. In contrast, 12 species (hermit thrush (*Catharus guttatus faxoni*), chimney swift (*Chaetura pelagica*), blue jay (*Cyanocitta cristata bromia*), American redstart (*Setophaga ruticilla*), American robin (*Turdus migratorius migratorius*), red-eyed vireo (*Vireo olivaceus*), Canada warbler (*Wilsonia canadensis*), American eel (*Anguilla rostrata*), coyote, white-tailed deer, red fox (*Vulpes vulpes rubicosa*), and red oak) were Increase Likely (IL). Red pine showed a contrasting result (IL vs. MV) between the two climate-change scenarios. As well, sugar maple (*Acer saccharum*) was judged as stable or adaptable (PS/IL) under the moderate scenario but vulnerable (MV) under the severe scenario.

According to the MVA, only Bicknell's thrush was assessed as Highly Vulnerable (HV). A combination of Highly Vulnerable and Moderately Vulnerable (HV/MV) was given for gray jay (*Perisoreus canadensis*), balsam fir, white birch, black spruce, and white spruce. The class of HA was given for just two species, red maple and red oak. Responses of blue jay, white-tailed deer, and American elm were considered as MA/HA. When comparing results between the two climate-change scenarios, snowshoe hare (*Lepus americanus struthopus*), striped maple, yellow birch, and red pine were judged possibly adaptable to the moderate scenario but vulnerable to the severe scenario.

When comparing results of the two approaches, hermit thrush was assessed as IL by the CCVI but MV/PS by the MVA under the severe climate change scenario. In contrast, black bear and sugar maple were judged as MV by the CCVI but PS/MA by the MVA.

Species in Fundy National Park

According to the CCVI, the American marten was HV, while brook trout and black spruce were HV/MV (Table 4.3). There were, on the other hand, 11 species that were IL: hermit thrush, Peregrine falcon (*Falco peregrinus anatum*), dark-eyed junco (*Junco hyemalis hyemalis*), white-winged crossbill (*Loxia leucoptera*), coyote, snowshoe hare, little brown bat (*Myotis lucifugus lucifugus*), white-tailed deer, raccoon (*Procyon lotor lotor*), red maple, and red oak.

According to the MVA, white birch and red spruce were judged as HV, and four species (brook trout, balsam fir, white spruce, and black spruce) were HV/MV under the severe scenario. In contrast, red maple and red oak were considered as HA, while a combination of MA/HA was given for white-tailed deer. Ruffed grouse (*Bonasa umbellus togata*), American beaver, snowshoe hare, yellow birch, and red pine were adaptable (and presumably stable) to the moderate scenario but vulnerable (and presumably stable) to the severe scenario.

Lastly, hermit thrush, white-winged crossbill, and snowshoe hare were judged as IL by the CCVI but MV/PS by the MVA under the severe scenario. On the other hand, black bear, sugar maple, American beech, and Eastern hemlock were MV or MV/PS according to the CCVI but MA or PS/MA according to the MVA.

Suggestions for species-specific adaptation measures

Adaptation measures were considered for species that are listed as relatively threatened (spanning indices of S1/S2-S3/S4) and also vulnerable (spanning indices of HV-HV/MV) to climate change according to our study: American moose, American marten, and brook trout in Kejimkujik National Park; Bicknell's thrush and American marten in Cape Breton Highlands National Park. There were no species meeting our requirement for “threatened species” in Fundy National Park, because every species judged as HV or HV/MV were ranked as S4/S5 (Apparently Secure or Secure) at the provincial level. Therefore, the following species in Fundy National Park were considered based on just the result of CCVAs: brook trout, American marten, white birch, and red spruce. Possible adaptation measures are based on insights gleaned from the literature and expert consultation meetings (Appendices 4.29-4.36).

As examples, potential adaptation measures for two species, American moose and brook trout, in Kejimkujik National Park include protecting/creating habitats and controlling harmful species (Table 4.4). More specifically, riverine and marsh habitat are beneficial for American moose by alleviating heat stress (Parker 2003; Dou et al. 2013). A drier environment will contribute to moose’s vulnerability to climate change, as evaluated in the subfactor of C2bii. Therefore, maintaining total areas/number of waterbodies (as summer shelters) through greater protection, restoration and enhancement measures is suggested as Option 1. According to experts consulted, wetlands may be shrinking or at least drying in the park, and it may be possible to create wetlands on the edges of waterbodies.

On the other hand, some literature-based ideas were challenged by consulted experts. Parker (2003) suggested that post-fire forest regeneration often produces many aspen trees (*Populus* spp.) and that such aspen trees could be beneficial for beavers. Beavers then create wetlands, and such wetlands are useful for moose during the summer season (Parker 2003) (Option 2). However, one park expert stated that most Kejimkujik wetlands are surrounded by black spruce rather than broadleaf trees, and moving towards an aspen-free forest with climate change. Thus, the expert suggested that the pathway of aspen-beaver-moose is unlikely to be valid for the landscape in Kejimkujik National Park.

In terms of C4a subfactor (other species required for habitat), mature coniferous stands could be also useful for American moose to adjust its body temperature during the summer season (Parker 2003). In support of this idea, Broders et al. (2012) observed moose in mostly coniferous or mixed forests during the summer season in mainland Nova Scotia. Therefore, protecting such vegetation was suggested as Option 3.

Finally, continued flourishing of white-tailed deer populations could lead to further declines in moose populations via interspecific competition for food/habitats and increased exposure to a parasitic nematode, *Parelephostrongylus tenuis* (Robinson et al. 2010, Beazley at al. 2006). There are already many deer in Kejimkujik, but negative influences of deer on moose may be enhanced with a larger number of deer in warmer climates. Thus, controlling deer populations (to protect moose from *P. tenuis*) was suggested as Option 4. A consulted expert stated that lowering the deer population has been implemented in other parks, but this was done to protect natural regeneration of non-coniferous trees species and not for managing moose.

Regarding brook trout in Kejimkujik National Park, the most important contribution to the species vulnerability appeared to be physiological thermal niche (C2aii). In support of this, warmwater zones in Nova Scotia are mostly confined to its southwestern part, and such zones will be unsuitable for brook trout in a warming climate (MacMillan et al. 2005). Exceptionally, Mountain Lake is a possible refugium for this species in future climates in Kejimkujik National Park (Corbett 2003) (Option 1). In response to this option, many experts agreed that thermal refugia would be relevant to this species' survival. An expert told us that the dam pulled out of Cobrielle Lake could become another refugium for brook trout. He suggested that overhang from trees (e.g., hemlock, pines, red maple) might also help the water to stay cool. Another participant suggested that it would be advantageous to ask the province to implement a 30-m riparian reserve in forests upstream of Kejimkujik National Park. This would be consistent with a no-cut riparian reserve of 30 m implemented by the Government of Nova Scotia (on the former Bowater lands) (Dr. Boates personal communication) and the former Bowater-Mersey Paper Company (which owned a few hundred thousand hectares of timber-producing forest land near the Park). It would represent an increase over the 20-m reserve (with some tree cutting allowed) required by the province (which now owns that land) elsewhere. Some experts (e.g., Stoffyn-Egli and Duinker 2013) suggest a 50-m no-cut reserve for these wooded landscapes in southwestern Nova Scotia.

Given that wildfires are likely to negatively affect salmonid thermal habitats (Isaak et al. 2010), we also suggested preventing and suppressing accidental fires (e.g., keeping fireproof belts) as Option 2. In terms of snow/ice change (subfactor C2d), snow accumulation could contribute to stability of winter habitats of this species (Lindstrom and Hubert 2004). If snow shifts to a snow-rain mix, high waterflows (floods) in winter would be frequent, negatively affecting brook trout (Wenger et al. 2011). This is because this species spawns in autumn, and its eggs are damaged or washed away by the waterflows (Wenger et al. 2011). Hence, buffering snowmelt was suggested as Option 3. In this regard, snow fencing was suggested as an adaptation measure to climate change by Cross et al. (2012) for cutthroat trout in the Greater Yellowstone Ecosystem in the USA. In response to this idea, an expert in our consultation said that it would only work for a wind-blown environment, not an environment with trees.

From the viewpoint of other interactions with species (C4e), brook trout is the loser in interspecific competition with alien rainbow trout in many areas (Bivens 1984). A negative impact of temperature increase on rainbow trout can be mitigated by high waterflow during winter under climate change (Wenger et al. 2011). In other words, less snow and more winter rain may help rainbow trout to flourish, and thus further outcompete brook trout. Consequently, we list eradicating non-native competing species, rainbow trout, as Option 4. However, the consulted experts stated that brook trout is threatened by bass and chain pickerel rather than rainbow trout in Kejimkujik National Park. It means that, even though we need to examine feasibility in the future, eradicating or controling bass and chain pickerel may be helpful for brook trout.

In the two other national parks, similar suggestions and opinions from the consulted experts were discussed. However, in Cape Breton Highlands National Park, keeping western moose (*A. alces andersoni*)-free areas or controlling the moose population was often mentioned as one possible adaptation measure for relatively threatened and vulnerable species, because the reintroduced moose population has disturbed vegetation in the park drastically. As well, in the consultation in Fundy National Park, the importance of protecting habitats around (outside) the park, including Crown forests, was mentioned by multiple experts.

(4) Discussion

Overall, the most vulnerable species were similar across the three parks, likely because they are situated in the same Maritime region. When comparing results of the CCVI among the three parks with 19 species whose vulnerability was assessed for all the three parks, no species showed contrasting responses to the severe climate change scenario qualitatively across the three parks (Appendix 4.26.). In other words, there were no species judged as vulnerable in any of the parks but judged as adaptable in the other parks. According to the MVA, there were contrasting responses (vulnerable vs. adaptable) of two species, sugar maple and eastern hemlock, among the three parks (Appendix 4.26.).

However, there were other subtle differences among the three parks in the obtained results especially under the severe climate change scenario (Appendices 4.27. and 4.28.). Hereafter, the main features that are relevant to climate change vulnerability of species in each park are discussed.

Climate-change impacts on species in Kejimkujik

According to the CCVI, Kejimkujik National Park showed the largest proportion of vulnerable species (i.e., species judged as HV and/or MV) under the severe climate change scenario among the three parks (50%). It is also noteworthy that the same park showed the largest proportion of HV (Highly Vulnerable) species among the three parks (28%) according to the MVA. These are mainly because this park is expected to experience the warmest climate among the three parks (c.f., annual temperature will be ~10.6°C under the severe scenario), and the future thermal condition will be adverse for many boreal species. Clayden et al. (2011) documented that the interior of southern Nova Scotia is one of the warmest regions in eastern Canada with ample precipitation in summer. Indeed, the factor value of "Inc" (increase vulnerability) was given in the subfactor of physiological thermal niche for brook trout, American moose, balsam fir, white birch, eastern larch, white spruce, and black spruce.

Among these species, moose has relatively plenty of information on the species' thermal niche. McCann et al. (2013) reported heat-stress thresholds of 17°C under calm conditions and 24°C under windy ones, by observing moose at the Minnesota Zoological Garden. Nova Scotia is near the southern limit of this species' distribution, and is likely to be affected by heat stress (Snaith and Beazley 2004; Beazley et al 2006). Broders et al. (2012) observed the fact that moose sought cooler sites when the temperature reached 14°C on summer nights and 24°C on summer days in mainland Nova Scotia. In support of this, proportions of moose staying in coniferous woods or at watersides were higher during warmer conditions (Broders et al. 2012). Thus, further temperature increases in Kejimkujik National Park during the summer season will be negative for the moose population.

An example of contrasting impact of temperature increase on the same species among the parks is the case of sugar maple. Sugar maple was judged to be possibly vulnerable in terms of physiological thermal niche in the severe scenario in Kejimkujik National Park due to an excessively warm condition for the species in addition to a couple of other negative factors (e.g., deer increase, decline of snow accumulation) (Phillips 2009;

Comerford et al. 2013; MTRI and Parks Canada 2014). In contrast, sugar maple was considered to gain benefits from the same scenario in the other two parks, which will be at thermally optimal conditions under climate change for the species.

Other subfactors relevant to species' vulnerability in Kejimkujik National Park include physiological hydrological niche (C2bii) as well as physical habitats (C3). A typical example of species that are sensitive to hydrology is rusty blackbird. This species often breeds in streams with coniferous trees, swamps and bogs (MTRI 2008). Warming could bring about wetland drying, thus growth and survival rates of particularly young individuals of this species may be lowered (Greenberg et al. 2011). Wetland drying could change aquatic invertebrate communities, which are valuable food resources for this species (Loomis 2013). A consulted expert suggested that drying has already begun in Kejimkujik National Park, which is likely to be negative for rusty blackbird.

High mercury contamination was found in the same species, rusty blackbird, in Kejimkujik National Park. The high bioavailability of methyl mercury (MeHg) is due to low pH and low dissolved oxygen (Edmonds et al. 2010; 2012). The effects of the elevated mercury concentration on the species (at the population level) are not fully understood (Edmonds et al. 2010; Environment Canada 2014). Nonetheless, high mercury contamination in common loon as well as yellow perch in acid lakes in the park was also observed, and such contamination has led to decline of these species' populations (Burgess and Meyer 2008; Wyn et al. 2010). Such mercury effects on aquatic species and their predators will be generally enhanced by climate change (MacLeod and Pessah 1973; Krabbenhoft and Sunderland 2013). The consulted experts also suggested the importance of considering the mercury effect on fish and bird species. Therefore, such possibly harmful impacts of mercury accumulation under a changing climate were reflected in our current assessment of physical habitat (subfactor of C3).

On the other hand, the same park (Kejimkujik) showed the highest percentage of species that would be highly adaptable to the severe climate change scenario among the three parks (20%), according to the MVA. There are also some southern relic populations since the Hypsi-thermal period, thanks to a warm condition in Kejimkujik National Park (e.g., southern flying squirrel) (Lavers 2004; Petersen and Stewart 2006). As well, a few species (e.g., white/yellow perch, brown bullhead) that can gain benefits from high temperature were considered to be able to flourish under new climates, even though they have some risk of mercury accumulation. These species could enjoy warmer climates. Also, lack of highlands (i.e., topographical simplicity) would allow these species to expand their distributions easily. In this regard, the park is likely to harbour both highly vulnerable and highly adaptable species, suggesting that it is a typical ecotone area.

Climate-change impacts on species in Cape Breton Highlands

According to the CCVI, Cape Breton Highlands National Park showed the largest proportion of highly vulnerable species among the three parks (17%) while it showed the smallest proportion of vulnerable species (32%). The MVA showed, on the other hand, a lower proportion of vulnerable species (37%) and that of highly vulnerable species (9%) in the same park when compared to those in the other two parks. The gap in the results between the CCVI and the MVA could be attributed to some technical uniqueness and limitations of the CCVI. We discuss the technical details in a companion article (Chapter

5), but for instance in the CCVI, mountains like those of Cape Breton Highlands are regarded as impediments for plant species' adaptation to climate change (the subfactor of natural barriers (B2a)). This idea is based on Young et al.'s protocol (2011), while the highlands could provide adaptation opportunities (c.f., "mountain island effect" (Oline et al. 2000)) rather than maladaptation (c.f., B2a subfactor in Appendix 4.12).

Historical thermal niche (C2ai) was also contributing to species' vulnerability in Cape Breton Highlands National Park in the CCVI. In other words, limited variation in past temperature in the park leads to limited species' adaptability to climate change. Biologically, this idea could be explained by possible acclimation (e.g., Ueyama et al. in press) and/or natural selection (e.g., Jump et al. 2006), but actually we do not have evidence about impacts of historical thermal niche on species' vulnerability to climate change.

Cape Breton Highlands National Park is larger than the other two parks, though the relatively larger size was not reflected in the current CCVAs in the frame of the CCVI. Physically, large protected areas are generally thought to be more effective in protecting wide-ranging wildlife (Noss and Harris 1986; Scott et al. 1999). From the viewpoint of conservation genetics, large protected areas could avoid reduction in within-population genetic diversity by genetic drift as well as inbreeding depression (Young et al. 1996). In these regards, although we also acknowledge that incorporating the park size into the CCVI is technically difficult, we suggest that the CCVI may have overestimated species' vulnerability by ignoring the large size of the park.

However, temperature increase was still considered to be adverse for some species in Cape Breton Highlands National Park, such as Bicknell's thrush and white birch.

Bicknell's thrush is mainly distributed in New York and northern New England in the breeding season, while there are small patches in Quebec, New Brunswick as well as Nova Scotia (Lambert and McFarland 2004). In this sense, the main distribution is located in more southern positions than Cape Breton, but these southern habitats are at high elevations. A linear negative relationship between latitude and elevation for Bicknell's Thrush occurrence (-81.6 m/1◦ latitude) suggests that this species' distribution is primarily determined by temperature gradients (Lambert et al. 2005). According to this relationship, a suitable habitat for this species in Cape Breton Highlands should be at 660 m a.s.l. or higher, and therefore (at elevations of 0-534 m) this park is already low and therefore too warm for the species. This is a typical example showing that future temperature increases will be devastating for it.

In contrast, it is noteworthy that the impact of disturbances caused by active moose browsing may be weakened a little, because temperature increase as well as further infections of *P. tenuis* could affect moose negatively (see above for detail). In Cape Breton, moose browsing has supressed regeneration of balsam fir and white birch (Bridgland et al. 2007; Smith et al. 2010). In this respect, climate change could possibly buffer such a negative impact of disturbances on the tree species, though they could also be devastated by temperature increases. As such, climate change could influence species in complicated mechanisms via multiple pathways.

Climate-change impacts on species in Fundy

Fundy National Park exhibited the highest percentage of species that were judged as IL (33%) and the smallest one of species judged as HV (5%) among the parks according to the CCVI. Some of these results could be attributed to proportions of each taxon in the assessed species among the parks. For instance, all the bird species except pileated woodpecker in Fundy National Park were judged as PS and/or IL under both climate-change scenarios. Compared to species of other taxa like plants, bird species have high dispersal ability, little specificity to uncommon geological features or derivatives, and little dependence on interspecific interactions with other species (c.f., Appendices 4.14-4.25). Byers and Norris (2011) reported the same trend. Interestingly, 21% of the assessed species in Fundy National Park are birds, which may affect the overall trend.

However, the result needs to be interpreted with caution. The CCVI did not take into account the risks of climate change on migratory bird species in their wintering sites (Young et al. 2011). Likewise, the MVA did not. Thus, even though these species were judged as not vulnerable in our study, they might be vulnerable to climate change in their wintering sites in Central/South America. Small-Lorenz et al. (2013) critically pointed out the oversimplification of ecology of these migratory species in pre-existing CCVAs including the CCVI. Furthermore, from an ecological viewpoint, most of these bird species are high-level predators in food webs. A few previous studies reported that species at higher trophic levels are more sensitive to climate change, possibly due to greater metabolic requirements, smaller population size and bottom-up effects (as reviewed by Gilman et al. 2010). However, in our current assessment, population size was not taken into account, for instance, according to the protocol of the CCVI (Young et al. 2011). Thus, extinction risk should be considered based on the vulnerability but also species' demographic status.

Meanwhile, coastal fog in combination with the local cooling effect of the Bay of Fundy have created local refugia for red spruce in the east coast of Maine between 6,000 and 5,000 years ago, and probably this species recolonized extensively from these refugia especially during the last cooling 1,000 years ago (Schauffler and Jacobson 2002). Such a locally cool climate is another reason for relatively low proportion of vulnerable species in Fundy National Park.

Challenges of suggested adaptation measures

Most previous studies conducting CCVAs discussed species' vulnerability to climate change but not adaptation measures of vulnerable species (Keenan 2015). In contrast, Cross et al. (2012) introduced a framework of Adaptation for Conservation Targets (ACT). This method consists of making conceptual diagrams among causes and effects, consulting experts (including stakeholders), and prioritizing adaptation options in consideration of socio-economic constraints (Cross et al. 2012; 2013). In another setting, Geyer et al. (2015) consulted conservation practitioners regarding feasibility and usefulness of adaptation measures in Brandenburg, Germany.

In concert with these studies, we explored possible adaptation measures with the aid of park and other experts. Most of the suggestions arising from the literature were challenged by the experts, and some of the suggestions were regarded as inappropriate measures in the parks. For instance, because aspens will not flourish in the future, the park experts did not agree with the utility of the pathway of aspen-beaver-moose proposed by Parker (2003) for the landscape in Kejimkujik National Park. This opinion is consistent with our CCVA about American beaver. Suitable habitats of aspen species (*Populus grandidentata* and *P. tremuloides*) will move north of Kejimkujik National Park under the severe climate change scenario according to simulations based on SDMs (Natural Resources Canada 2014). So, given that these species will decline, ratings of PS and MV were chosen for the beaver under the severe scenario in our MVA.

The effects of our suggested measures (e.g., establishing snow fence and genetic-assisted colonization) are sometimes uncertain, and more evidence will be needed prior to their implementation. In our consultations, the experts provided other suggestions that we did not reveal from the literature, but their ideas also require supporting data. For instance, creating thermal refugia by covering streams with riparian forests was suggested as an adaptation measure for brook trout in Kejimkujik National Park. Indeed, riparian vegetation has been generally acknowledged as a key element in creating thermal refugia in water streams (Capon et al. 2013). For instance, a ca. 10% increase of shade by riparian vegetation along streams is considered able to decrease water temperature by 1°C in southwestern Australia (Davies 2010). However, a cross-sectional analysis with 18 headwaters in Brecon Beacons National Park in the UK did not support the idea that increasing broadleaf cover along streams could lead to improvements in salmonid biomass and density (Thomas et al. 2015). According to the same study, coniferous cover also had a negative impact on salmonids, likely due to the limited palatability of conifer needles for macroinvertebrate taxa. Thomas et al. (2015) still acknowledged that little is known about this issue, calling for more studies examining effectiveness of possible adaptation measures.

We also have to note that protecting some specific species selectively may be harmful to other species, because available land and budget are limited in each protected area. Thus, although some possible adaptation measures were discussed in this study, careful consideration about side effects of these measures on other species must be taken into account before implementing adaptation measures. We can never ignore the history of pre-existing natural environments in each area even when considering such new approaches (Keenleyside et al. 2012). In these regards, among the four conservation approaches under climate change suggested by Suffling and Scott (2002) together with Scott and Lemieux (2005), we cannot rule out any of them from our options for the moment. Also, pursuing just the third option, adaptive management, may not be realistic. According to an interview survey, not only lack of information but also lack of resources (i.e., lack of stuff and budget) are major obstacles for implementing adaptation measures in protected areas (Jantarasami et al. 2010). Therefore, while previous researchers tended to focus on predictions of species' responses to climate change alone, we will need to tackle more practical issues of future adaptation strategies, such as effectiveness, side effects, and feasibility (e.g., costs) of adaptation measures.

Finally, our study found a few species that showed contrasting responses to the two climate change scenarios, posing a question about how we should treat them for the future. Most of such species were judged as vulnerable under just the severe climate change scenario, and therefore we could have some time to understand impacts of climate change on them and adaptation measures for the species. In other words, considering limitations of our capacities, maybe we should begin our practical studies on the most vulnerable species. Subsequently, we could target the species that showed contrasting responses to the two scenarios. Also, our results suggest that the species that are adaptable to the moderate climate change scenario are not necessarily adaptable to the more-severe scenario (e.g., yellow birch). In this regard, monitoring and adaptive management may be crucial (Abbott and Le Maitre 2010).

Challenges at the inter-protected area level

A director of the US National Park Service stated that, according to conventional policy, species coming from outside of national parks due to climate change may be regarded as alien (Kunzig 2012). However, he still argued that they might need to accept invasion of these new species, especially if they have no other habitats elsewhere.

In this respect, Cape Breton Highlands and Fundy National Parks in particular might need to accommodate some species from outside as "last refugia" under climate change. The northern territory and the inland area in Canada are supposed to experience pronounced temperature increases as well as frequent and/or severe droughts (Parks Canada 2009; CPCCCWG 2013; Wang et al. 2014). In comparison with these areas, the parks in the Maritimes will experience mild climate change. Therefore, someone might ask these parks to accommodate the most vulnerable species from the northern territory or the inland area in the future, if there are no other available shelter sites. In support of this, recent paleobiological studies using molecular techniques found that a few species (e.g., jack pine (*Pinus banksiana*) (Godbout et al. 2005 and 2010) and masked shrew

(*Sorex cinereus*) (Stewart and Baker 1992)) have shaped refugia and persisted in and around the Maritime region during the Last Glacial Maximum, because the severe glacial climate (including glaciation) was buffered in this region by the Atlantic Ocean.

As well, it might be possible to move some vulnerable species in Kejimkujik National Park (e.g., American moose) to somewhat cooler sites like Fundy National Park in the future. As such, these two national parks will possibly play a pivotal role for *ex-situ* protection of some species in Canada or even North America. We could not fully address these issues in our study, and again we will need to consider effectiveness and feasibility of these measures when implementing them.

(5) Conclusions

By contrast with previous CCVA studies, this study targeted animal and plant species in three national parks, and combinatorial assessment and discussion were realized. Although the three parks are situated in the same Maritime region, they are characterized by different features. Kejimkujik National Park is characterized by its small size, flat, and inland location, while Cape Breton Highlands National Park is featured with its medium size, coastal location, and small mountains. Fundy National Park is a small and hilly park situated on the coast with frequent fog. Therefore, although all the three parks will experience less drastic climate change than climate change in inland areas of North America, Kejimkujik National Park is relatively vulnerable to climate change among the three parks. Flat topography means that there are no highlands that could be shelters for species, and the inland location could lead the park to experience drier and more unstable climate than a coastal one.

Indeed, according to our CCVA results, Kejimkujik National Park is considered as the most typical ecotone, harbouring both highly vulnerable and highly adaptable species under changing climates. Ecotones are generally sensitive to climate change and could be easily dominated by a few adaptable tree species (Kappelle et al. 1999; Milad et al. 2011). Thus, this park needs to be taken care of in particular, as discussed above with possible adaptation measures, when it comes to climate change. As such, despite proximity among the three parks, we can and should be aware of differences in climate change vulnerability among them.

Although our study targeted the three national parks in Canada, this study has a few important insights that could be useful for other places as well. First, our cross-taxon CCVAs showed that assessing species' responses to climate change should take into account information about these other species' responses. Second, we could demonstrate that assessing species' vulnerability between/among different protected areas is beneficial to highlight advantages and disadvantages of each area in the context of climate change. In other words, such comparative studies could clarify features and values of protected areas. Third, we explored what kinds of adaptation measures we can suggest based on CCVAs for practical conservation. While identifying feasible and effective adaptation measures is difficult, discussing such issues allows us to start understanding what we should do and what we should study as next steps. *Laissez-faire* approaches could then be better than the other approaches, depending on effectivess (including side effects) and feasibility of adaptation measures. As well, cross-taxon CCVAs and cross-park CCVAs allowed us to explore adaptation measures that involve many species and/or parks. Thus, our current approach would be helpful for extensive exploration of adaptation measures even outside Canada.

We anticipate that similar cross-taxon CCVAs will become common for other protected areas and that the feasibility and effectiveness of suggested adaptation measures will be examined.

Table 4.1. Result of climate change vulnerability assessment with species in Kejimkujik National Park under the severe climate change scenario in the 2080s.

Tx‡	Species name	CCVI						MVA				
		EV	HV	MV	PS	IL		HV	MV	PS	MA	HA
B	Rusty blackbird	0	0	100	0	0	*		■			
B	Common loon	0	0	12	88	0			■			
B	Eastern barred owl	0	0	0	71	29				▨		
F	Brown bullhead	0	0	0	35	65						□
F	White perch	0	0	0	0	100						□
F	Yellow perch	0	0	50	50	0					□	□
F	Brook trout	0	91	9	0	0	*	■				
M	American moose	0	50	50	0	0	*	■				
M	Coyote	0	0	0	0	100				▨		
M	American beaver	0	2	34	62	2			■	▨		
M	Porcupine	0	0	0	50	50				▨		
M	Southern flying squirrel	0	0	0	13	87					□	□
M	American marten†	0	86	14	0	0	*					
M	Fisher	0	0	0	0	100	*				□	
M	white-tailed deer	0	0	0	0	100	*				□	□
M	Black bear	0	1	32	67	0				▨	□	
T	Balsam fir	0	50	50	0	0	*	■				
T	Red maple	0	0	0	26	75	*					□
T	Sugar maple	0	27	73	0	0	*		■	▨		
T	Yellow birch	0	74	26	0	0	*		■			
T	White birch	0	0	100	0	0	*	■				
T	American beech	0	0	100	0	0	*			▨	□	
T	Eastern larch/American larch/Tamarack	0	0	100	0	0	*	■				
T	Ironwood	0	0	0	0	100	*					□
T	White spruce	0	11	89	0	0	*	■				
T	Black spruce	0	50	50	0	0	*	■				
T	Red spruce	0	0	100	0	0	*	■	■			
T	Red pine	0	0	100	0	0	*	■				
T	White pine	0	0	24	76	0	*			▨		
T	Red oak	0	0	0	0	100	*				□	□
T	Eastern hemlock	0	0	100	0	0	*		■	▨		

The result of the CCVI is shown in percent based on Monte Carlo simulations (1,000 runs). The index value(s) that was supported the most by each simulation is (are) highlighted in black (that corresponds to "vulnerable"), grey ("presumably stable"), or white with black frame ("increase likely"). Similarly, the result of the MVA is shown with the highlighting colors: black (that corresponds to "vulnerable"), grey ("presumably stable"), or white with black frame ("adaptable").

‡, Tx refers to taxon (B, bird; F, fish; M, mammal; T, tree).

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*, vulnerability of the species shown with the asterisk were judged with information of category D (documented and/or predicted species' response to climate change by previous studies).

†, vulnerability of the American marten was not determined by the MVA.

Table 4.2. Result of climate change vulnerability assessment with species in Cape Breton Highlands National Park under the severe climate change scenario in the 2080s.

Tx‡	Species name	CCVI						MVA				
		EV	HV	MV	PS	IL		HV	MV	PS	MA	HA
B	Bicknell's thrush	0	50	50	0	0		■				
B	Hermit thrush	0	0	0	0	100			■	▨		
B	Chimney swift	0	0	0	0	100					□	
B	Olive-sided flycatcher	0	0	0	74	26			■			
B	Blue jay	0	0	0	0	100					□	□
B	Spruce grouse	0	0	25	75	0			■			
B	Boreal chickadee†	0	0	0	100	0	*					
B	Gray jay	0	0	23	77	0		■	■			
B	American redstart	0	0	0	0	100				▨	□	
B	Greater yellowlegs	0	0	5	44	0			■	▨		
B	American robin	0	0	0	0	100				▨	□	
B	Red-eyed vireo	0	0	0	0	100					□	
B	Canada warbler†	0	0	0	16	84						
F	American eel	0	0	0	27	73					□	
F	Atlantic salmon	0	0	31	69	0					□	
M	Western moose	4	38	37	22	0			■			
M	Coyote	0	0	0	0	100				▨	□	
M	Snowshoe hare	0	3	33	64	0			■	▨		
M	Canada lynx†	0	6	94	0	0	*					
M	Bobcat	0	0	0	100	0	*				□	
M	American marten†	0	100	0	0	0	*					
M	white-tailed deer	0	0	0	25	75					□	□
M	Deer mouse	0	0	3	78	19				▨	□	
M	Masked shrew	0	0	8	86	7				▨	□	
M	Red/Pine squirrel†	0	0	27	73	0						
M	Black bear	1	33	32	34	0				▨	□	
M	Red fox	0	0	0	0	100					□	
T	Balsam fir	0	100	0	0	0	*	■	■			
T	Striped maple	0	0	34	66	0	*		■	▨		
T	Red maple	0	0	0	100	0	*					□
T	Sugar maple	0	0	67	33	0	*			▨	□	
T	Yellow birch	0	81	19	0	0	*		■	▨		
T	White birch	0	50	50	0	0	*	■	■			
T	American beech	0	0	0	100	0	*				□	
T	Eastern larch/American larch/Tamarack	0	75	25	0	0	*		■			

T	White spruce	0	50	50	0	0	*	■	■			
T	Black spruce	0	100	0	0	0	*	■	■			
T	Red spruce	0	86	15	0	0	*		■			
T	Red pine	0	23	77	0	0	*		■	▨		
T	White pine	0	0	14	86	0	*				□	
T	Red oak	0	0	0	6	94	*					□
T	Eastern hemlock	0	0	0	88	12	*				□	
T	American/White elm	0	0	0	50	50	*				□	□

The result of the CCVI is shown in percent based on Monte Carlo simulations (1,000 runs). The index value(s) that was supported the most by each simulation is (are) highlighted in black (that corresponds to “vulnerable”), grey (“presumably stable”), or white with black frame (“increase likely”). Similarly, the result of the MVA is shown with the highlighting colors: black (that corresponds to “vulnerable”), grey (“presumably stable”), or white with black frame (“adaptable”).

‡, Tx refers to taxon (B, bird; F, fish; M, mammal; T, tree).

*, vulnerability of the species shown with the asterisk were judged with information of category D (documented and/or predicted species’ response to climate change by previous studies).

†, vulnerability of the species with the symbol of † were not determined by the MVA. †, vulnerability of the species marked with † was not determined by the MVA

Table 4.3. Result of climate change vulnerability assessment with species in Fundy National Park under the severe climate change scenario in the 2080s.

Tx‡	Species name	CCVI						MVA				
		EV	HV	MV	PS	IL		HV	MV	PS	MA	HA
B	Great blue heron	0	0	0	50	50				▒		
B	Ruffed grouse	0	1	20	78	1			■	▒		
B	Hermit thrush	0	0	0	0	100			■	▒		
B	Semi-palmated plover†	0	0	0	50	50						
B	Pileated wood-pecker	0	7	64	30	0			■	▒		
B	Peregrine falcon	0	0	0	0	100				▒		
B	Dark-eyed junco	0	0	0	0	100					░	
B	White-winged crossbill	0	0	0	0	100			■			
F	American eel	0	0	0	50	50					░	
F	Atlantic salmon†	0	7	60	33	0						
F	Brook trout	12	38	39	11	0		■	■			
M	American moose	0	0	0	100	0			■			
M	Eastern coyote	0	0	0	0	100				▒	░	
M	Beaver	0	0	6	74	20			■	▒		
M	Northern flying squirrel	0	0	7	93	0			■			
M	Snowshoe hare	0	0	0	13	87			■	▒		
M	Canada lynx†	0	0	88	12	0	*					
M	American marten†	0	68	32	0	0	*					
M	Little brown bat	0	0	0	12	88				▒	░	
M	white-tailed deer	0	0	0	0	100					░	░
M	Raccoon	0	0	0	31	69					░	
M	Eastern chipmunk	0	0	2	83	15					░	
M	Red/Pine squirrel†	0	0	0	76	24						
M	Black bear	1	5	45	50	0				▒	░	
T	Balsam fir	0	30	70	0	0	*	■	■			
T	Red maple	0	0	0	12	88	*					░
T	Sugar maple	0	0	50	50	0	*				░	
T	Yellow birch	0	6	94	0	0	*		■	▒		
T	Mountain paper birch†	0	4	49	47	0						
T	White birch	0	12	88	0	0	*	■				
T	American beech	0	0	50	50	0	*				░	
T	Eastern larch/American larch/Tamarack	0	0	100	0	0	*		■			
T	White spruce	0	3	97	0	0	*	■	■			
T	Black spruce	0	50	50	0	0	*	■	■			
T	Red spruce	0	45	55	0	0	*	■				
T	Red pine	0	0	100	0	0	*		■	▒		
T	White pine	0	0	0	50	50	*				░	

T	Red oak	0	0	0	0	100	*				☐
T	Eastern hemlock	0	13	87	0	0	*		▨	☐	

The result of the CCVI is shown in percent based on Monte Carlo simulations (1,000 runs). The index value(s) that was supported the most by each simulation is (are) highlighted in black (that corresponds to “vulnerable”), grey (“presumably stable”), or white with black frame (“increase likely”). Similarly, the result of the MVA is shown with the highlighting colors: black (that corresponds to “vulnerable”), grey (“presumably stable”), or white with black frame (“adaptable”).

‡, Tx refers to taxon (B, bird; F, fish; M, mammal; T, tree).

*, vulnerability of the species shown with the asterisk were judged with information of category D (documented and/or predicted species’ response to climate change by previous studies).

†, vulnerability of the species with the symbol of † were not determined by the MVA.

Table 4.4. Suggested adaptation opportunities for American moose and brook trout in Kejimukujik National Park.

[Relevant subfactor] Literature-based adaptation opportunities	Source	Comments/feedbacks from expert consultation
American moose		
Adaptation opportunities by physical approaches		
[C2bii] Protecting total areas/number of waterbodies (as summer shelters) (e.g., creating artificial wetlands as compensation for loss of natural wetlands)	Gomer (1999), Parker (2003), Dou et al. (2013)	· Wetlands may be shrinking or at least drying. · It might be possible to create wetlands on the edge of water bodies.
Adaptation opportunities by protecting and/or increasing other species		
[C2bii/C4a] Increasing beavers by increasing aspen trees to create wetlands	Parker (2003)	· Most of our wetlands are surrounded by black spruce, but not broadleaf trees. We will move towards an aspen-free forest with climate change. The pathway of aspen-beaver-moose is unlikely to be valid for the landscape in Kejimkujik National Park.
[C4a] Protecting coniferous woods (or mixed woods) with enough canopies as summer shelters	Gomer (1999), Parker (2003), Broders et al. (2012)	(c.f.) adaptation opportunities for red spruce (Appendix 4.31) · Mature forest cover habitat is the most limiting habitat feature for moose in Nova Scotia.
Adaptation opportunities by removing or controling other species		
[C4e] Controlling deer populations (to protect moose from *P. tenuis*)	Robinson et al. (2010)	· Lowering deer population has been implemented in other parks, but not necessarily for managing moose.
Others		
		· I think the issue is genetic or something we can't necessarily control. · Mitigation may be to relieve other stresses on the population. · If one subfactor is so dominant, there's almost no point mitigating the other factors.
Brook trout		
Adaptation opportunities by physical approaches		
[C2aii] Protecting the Mountain Lake as a refugium	Corbett (2003)	· The dam pulled out of Cole Rail Lake could become a refugium for brook trout. Overhang from trees species (e.g., hemlock, pines, red maple) over the water might allow water to stay cool. · Bowater has 30 m no-cut, while the province only has 20 m. Perhaps should ask the province to implement Bowater 30m standards (or greater) outside of Kejimkujik National Park.
[C2c] Preventing accidental fires (e.g., keeping fireproof belts)	Isaak et al. (2010)	

[C2c/C2d] Buffering snowmelt (e.g., snow fences)	Lindstrom and Hubert (2004), Wenger et al. (2011)	· This would only work for a wind-blown environment, not an environment with trees. (c.f.) Snow fence was suggested as one of adaptation measure to climate change by Cross et al. (2012) for cutthroat trout in Greater Yellowstone Ecosystem in the USA.
Adaptation opportunities by removing or controling other species		
[C4e] Eradicating non-native competing species, rainbow trout, which could flourish with snow decline	Bivens (1984) and Wenger et al. (2011)	· Brook trout is threatened by bass and chain pickerel rather than rainbow trout in Kejimkujik National Park. · However, it is hard to remove bass or pickerel. Unlimited recreational take (fishing) is under consideration, but it is the jurisdiction of the Department of Fisheries and Aquaculture of Nova Scotia.

Fig. 4.1. Locations of three targeted national parks.

Chapter 5. Promises and Pitfalls of Algorithmic Approaches to Trait-Based Climate-Change Vulnerability Assessment

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(1) *Introduction*

To conserve biodiversity in the face of climate change, many researchers (e.g., Stern 2006, Hannah et al. 2002) have offered ideas focusing on adaptation, including climate-change-integrated conservation strategies (CCS). Climate change vulnerability assessment (CCVA) for species and ecosystems can deliver important information for such actions and strategies, including which species and ecosystems are most likely to be influenced by climate change, and why they are so vulnerable (Glick et al. 2011; Pacifici et al. 2015). The final purpose of such CCVAs is to assist managers in identifying conservation actions and prioritizing them in response to climate change (Glick et al. 2011). While promising, many such CCVAs are fraught with pitfalls. Closely examining the methods and outputs of CCVA models is crucial for bettering our overall understanding of the real vulnerability of species and ecosystems to climate change, and this paper addresses that challenge.

More specifically, among recent CCVAs, index approaches using algorithms have become popular. Young et al. (2011), for example, developed a widely used Climate Change Vulnerability Index (CCVI) which evaluates vulnerability relative to both exposure and sensitivity. To apply the CCVI, assessors answer up to 24 questions for each species assessed by choosing one or multiple factor values in each question (subfactor) (Table 5.1). The resultant calculated index value is assigned to one of five categorical outcomes, or “index scores”, from “Extremely Vulnerable (EV)” to “Increase Likely (IL)”. Similarly, Bagne et al. (2011) developed a System for Assessing Vulnerability of Species (SAVS) to predict species’ responses to climate change. Like the CCVI, the SAVS assesses species’ vulnerability through 22 criteria about species’ habitat, physiology, phenology, and interspecific interactions. An overall vulnerability score is shown by the sum of positive scores (contribution to vulnerability) and negative scores (contribution to adaptability). Similarly, although no specific names were given, Gardali et al. (2012) and Stortini et al. (2015) developed algorithmic CCVAs for bird species and marine fish/invertebrate species respectively.

Interest in such CCVAs among ecologists and conservationists is growing. For instance, in the United States alone, the CCVI has been used in at least ten jurisdictions as of 2012 (Brinker and Jones 2012) and to evaluate more than 1,700 species as of 2015 (Wright et al. 2015). However, the latest review on CCVAs suggested that, in trait-based CCVAs including the CCVI, vulnerability thresholds are usually unknown (Pacifici et al. 2015). Some studies (Anacker et al. 2013; Lankford et al. 2014) that examined the effectiveness of the CCVI have reported that it produced different results from those of other CCVAs. Young et al. (2012) themselves explained that they had to compromise when making this program user-friendly. For instance, effects of exotic species and natural enemies are not considered in the CCVI assessment, and such effects would need to be considered independent from the CCVI (Young et al. 2015). As well, they conducted a questionnaire survey with CCVI users who levelled significant criticisms toward the tool (Young et al. 2015). About a third of the respondents modified the tool when using it (Young et al. 2015).

Despite such challenges to algorithmic CCVA methods, they are still extensively used. Serious reconsideration of CCVA tools is crucial to their improvement. Similar technical discussions that led to or will lead to improvements have been accomplished for some other assessment methods that rank species/ecosystems (e.g., weed risk assessment systems (Simberloff 2005; McClay et al. 2010) and a Red List of Ecosystems (Boitani et al. 2014)).

In our study, we examined the validity of various assumptions used in algorithmic approaches to CCVA and explored an alternative approach that tries to address some of the identified pitfalls. Herein, we examined not only the algorithms themselves but also the balance of perspective in the CCVA between vulnerability and adaptability, because both of them are common challenges among various CCVAs (see later for details). To achieve our goal, first, we introduce the methods of the CCVI with a case study of species in three forested national parks in eastern Canada. Second, we discuss major pitfalls of the CCVI approach. Although Young et al. (2015) reported some criticisms on the CCVI given from its users (i.e., respondents of their survey), our study aimed to detail these challenges with specific examples and opinions of the conservation experts we consulted. Furthermore, to try to avoid the identified challenges, we introduce a qualitative approach (the Modified Vulnerability Assessment (MVA); see the following section for detail) to CCVA and apply it to the same species in the three parks. The MVA is a simple reasoned-argumentation approach and therefore allowed us to highlight some strengths and weaknesses of the CCVI. Finally, by comparing the results of the two approaches, we explored how to compensate for pitfalls of the CCVI and similar algorithmic approaches by using a qualitative examination of the same questions.

Although our main focus was an evaluation of the CCVI, similar evaluations could be made of other CCVAs and even other species ranking systems. Our study sheds light on the importance of examining the methodological assumptions underlying algorithmic approaches and skewed viewpoints inherent in many species ranking systems. To illustrate this idea, we mention not only the CCVI but also a few other CCVAs having the same pitfalls that we explored.

(2) Methodology of the CCVI

Approach to the CCVI

There are four categories of considerations for which assessors are supposed to input information to the CCVI program (Young et al. 2011). Category A represents exposure to climate change, (the climate-change scenario information), category B represents indirect exposure to climate change (e.g., sea-level rise), category C is about species' sensitivity to climate change, and category D includes information, if available, about documented and/or modeled response of the assessed species to climate change (typically species distribution models (SDMs)).

Categories B and C have four and 16 subfactors respectively. Each subfactor has a set of possible categorical values (Table 5.1). Once each categorical value is scored, subscores are calculated by multiplying the categorical values with exposure weighting (temperature and/or moisture changes). Subsequently, these subscores are summed to calculate the CCVI score (Young et al. 2012). If optional category D, which has four subfactors, is used simultaneously, the CCVI score is given by averaging the score based on categories B and C vs. the score based on category D. The score is finally translated into a categorical index, which is any one of EV (Extremely Vulnerable), HV (Highly Vulnerable), MV (Moderately Vulnerable), PS (Not Vulnerable/Presumed Stable), or IL (Increase Likely) (Young et al. 2011) (Fig. 5.1).

When choosing only one specific factor value proves difficult, multiple scores can be chosen. The assessment outcome is then given using a thousand iterations in a Monte Carlo simulation in this method (Young et al. 2011).

Application of the CCVI to three national parks in eastern Canada

We assessed future species' responses to climate change by the CCVI with selected terrestrial and freshwater species of birds, fish, mamals and trees (31 species in Kejimkujik National Park and Historic Site of Canada, 43 species in Cape Breton Highlands National Park of Canada, and 39 species in Fundy National Park of Canada) (hereafter, we call them just national parks) (Chapter 4).

Briefly, the climate during the period 1961 and 1990 was considered as the baseline climate in our study. We then assumed two scenarios for each park in the 2080s: "moderate climate change scenario" (relatively limited temperature increase (~ +2.2-2.5 ℃)) and "severe climate change scenario" (greater temperature increase (~ +4.2℃)). To gain data about thermal and moisture changes, we estimated the data by using Climate Wizard Custom (Girvetz et al. 2009). In our study, the moderate climate change scenario assumed no change in snow accumulation whereas the severe climate change scenario assumed decline in snow accumulation considering a drastic temperature increase.

To conduct the CCVI, we consulted previous studies including species' encyclopediae for each species. To assist the assessment, an expert consultation meeting was also held in each of three national parks in autumn 2014. Through comparing results of the CCVI and the MVA, we also got comments on CCVA methodology from the experts (Appendix 5.1), which are reflected below. As far as the insights provided in these consultations were reasonable and consistent with protocols of the CCVI and other literature, they were reflected in our assessments.

As a result, under the severe climate change scenario, the species proportions of EV (Extremely Vulnerable), HV (Highly Vulnerable), MV (Moderately Vulnerable), PS (Presumably Stable), and IL (Increase Likely) across the three parks were 0%, 12%, 29%, 29%, and 30% respectively. Note that details of our CCVI assessment and a discussion on adaptation measures based on its results have been reported in Chapter 4.

(3) Pitfalls of the CCVI

Overview on challenges of the CCVI

To understand some key pitfalls of the CCVI, we reviewed previous studies that mentioned challenges of the CCVI (Appendix 5.2). As written above, some studies reported that it produced different results from those of other CCVAs, which could be attributed to challenges of both the CCVI and the other CCVAs. For instance, Lankford et al. (2014) compared assessment results among the CCVI, the SAVS, and Climate

Change Sensitivity Database (CCSD) for 95 wildlife species in the western United States, finding much discrepancy among the results. For 156 rare plant species in California, Anacker et al. (2013) compared scores from the CCVI with results from a topographic complexity analysis, but did not find any significant association between the two results. Anacker et al. (2013) also pointed out that some attributes are not considered in the CCVI program, like plant mating systems (selfing or out-crossing). Sperry and Hayden (2011) stated that changes in scales of assessed areas (i.e., variations in the subfactor of historical hydrological niche) could influence final assessment results (the CCVI) drastically.

On the other hand, according to the questionnaire survey by Young et al. (2015), the most common criticism on the CCVI was the "black box" of its algorithm. This algorithm is hard to understand, and also its outcome (vulnerability index) could be hard to interpret (e.g., should the same vulnerability index for wide-ranging species and narrow-ranging species be interpreted in a same way?) (Young et al. 2015). This issue was pointed out even by some of the studies in Appendix 5.2 (e.g., Ring et al. 2013).

What is in the black box?

Regarding the black box that Young et al. (2015) reported, we describe the structure of the algorithm in Fig 5.1. The CCVI converts qualitative and quantitative data into integers, multiplies them by degrees of exposure to climate change, averages them, and comes up with a continuous quantification of vulnerability index that is finally discretized into categories. We then identified the following three major misgivings we have with the algorithm of the CCVI (Fig. 5.1; see the places with [i], [ii], and [iii]).

(i) Classifications of continuous variables

The act of translating outcomes on a continuous quantitative scale into categories was mentioned even by Young et al. (2015). Classifications of factor values and the vulnerability index were designed arbitrarily in the CCVI. For instance, categorical values with equal intervals (3.0, 2.0, 1.0, 0, -1.0, and -2.0) are assigned to six levels of contributions of each subfactor to species' vulnerability (GI (Greatly Increase Vulnerability), Inc (Increase Vulnerability), SI (Somewhat Increase Vulnerability), N (Neutral), SD (Somewhat Decrease Vulnerability), and/or Dec (Decrease Vulnerability)) (Young et al. 2012). For instance, a subfactor of GI (Greatly Increase Vulnerability) is converted into 3.0, while a subfactor of Inc is 2.0. However, there is no scientific rationale justifying such assignments.

According to Young et al. (2011), final calculated scores are assigned to one of five categorical variables, which they call "index scores", such as EV (Extremely Vulnerable) or HV (Highly Vulnerable), with specific thresholds (+10, +7, +4, and -2). Herein, for instance, EV refers to the species' conditions where at least two subscores of categories B and/or C are GI with high exposure to climate change or where three subscores are Inc with the high exposure (Young et al. 2012). Yet, the classes defined by these thresholds cannot be justified on biological grounds, given that ecological thresholds are defined as the points at which non-linear relationships are observed (i.e., stationary points or inflection points along mathematical functions) between species' responses vs. environmental factors (Johnson 2013). Following Young et al.'s (2011) protocol, two scores of 10.1 and 9.9 are assigned to different levels (EV and HV respectively), while another pair of two scores, 9.9 and 7.1, is regarded as the same level of vulnerability (HV for the both scores). However, the latter pair includes a larger difference in vulnerability than that of the former pair. As well, we have no mathematically supporting clues for non-linear changes at the given "threshold" points in the species' vulnerability to climate change.

We are not arguing that we should never use any categories, but we should be aware that it is hard to assign categorical values to continuous data without significant arbitrariness. As well, such an issue is seen in some, but not all, of the subfactors in the CCVI, and hence we showed which subfactors have this issue (Table 5.1). Wright et al. (2015) pointed out that discretizing results of future habitat simulations (the subfactor of D2 in the CCVI program) and incorporating them into the CCVI rank are challenging. Similar problems were pointed out with other trait-based CCVA methods (as reviewed by Pacifici et al. (2015)) and assessment methods that develop prioritized lists (e.g., a Red List of Ecosystems (Boitani et al. 2014)).

(ii) Combinatorial algorithm: different contributions of subfactors to species' vulnerability

Subscores are the product of multiplying categorical values with exposure weighting, and subsequently these subscores are summed to calculate the CCVI (Young et al. 2012). This calculation is called a "weighted sum method", a typical approach of CCVAs (Kim and Chung 2013). Exposure weighting is done differently depending on subfactors in the CCVI. For instance, subscores of thermal subfactors (C2a) are calculated by multiplying factor values and degree of exposure to temperature change, while those of hydrological subfactors (C2b) are calculated by multiplying factor values and degree of exposure to moisture change (Young et al. 2011). However, an identical way of integrating different subfactors into a single metric of species' vulnerability may not be applicable to a wide range of species because weighting values may arguably be different depending on species and/or locations. Experts consulted in Fundy National Park suggested that the algorithm should be altered depending on taxonomic groups.

As well, weights of some subfactors are hard to justify. For example, the two subscores of historical thermal niche (C2ai) and physiological thermal niche (C2aii) are supposed to be calculated in the same way (weighted by temperature change). In other words, these two subfactors are considered to contribute to the final index equivalently. Historical thermal niche means variation in temperature that an assessed species has experienced in the past (50 years) (Young et al. 2011). We do not deny the possibility of the contribution of C2ai to species' vulnerability, because of possible acclimation (e.g., Ueyama et al. in press) and natural selection (e.g., Jump et al. 2006). Nonetheless, we still argue that C2aii is more influential than C2ai on species' vulnerability. In support of this, physiological thermal niche has been considered in most other CCVA methods, which reflects the importance of this subfactor. We should refrain from regarding the subfactor of C2ai to be as relevant as the other subfactor of C2aii, unless the effect of the historical thermal niche is scientifically justified and understood.

Assessing climate change vulnerability of water-resource systems, Kim and Chung (2013) overcame the issue of determining such weights by averaging suggested weighting coefficients from multiple experts. However, when it comes to assessing vulnerability of species and ecosystems, it may be hard to quantify such weights (particularly common weights applicable for every species) even by experts due to limited information. The same problem is seen in other ecological CCVAs (e.g., the SAVS (Bagne et al. 2011) and CCVA of Nova Scotian marine species (Stortini et al. 2015)) as well. Stortini et al. (2015) gave some rationales for the weighting of each subfactor in their algorithm. However, they still used just whole numbers such as 1, 2, and 3 for the weighting, and some of these weights were determined based on data availability. In these regards, these values might have to be changed depending on species and locations, and Stortini et al. (2015) acknowledged the same issue in part (e.g., weighting of diet specificity factor). Simultaneously, these authors used not only a weighted sum method but also exponential weightings, suggesting that algorithms of CCVAs using just a weighted sum method, as seen in the CCVI, may insufficiently reflect real vulnerability.

(iii) Vulnerability and adaptability

Finally, we point out the stance of the CCVI in favouring attention on species' vulnerability to climate change over adaptability. This bias has been rarely addressed in previous studies, though it could be a fundamental element in obtaining accurate assessment results.

The CCVI was designed to emphasize the negative influences of climate change rather than the positive ones, likely because previous CCVAs focus on just vulnerable species. Indeed, there is a selectable factor value of "Greatly Increased Vulnerability

(GI)", but not "Greatly Decreased Vulnerability" in the CCVI. As well, some subfactors have no selectable factor values that regard climate change as beneficial for species (Table 5.1). For instance, the subfactor of "dependence on snow/ice" (C2d) does not allow one to incorporate positive effects of less snow/ice into the assessment, though many species suffer from food unavailability, increased locomotion costs, and/or high depredation rates during snowy periods (e.g., Garroway and Broders 2005).

As well, the subfactor of "dependence on other species to generate habitat" (C4a) only reflects the vulnerability of species that generate habitats of assessed species. More specifically, if an assessed species' habitat is generated by one or a few species that are vulnerable to climate change, either of GI (Greatly Increase Vulnerability), Inc (Increase Vulnerability), or SI (Somewhat Increase Vulnerability) should be chosen as the factor value of C4a. However, if an assessed species' habitat is generated by species that are adaptable to climate change, such positive changes cannot be evaluated in the same subfactor.

On the other hand, subfactors of "reliance on interspecific interactions" focus on positive and pre-existing interspecific interactions, but not negative ones (Young et al. 2011; 2015). However, climate change may bring about occurrences of some new interactions that could be detrimental for species' survival. For example, some species will have more chances to compete and/or hybridize with related species that come from the south in Canada (Smith et al. 2012). Influences of such invasive species are not intended to be considered in the CCVI calculation (Young et al. 2012; Anacker et al. 2013). Both positive and negative influences of each subfactor could be considered at least qualitatively.

Previous studies using the CCVI concluded that just a few of the assessed species could gain benefits from climate change (e.g., Byers and Norris 2011). Some of their conclusions, however, might be due to the skewed (pessimistic) assessment frame of the CCVI. This is because there are many subfactors that could be too pessimistic and also a few subfactors that could be too optimistic (Table 5.1). Because a few positive effects of climate change (e.g., improvements in tree growth) were not incorporated into most studies using SDMs, such map-based prediction studies on species' future distributions also generate excessively negative predictions (Loehle 2011; 2014). Instead, both positive and negative viewpoints should be incorporated to conduct accurate CCVAs. There are already many studies that reported not only negative but also positive impacts of climate change on forest species (as reviewed by Milad et al. 2011).

Furthermore, the species judged to be adaptable in CCVAs should be worth further assessment to determine whether they might become future key species sustaining the ecosystems or future invasive species harming the ecosystems (Appendix 5.3). Making use of adaptable species has been proposed as one adaptation measure in forest ecology (as reviewed by Gauthier et al. 2014), but measuring and discussing which species are adaptable to new climates have not yet been sufficiently addressed. Moyle et al. (2013) predicted future changes of native as well as alien freshwater fish species in California by scoring methods, but they also focused solely on vulnerability to climate change, not on weediness or adaptability.

In sum, the CCVI algorithm includes the aforementioned shortcomings in many applications, though the influence of these issues have been rarely discussed. Actually, the CCVI may well have additional issues. For instance, an expert in our consultation suggested that some of the subfactors of the CCVI could be redundant. In other words, the algorithm could overestimate some impacts of climate change on species, which is known as an issue of multicollinearity in statistics (Graham 2003). Some of the CCVI users may have been aware of some of these issues, but most seem keen nevertheless to use the CCVI. In our view, compared to the abundance of outputs from recent use of the CCVI, its underlying processes have been neglected in previous literature.

(4) An alternative approach: the MVA

Approach to the MVA

We developed and applied a qualitative approach by dramatically simplifying the basic concept of the CCVI developed by Young et al. (2011) as a means of overcoming the aforementioned challenges. We call our modified method the MVA. First, each subfactor of the CCVI should have five selectable scores, which include two negative scores, a neutral score, and two positive scores (Inc, SI, N, SD, Dec) so that negative and positive contributions of each subfactor to vulnerability could be equally considered and evaluated. For instance, if an assessed species' habitat is generated by a few species that are moderately adaptable to climate change, "SD (Somewhat Decrease Vulnerability)" should be given at the subfactor of C4a (dependence on other species to generate habitat). Further, if the habitat is generated by a specific species and this habitat-generating species is highly adaptable to climate change, "Dec (Decrease Vulnerability)" could be chosen. In contrast, if any negative interspecific interactions are considered of concern due to climate change in previous literature, they could be rated in the subfactor of C4e (which forms part of an interspecific interaction not covered by C4a-d).

Furthermore, collected insights were expressed in five categorical classes that could describe both a decline and a flourishing of species (i.e., vulnerability and adaptability) equally (Appendix 5.4). Without any classification, it would be difficult to communicate vulnerability or adaptability of assessed species. As well, classifications may be helpful to understand and/or compare assessment results roughly (Pacifici et al. 2015). That is why we still assign classes to each species' vulnerability/adaptability in CCVAs. However, we refrained from making any unjustifiable calculations (pseudo-quantifications, which are the first two of the aforementioned three challenges of the CCVI).

Alternatively, the final classes were determined qualitatively on the basis of physiological thermal niche, (C2aii) as the most fundamental factor, in consideration of substantial factor values ("Inc", "SI", "SD" or "Dec") of other relevant attributes ((C2bii,) C2c, C2d, C4a, and C4e) (Table 5.1). This is because various changes of hydrology (that corresponds to C2bii), disturbance regimes (C2c), snow/ice covers (C2d), habitat scale/quality (C4a), and other interspecific interactions (C4e) have been considered as a consequence of climate change, though these changes are more uncertain to occur than a temperature increase (IPCC 2013). Information on other subfactors (that are listed without the symbol of "*" in Table 5.1) are generally less relevant to species' vulnerability than the aforementioned subfactors, though they were also taken into account if necessary (Appendix 5.5). Information on category D may not be suitable to be used in the MVA as well. In particular, modeled species' responses to future climate change is not robust to small changes in assumptions and simulation models (Araújo and Peterson 2012; Wright et al. 2015). Thus, reflecting the “black box” of such simulations into the MVA is risky and was avoided.

Importantly, rerating each factor value in each subfactor which was previously rated by the CCVI assessment is not used for determining a final conclusion of the MVA because no calculation is needed to determine species’ vulnerability. Rather, the rerated factor values are useful for visualizing which subfactors are relevant to vulnerability/adaptability of each assessed target species and also for clarifying which factor values of the CCVI need to be revised from the corrected perspective. Rather than these factor values, rationales (reasoned argumentation) are more important for each final assessment conclusion in the MVA.

Application of the MVA to three national parks in eastern Canada

We applied the MVA to the same species whose vulnerability was assessed by the CCVI so that we can compare the results of the two approaches. The assumed climate change scenarios, as well as the methods of collecting information for the assessment, were the same as those of the CCVI, as noted above. Details of our MVA assessment in the parks and discussion on adaptation measures based on its results were reported in Chapter 4. Species-specific reasoned argumentation is provided in Electronic Supplements (species-specific assessment sheets).

Although 113 species-specific assessments were conducted, 12 of them did not give conclusions in the MVA due to a lack of information on physiological thermal niche of the assessed species. The species proportions of HV (Highly Vulnerable), MV

(Moderately Vulnerable), PS (Presumably Stable), MA (Moderately Adaptable), and HA (Highly Adaptable) across the three parks were 16%, 25%, 20%, 27%, and 12% respectively.

(5) Discussion

Similarities and differences between results of CCVI and MVA

We could not conduct a precise (quantitative) comparison between outputs of the two approaches, partly because the category of “HV” in the CCVI is not exactly the same as that (“HV”) in the MVA, for instance. However, in both approaches, the categories of “HV” and “MV” refer to vulnerable species, while those of “IL, “MA” and “HA” indicate adaptable species under climate change. Also, the species that were judged as MV/PS (Moderately Vulnerable/Presumably Stable) can be regarded as vulnerable species (in part), while those judged as PS/IL (Presumably Stable/Increase Likely) or PS/MA (Presumably Stable/Moderately Adaptable) can be regarded as adaptable species (in part). When following this idea, 41% of the assessed species were judged as vulnerable to the severe climate change scenario by both the CCVI and the MVA. 30% of the assessed species were adaptable according to the CCVI, while 39% of them were adaptable according to the MVA. Out of 101 species-specific assessments across the three parks, 13 assessments resulted in contrasting species’ responses to climate change between the CCVI and the MVA (Table 5.2). Therefore, as a whole, the outputs of the two approaches were close to each other, suggesting that most of the assessments using the CCVI were supported by qualitative interpretation of each species.

Contrasting results between the CCVI and the MVA were obtained mostly with the severe climate change scenario, while only two out of 13 species (sugar maple in Cape Breton Highlands National Park and white-winged crossbill in Fundy National Park) resulted in contrasting responses even under the moderate climate change scenario. Among the 13 species-specific assessments (15, when including the results of the moderate scenario), nine (ten, when including the moderate scenario) of them gave positive judgements by the MVA and negative ones by the CCVI. In other words, the species in these cases were judged as adaptable to climate change according to the MVA but vulnerable according the CCVI. On the other hand, four (five, when including the moderate scenario) cases showed the opposite pattern. The main reasons for discrepancies in results between the CCVI and the MVA are documented in Table 5.2.

There are several possible reasons for such discrepancies. First, some subfactors may not accurately reflect species' vulnerability/adaptability. According to the protocol provided by Young et al. (2011), for instance, soil endemics are more vulnerable to climate change than soil generalists (subfactor of C3). However, this idea may not be the case in reality (Anacker et al. 2013). For example, plant species that are distributed specifically on serpentine soils could be less vulnerable to climate change than other species that are on common soils, since the former group may already have high tolerance to stress such as limitations of water and nutrients (Damschen et al. 2012). Serpentine soils could be shelters for such plants even under climate change, while avoiding invasions of exotic species (Harrison et al. 2008). Thus, irrespective of whether each species is a generalist or a specialist to soil habitats, such special traits (e.g., serpentine plants) should be regarded as attributes for climate-change adaptation. An automatic translation from “limited tolerance to environmental conditions” into “species’ vulnerability” by algorithms seems to be convenient when dealing with a number of species, but such translations may be invalid for the subfactors that need painstaking interpretations.

Likewise, species’ specificity in terms of available resources is linked to species’ vulnerability to climate change directly in other subfactors. Omnivores are supposed to be judged with the score of SD (Somewhat Decrease Vulnerability) in the subfactor of C4b, while species that feed on a few species during any season in each year are supposed to be allocated a score of SI (Somewhat Increase Vulnerability). American black bear is an omnivorous and opportunistic predator of ungulates (Banfield 1974; Zagar and Beecham 2006). Fruits and seeds are common food resources for black bear (Beeman and Pelton 1980). Availability of nuts produced by oaks and beeches during autumn is crucial for some black bear populations (Beeman and Pelton 1980; Elowe and Dodge 1989). To show such a specific dietary preference, not only SD but also SI were chosen for the CCVI calculation. However, under warming climates, most of these foods will flourish rather than decline (e.g., oak). Thus, in the MVA, only SD was considered to be a plausible choice.

As well, the CCVI took into account every negative subfactor for species’ survivals automatically and integrated them into final calculation, while the MVA considered vulnerability/adaptability mainly based on physiological thermal niche (C2aii). For instance, in North America, American beech is distributed in and around the temperate zone (Fang and Lechowicz 2006), and in Fundy National Park this species may be moderately adaptable to warmer climates in terms of its physiological thermal niche.

Meanwhile, there are a few kinds of negative subfactors (e.g., B2a: natural barriers, C2bii: physiological hydrological niche, C2c: disturbance, C2d: ice/snow, and C4d: dependence on other species for dispersal) that have contributed to the species' vulnerability incrementally in the CCVI calculation. For instance, in cold regions within this species' range (e.g., highlands in west-central New Brunswick), cold winter temperature may have controlled the spread of bark disease, which is very common and serious in Acadian forests (Houston and Houston 2000; Simpson 2008). Although this disease is already common in Fundy, warming could contribute to expanding the disease infection further to the north (Betts and Forbes 2005; Ramirez et al. 2007; Parks Canada 2010d). Consequently, the benefit of a temperature increase (C2aii) on this species was cancelled out by these small negative subfactors on beech, which was finally judged as Moderately Vulnerable in part (i.e., MV at 50% and PS at another 50%) under the severe climate change scenario according to the CCVI.

Yet, positive effects of warming on growth of this species are considered to outweigh additional negative effects of the bark disease in warm climates (Witter et al. 2004). Also, disturbances including forest fires caused by warm climates could be negative to the species (Fowells 1965; Telfer 2004), but influences of a small increase of disturbance frequency and intensity may be limited on beech in the park. Otherwise, the same species would not be distributed in the United States extensively. Because of these, the MVA judged American beech moderately adaptable mainly based on its physiological thermal niche. In other words, the CCVI obviously neglected possible positive effects of temperature increase on the beech by piling up small negative effects of climate change in its algorithm without considering which subfactor is the most relevant to the species' vulnerability.

Defensibility of algorithmic approaches vs. reasoned argumentation

The CCVI has a couple of strengths, such as applicability for a wide range of species including both animals and plants, as well as its user-friendly design (Young et al. 2011; 2012). Also, algorithmic CCVAs, including the CCVI, try to integrate pieces of information on assessed species' ecology, physiology, and genetics into a single metric of vulnerability and rank the species based on vulnerability. Such trials are relatively new, ambitious, and seemingly convenient, having led to wide use of these CCVAs.

In this study, on the other hand, some pitfalls of the CCVI and similar CCVAs were clarified. Although some users of the CCVI have reported just their results using this method without questioning or challenging the approach (e.g., Byers and Norris 2011; Brinker and Jones 2012), our study tried to shed light on the risks of using the CCVI. Importantly, the challenges explored in this study are not peculiar to the CCVI but prevalent among other species-ranking systems as well as map-based species' distribution predictions (SDMs). In this regard, we argue that qualitative reassessment and reinterpretation of species is helpful to compensate for the challenges when ranking/assessing species by algorithms and models. As mentioned above, qualitative assessments like the MVA are so simple that we could clarify the advantages and shortcomings of other CCVAs by comparing between the MVA and other CCVAs. We also have low risk of being misled by pseudo-quantifications and other faulty assumptions/conditions of algorithms/models. A methodological contrast between the CCVI and the MVA is summarized in Table 5.3.

However, there are also potential weaknesses with the MVA. First, this qualitative approach cannot give precise and quantitative evaluations of species' responses to climate change. For instance, because it was hard to assess the negative impact of climate change on species by differentiating GI (Greatly Increase Vulnerability) from Inc (Increase Vulnerability) in each subfactor, we therefore removed the choice of GI (Greatly Increase Vulnerability) in the MVA. Likewise, it was hard to differentiate EV (Extremely Vulnerable) from HV (Highly Vulnerable), while both EV and HV may need to be thought through in terms of practical conservation. So, the class of EV was not used in the MVA.

As well, while the MVA avoids some of the challenges of the CCVI, it should be noted that the MVA still involves classifications. Even though a rationale is provided for each classification, some of the classification results might be controversial and debatable. After all, no ranking system can completely resolve the issue of arbitrary classifications (Gardali et al. 2012), and the MVA just tackled the issue partly by decreasing the number of classes/thresholds. However, we could correct the argumentation in the future when more data become available, if necessary, because the argumentation is more transparent and flexible than the algorithmic approach of the CCVI.

Finally, the MVA visualizes how we integrate many subfactors into final results by explicitly documenting the thinking process (e.g., American beech, as described above), while the CCVI assessments have usually shown each subfactor's contribution just by subscores without reasoning. The consulted experts in Fundy National Park also supported the transparency of the MVA process as its strength. Nonetheless, the reasoned argumentation underlying the MVA could still be wrong. Ultimately, to know whether the expected algorithm is correct, we will need to monitor actual species' responses to climate change for the next several decades and compare them to expected responses. By doing so, future ecologists and conservationists could revise both the combinatorial algorithm of the CCVI as well as reasoned argumentation of the MVA. This is the essence of adaptive management (Duinker and Trevisan 2003).

(6) Conclusion

We explored the issues of algorithmic approaches and skewed viewpoints of the CCVI and similar CCVAs using a case study in three wooded national parks in Canada. Particularly, the latter issue (the viewpoint issue) has been pointed out by few researchers, and it is originally a different issue from the algorithm issue. However, as shown in Fig 5.1., the viewpoint issue is embedded in the evaluation process of many subfactors, which distorts the algorithmic evaluation process. Thus, the two issues were discussed in our article simultaneously. We then introduced a simple reasoned argumentation approach, the MVA, which allowed us to keep the strengths and avoid some key weaknesses of the CCVI. If both of the CCVI and the MVA had complicated assessment processes/algorithms, it would have been difficult to characterize the CCVI by comparing the two approaches. Therefore, the simplicity of the MVA was helpful for our comparative study. Consequently, we found that most species were assessed in the same directions (vulnerable or adaptable to climate change), though a few species showed contrasting responses to climate change between the two approaches. We then discussed possible reasons for the discrepancies in the result.

Importantly, we do not convey a message that the CCVI is to be avoided in favour of approaches like the MVA. Rather, we argue that the kinds of pitfalls that we explored should be fully exposed and analyzed when people use the CCVI or similar species evaluation tools. Ultimately, incisive qualitative interpretation of the outputs from these tools is paramount for correcting errors in assumptions, and therefore outputs and understanding climate-change vulnerability at deeper levels.

Table 5.1 Subfactors of the Climate Change Vulnerability Index (CCVI) (Young et al. 2011) and their misgivings.

Subfactor	Selectable factor values†		Relevance	Misgivings‡		Other misgivings and/or supplemental explanation
				(i)	(iii)	
B1	GI-Inc-SI-N-SD	Exposure to sea level rise		*	*P	
B2a	GI-Inc-SI-N	Natural barriers			*P	Available adaptation opportunities should be also considered (c.f., Berry et al. 2013).
B2b	GI-Inc-SI-N	Artificial barriers			*P	A few species could gain benefits from habitat fragmentation.
B3	Inc-SI-N-SD-Dec	Predicted impact of land use changes resulting from human responses to climate change				
C1	GI-Inc-SI-N-SD-Dec	Dispersal and movement		*	*O	Generation time may need to be considered as well.
C2ai	GI-Inc-SI-N-SD	Historical thermal niche		*	*P	It seems to be less relevant than physiological thermal niche to species' vulnerability to climate change. As well, this subfactor may depend on scale of assessed areas (As an assessed area becomes larger, variation in temperature that a species experienced may be greater) (c.f., Ring et al. 2013).
C2aii	GI-Inc-SI-N-SD	Physiological thermal niche	*	*	*P	
C2bi	GI-Inc-SI-N-SD	Historical hydrological niche		*	*P	It seems to be less relevant than physiological hydrological niche to species' vulnerability to climate change. As well, this subfactor may depend on scale of assessed areas (As an assessed area becomes larger, variation in moisture that a species experienced may be greater) (c.f., Ring et al. 2013).
C2bii	GI-Inc-SI-N-SD	Physiological hydrological niche	*	*	*P	
C2c	Inc-SI-N-SD-Dec	Dependence on a specific disturbance regime likely to be impacted by climate change	*			It contains too many disturbance forces, and both positive and negative impacts of disturbances could be considered for many spcies. In other words, it could be hard to assign factor values to C2c in particular. Monte Carlo simulations tackle such uncertainty issues to some extents (Young et al. 2011; 2015). However, at least influences of pathogen outbreaks need to be assessed in other subfactors like C4e, because they are biotic effects.
C2d	GI-Inc-SI-N	Dependence on ice, ice-edge, or snow-cover habitats	*		*P	Positive effects of decline of snow/ice accumulations should be able to be reflected here.

C3	Inc-SI-N-SD-Dec	Restriction to uncommon geological features or derivatives			*O	High flexibility in dependence on geological features does not necessarily contribute to species' adaptation to climate change (c.f., Anacker et al. 2013).
C4a	GI-Inc-SI-N	Dependence on other species to generate habitat	*		*P	If species that generate habitats of assessed species are adaptable to climate change, factor values in the subfactor should be SD and/or Dec.
C4b	GI-Inc-SI-N-SD	Dietary versatility (animals only)			*P	If species that are primary food for assessed species are adaptable to climate change, factor values in the subfactor should be SD and/or Dec.
C4c	GI-Inc-SI-N	Pollinator versatility (plants only)			*P	If species that are primary pollinators for assessed species are adaptable to climate change, factor values in the subfactor should be SD and/or Dec.
C4d	GI-Inc-SI-N	Dependence on other species for propagule dispersal			*P	If species that are primary dispersers for assessed species are adaptable to climate change, factor values in the subfactor should be SD and/or Dec.
C4e	Inc-SI-N	Forms part of an interspecific interaction not covered by 4a-d	*		*O	It focuses on positive and pre-existing interspecific interactions, but not negative ones. However, climate change may bring about occurrences of some new interactions that could be detrimental for species' survivals.
C5a	Inc-SI-N-SD	Measured genetic variation			*P	Young et al. (2011) recommended assessors to consider the two indices of Master et al. (2012), G/S-ranks, to interpret results of scoring the CCVI. This is because the CCVI did not reflect species' demographic conditions. Yet, the subfactors of C5 could indirectly reflect population demography. Generally, intra-population genetic diversity is determined by effective population size together with a few other factors (Frankham, 1996). In this sense, the assessment viewpoint of the CCVI is partly overlapping with those of the G/S-ranks. Also, small intra-population genetic variation does not necessarily lead to species' vulnerability.
C5b	Inc-SI-N	Occurrence of bottlenecks in recent evolutionary history				
C6	Inc-SI-N-SD	Phenological response to changing seasonal temperature and precipitation dynamics			*P	
D1	GI-Inc-SI-N-SD-Dec	Documented response to recent climate change		*		
D2	GI-Inc-SI-N-SD-Dec	Modeled future change in population or range size		*		c.f., Wright et al. (2015)

D3	GI-Inc-SI-N	Overlap of modeled future range with current range	*
D4	Inc-SI-N	Occurrence of protected areas in modeled future distribution	*

† GI, Greatly Increase vulnerability; Inc, Increase vulnerability; SI, Somewhat Increase vulnerability; N, Neutral; SD, Somewhat Decrease vulnerability; Dec, Decrease vulnerability.

‡ Explanations about the misgivings of (i) and (iii) are included in the main text. The subfactors that could be too pessimistic and optimistic about impacts of climate change are shown with the letters of “P” and “O” respectively.

Table 5.2. Species that showed contrasting vulnerability responses to climate change between the CCVI and the MVA in the three national parks.

Park	Tx‡	English Name	CC scenario*	CCVI (with category D)**	CCVI (without category D)**	MVA	Main reasons for discrepancies (see Electronic supplements for details including supporting references)
Kejimkujik							
	F	Yellow perch	Severe	-	MV/PS	MA/HA	Positive effects of temperature increase (C2aii) cannot be fully reflected in the CCVI because of lacking option of "Dec". Also, a limited within-population genetic variation (C5a) was considered in the CCVI but not the MVA.
	T	American beech	Severe	MV	MV	PS/MA	Several non-thermal subfactors (C2bii, C2c, C2d, C4d) were contributing to the species' vulnerability and canceling out effects of thermal factor (C2aii) in the CCVI. In the MVA, by contrast, C2aii was considered as most relevant, while the other subfactors were also taken into account.
Cape Breton Highlands							
	B	Hermit thrush	Severe	-	IL	MV/PS	High dipersal ability (C1) and generalist trait to physical habitats (C3) lowered the species' vulnerability in the CCVI, though declines of boreal conifer species will lead to, in part, reduction of suitable habitats for the same species under future climates. The MVA considered this possibility as the most relevant factor (C4a).
	M	Black bear	Severe	-	MV	PS/MA	Several subfactors (e.g., B2b, C2ai, C2d) were contributing to the species' vulnerability in the CCVI. However, effects of these subfactors (e.g., historical thermal niche) are uncertain. Rather, given that some temperate trees like red oak will flourish under warmer climates, such vegetational change will possibly lead to richer food resources for black bear. According to the current CCVI protocol, possibly relevant subfactors, such as C4a or C4b, are not supposed to reflect such effects (changes of prey species).
	T	Sugar maple	Moderate	PS/IL	MV/PS	MA	Several subfactors (e.g., B2a, C2ai, C2bii, C2d, C5a) were contributing to the species' vulnerability in the CCVI. However, effects of these subfactors (e.g., genetic variation) are uncertain. In contrast, positive effects of temperature increase (C2aii) cannot be fully reflected in the CCVI because of lacking option of "Dec".
	T	Sugar maple	Severe	MV	EV	PS/MA	

	T	American elm	Severe	PS/IL	MV/PS	MA/HA	Several subfactors (e.g., B2a, C2ai, C2bii) were contributing to the species' vulnerability in the CCVI. However, effects of these subfactors (e.g., historical thermal niche) are uncertain. In contrast, positive effects of temperature increase (C2aii) cannot be fully reflected in the CCVI because of lacking option of "Dec".
Fundy							
	B	Hermit thrush	Severe	-	IL	MV/PS	High dispersal ability (C1) and generalist trait to physical habitats (C3) lowered the species' vulnerability in the CCVI, though remarkable temperature increase might affect the species negatively via increases of disturbance pressures and/or temperate deciduous forests. The MVA considered this possibility as the most relevant factor (C4a).
	B	White-winged crossbill	Moderate	-	PS/IL	MV/PS	High dispersal ability (C1), generalist trait to physical habitats (C3) and a few other subfactors lowered the species' vulnerability in the CCVI, though declines of boreal coniferous forests could contribute to vulnerability of the species under climate change. The MVA considered this possibility as the most relevant factor (C4a).
	B	White-winged crossbill	Severe	-	IL	MV	
	M	Snowshoe hare	Severe	-	IL	MV/PS	High dispersal ability (C1), generalist trait to physical habitats (C3) and a few other subfactors lowered the species' vulnerability in the CCVI, though declines of boreal coniferous forests and also declines of snow accumulation are much influential on the species. The MVA considered them as the most relevant factor (C2d and C4a).
	M	Black bear	Severe	-	MV	PS/MA	Several subfactors (e.g., B2b, C2d, C5a) were contributing to the species' vulnerability in the CCVI. However, effects of these subfactors (e.g., genetic variation) are uncertain. Rather, given that some temperate trees like red oak will flourish under warmer climates, such vegetational change will possibly lead to richer food resources for black bear. According to the current CCVI protocol, possibly relevant subfactors, such as C4a or C4b, are not supposed to reflect such effects (changes of prey species).

T	Sugar maple	Severe	MV/PS	MV	MA	Several subfactors (e.g., B2a, C2bii, C2d, C4c) were contributing to the species' vulnerability in the CCVI. However, effects of these subfactors (e.g., pollination versatility) are uncertain. In contrast, positive effects of temperature increase (C2aii) cannot be fully reflected in the CCVI because of lacking option of "Dec".
T	American beech	Severe	MV/PS	MV/PS	MA	Several subfactors (e.g., B2a, C2bii, C2d, C4d) were contributing to the species' vulnerability in the CCVI. However, effects of these subfactors (e.g., dependence on other species for seed dispersal) are uncertain. In contrast, positive effects of temperature increase (C2aii) cannot be fully reflected in the CCVI because of lacking option of "Dec".
T	Eastern hemlock	Severe	MV	MV	PS/MA	Several subfactors (e.g., B2a, C2bii, C2c, C5a) were contributing to the species' vulnerability in the CCVI. However, effects of these subfactors (e.g., genetic variation) are uncertain. In contrast, positive effects of temperature increase (C2aii) cannot be fully reflected in the CCVI because of lacking option of "Dec".

‡, Tx refers to taxon (B, bird; F, fish; M, mammal; T, tree).

*, Climate-change scenario.

**, Category D reflects documented and/or modeled response of assessed species to climate change based on previous studies (typically species distribution models (SDMs)). EV, Extremely Vulnerable; HV, Highly Vulnerable; MV, Moderately Vulnerable; PS, Not Vulnerable/Presumed Stable; IL; Increase Likely (which corresponds to MA/HA); MA, Moderately Adaptable; HA, Highly Adaptable. The cells in black and white show vulnerable and adaptable responses respectively, and therefore combinations of different colors are contrasting responses to climate change.

Table 5.3. Comparison between the CCVI and the MVA in terms of three challenges.

	The CCVI	The MVA
Overall structure	- Complex (known as a “black box”) - Semi-quantitative	- Simple and transparent - Qualitative
1. Classifications of continuous variables	- Classification is convenient, but discretizing continuous variables could distort data.	- Classification is still used qualitatively. - However, automatic assignment of categorical variables to continuous variables is avoided.
2. Generic combinatorial algorithm of subfactors	- An explicit and quantitative algorithm (“weighted sum method”) is given. - However, weightings could be varied depending on species and/or locations. - Some subfactors may be less relevant to species’ vulnerability than other subfactors (e.g., historical thermal niche vs. physiological thermal niche), and hence some weightings might be wrong.	- There is no algorithm in the MVA, but it integrates subfactors qualitatively based on species-specific information (i.e., reasoned argumentation). - Reasoned argumentation could sometimes be wrong and subjective. - However, we could correct the argumentation in the future, if necessary, because the argumentation is more transparent and flexible than the algorithmic approach of the CCVI.
3. Vulnerability and adaptability	- Each subfactor tends to evaluate negative influences of climate change rather than positive ones. - The final index scores are also designed to focus on vulnerability rather than adaptability.	- Both negative and positive influences of climate change are covered equally in its frame. - Hence, both of vulnerability and adaptability could be assessed neutrally.
(Other contrasts)	- Vulnerability is assessed in terms of as many as 20 subfactors, and some of them could be redundant with each other (i.e., multicollinearity). - Documented and/or modeled responses of species to climate change (typically SDMs) can also be incorporated into the assessment.	- Vulnerability/adaptability is assessed in terms of physiological thermal niche and a few other relevant subfactors. - Documented and/or modeled responses of species to climate change (typically SDMs) could be considered in the assessment process. Yet, they were not used in the MVA in our study, because SDM studies could also suffer from the same pitfalls as the CCVI (see the main text).

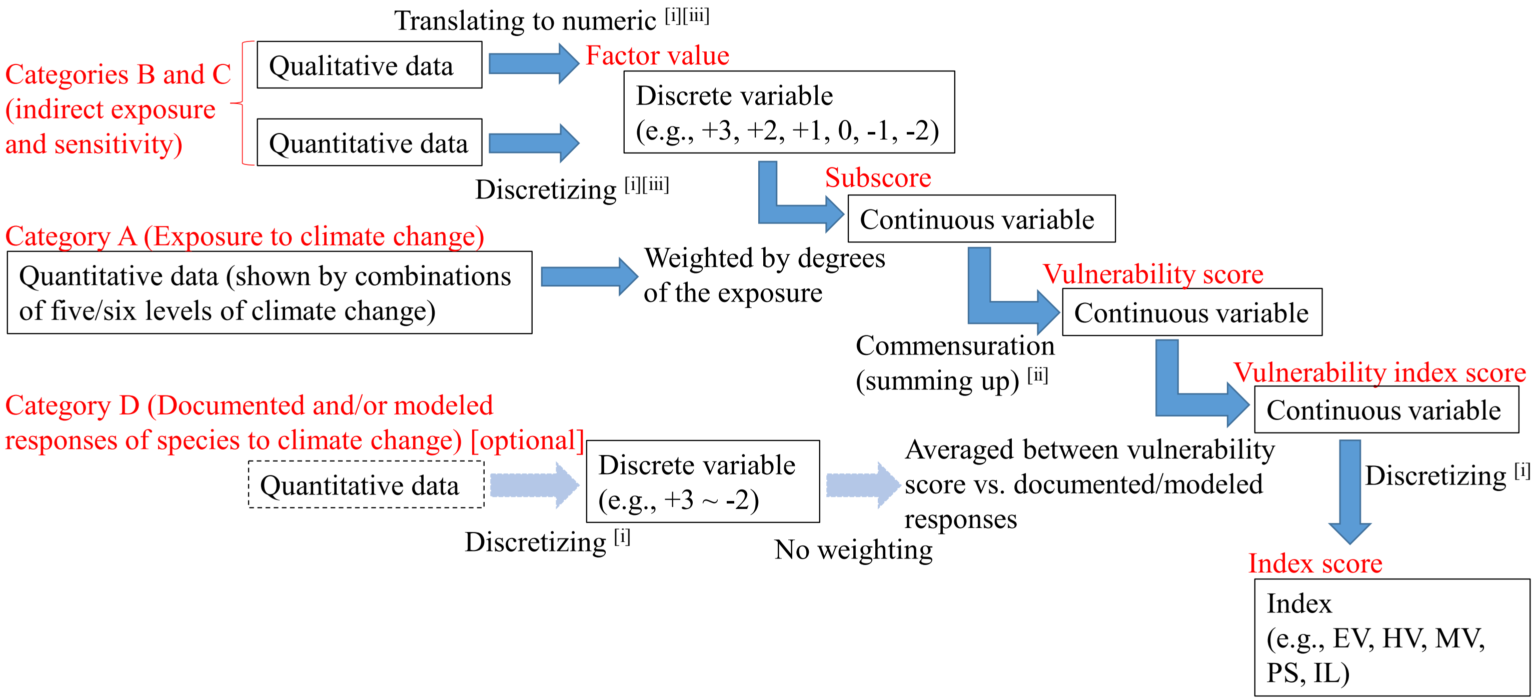

Fig 5.1. Algorithm of the Climate Change Vulnerability Index (CCVI) developed by Young et al. (2011). The processes with superscripts ([i], [ii], and/or [iii]) mean that they entail some of the three pitfalls described in the main text.

Chapter 6. Conclusions

Dicks et al. (2014) suggested the 4S hierarchy (Study, Systematic review, Summary, and Support system) for science-based conservation. According to them, each study should be integrated into systematic reviews (1), and several reviews could lead to summarizing academic insights for practical conservation (2). Such summaries are expected to be written in simple language, concise but still useful (including recommendations for conservation) for practitioners (3) (Dicks et al. 2014). Decision support systems based on such summaries may also be helpful for science-based conservation (4). Such a flow from (1) to (4) should be mainstream in the near future to enhance nature conservation.

The current study serves in the intermediate part of the flow, systematic review (2) and summary (3), for management in the three national parks with the onset of climate change. This is because our study did not provide original data on specific questions by conducting field surveys or experiments, and in this sense our study is different from a typical individual study. Rather, the study collected many pieces of information and integrated them to judge species' vulnerability/adaptability and also gave some tips on what we should do, and continue to study, as next steps. In other words, from a practical perspective, we hope that our current study will contribute to the last step of Dicks et al. (2014)'s flow, science-based conservation (4), in the future.

Regarding future research challenges, Gomer (1999), who conducted a qualitative CCVA in Kejimkujik National Park by expert consultation, suggested several recommendations, such as further studies on species that are sensitive to climate change, and those on pest and alien species that may flourish under warmer climates. We agree with her recommendations, though “alien species” could be redefined. According to “intervention ecology”, some new species can be regarded as important components in new climates (Hobbs et al. 2011) (Appendix 5.3 for details). New species coming from outside were previously targeted for eradication/removal, but recently a few studies suggested that the decision regarding such species’ eradication should be more context-dependent (e.g., Shakelford et al. 2013). In addition to these complicated and diverse perceptions on alien species, it is also unclear if species that have expanded their distributions by ongoing climate change should be regarded as “alien species” or not. So far, just a few people have stated that even species coming from elsewhere due to climate change could be regarded as exotic (Hoffman et al. 2011; Kunzig 2012).

There has been no official definition or extensive discussion about the definition of alien species in the context of climate change, which is the indirect result of anthropogenic activities such as burning fossil fuels and deforestation (Karl and Trenberth 2003; IPCC 2013), but not an artificial activity per se. Moreover, there is still public skepticism regarding the idea that current climate change has been caused by human activities (e.g., as described by Poortinga et al. 2011). In short, what are “native species” and “alien species” could be reconsidered in each park. This reconsideration is relevant particularly in parks where artificial introductions of some species have been conducted (e.g., Western moose in Cape Breton Highlands National Park (Beazley et al. 2006)). From a more technical perspective, we advocate for further developments of CCVAs including the CCVI. In the long term, we look forward to seeing integration between CCVAs and WRAs/pest risk assessments, as mentioned in Appendix 5.3.

As well, Gomer (1999) gave a couple of management recommendations, such as monitoring alien species, reconsidering policies about fires, and incorporating consideration of climate change into future park management plans. Thereafter, for instance, Fundy National Park drafted a fire management plan, and it is about to be approved. Thus, some of the recommendations by Gomer (1999) have been addressed.

However, current park management has documented no specific policies against climate change, which should be improved in the next decade. Furthermore, a drastic reduction in the budget of Parks Canada since 2012 has led to the decline of scientific activities by around one third, as well as a decline in park service (Canadian Parks and Wilderness Society (CPAWS) 2014). In this regard, as discussed in Chapter 4, examining the feasibility (cost) and effectiveness of adaptation measures will become more important than before. *Laissez-faire* approaches could be then better than the other approaches, depending on effectivess (including side effects) and feasibility of adaptation measures. Thus, although we hope protected area managers tackle the issue of climate change seriously, we do not necessarily argue that implementing some interfering measures is always better than *laissez-faire* approaches. In this regard, our view is contrasting with Suffling and Scott (2002) and Scott and Lemieux (2005), who suggested that adaptive management would be more effective, efficient and thus wise way than *laissez-faire* approaches. We believe that this idea needs to be examined based on more data and discussion with practitioners. We also suggested adaptation challenges at the inter-protected area level (e.g., assisted migration between parks) in Chapter 4.

However, the most important way to address the issue of climate change is, after all, the mitigation or reduction of greenhouse-gas emissions. We can never resolve the issue radically without substantial climate-change mitigation, even if we implement strong adaptation measures in protected areas (Hannah et al. 2002). Therefore, along with adaptation measures, we should do our best to mitigate climate change.

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Appendix 4.1. The likely changes in Atlantic parks and forests complied from Suffling and Scott (2002) and C-CIARN (2007).

Possible impacts of climate change on the Atlantic Canada

1) Sea-level rise
2) Increased coastal erosion and salt water intrusion
3) Altered coastal ecosystems (dunes, tidal pools, mudflats, salt marshes and estuaries)
4) Changed ocean currents and iceberg numbers, with possible coastal water cooling (expansion of cold-water species)
5) Exposure to extreme weather (e.g., strong rains, heavy snowfalls, strong winds)
6) Vulnerable infrastructure (e.g., transportation in lowlands)
7) Heavily natural resource-dependent communities (e.g., forestry)

Possible challenges for Acadian forests in this region

1) Compulsory northwards movements
    i) Increased mixed and deciduous forest, less boreal forest
    ii) Reduction, isolation and extirpation of arctic-alpine species and communities
2) Changing disturbance regimes
3) More frequent fires
4) Pathogen outbreaks
5) Invasions and expansions of some invasive species

Appendix 4.2. Assessed species list by climate change vulnerability assessments in three national parks in the Maritime Provinces of Canada.

Taxon	Scientific name	English name	S-rank in park(s)*		
			K	C	F
Bird	*Ardea herodias herodias*	Great blue heron			S4S5
Bird	*Bonasa umbellus togata*	Ruffed grouse			S4S5
Bird	*Catharus bicknelli*	Bicknell's thrush		S1S2	
Bird	*Catharus guttatus faxoni*	Hermit thrush		S4S5	S4S5
Bird	*Chaetura pelagica*	Chimney swift		S1S2	
Bird	*Charadrius semipalmatus*	Semi-palmated plover			S4S5
Bird	*Contopus borealis/cooperi*	Olive-sided flycatcher		S1S2	
Bird	*Cyanocitta cristata bromia*	Blue jay		S4S5	
Bird	*Dendragapus/Falcipennis canadensis canace*	Spruce grouse		S4S5	
Bird	*Dryocopus pileatus abieticola*	Pileated wood-pecker			S4S5
Bird	*Euphagus carolinus nigrans*	Rusty blackbird	S2S3		
Bird	*Falco peregrinus anatum*	Peregrine falcon			S1S2
Bird	*Gavia immer*	Common loon	S2S3		
Bird	*Junco hyemalis hyemalis*	Dark-eyed junco			S4S5
Bird	*Loxia leucoptera*	White-winged crossbill			S4S5
Bird	*Parus/Poecile hudsonicus*	Boreal chickadee		S3S4	
Bird	*Perisoreus canadensis*	Gray jay		S3S4	
Bird	*Setophaga ruticilla*	American redstart		S4S5	
Bird	*Strix varia varia*	Eastern barred owl	S4S5		
Bird	*Tringa melanoleuca*	Greater yellowlegs		S3S4	
Bird	*Turdus migratorius migratorius*	American robin		S4S5	
Bird	*Vireo olivaceus*	Red-eyed vireo		S4S5	
Bird	*Wilsonia canadensis*	Canada warbler		S1S2	
Fish	*Ameiurus nebulosus*	Brown bullhead	S4S5		
Fish	*Anguilla rostrata*	American eel		S2S3	S4S5
Fish	*Morone americana*	White perch	S4S5		
Fish	*Perca flavescens*	Yellow perch	S4S5		
Fish	*Salmo salar*	Atlantic salmon		S2S3	S3S4
Fish	*Salvelinus fontinalis*	Brook trout	S3S4		S4S5
Mammal	*Alces alces*	American/Western moose	S1S2	S1S2	S4S5
Mammal	*Canis latrans*	Coyote	S4S5	S4S5	S4S5
Mammal	*Castor canadensis acadicus*	Beaver	S4S5		S4S5
Mammal	*Erethizon dorsatum dorsatum*	Porcupine	S4S5		
Mammal	*Glaucomys sabrinus gouldi*	Northern flying squirrel			S4S5
Mammal	*Glaucomys volans*	Southern flying squirrel	S3S4		
Mammal	*Lepus americanus struthopus*	Snowshoe hare		S4S5	S4S5

Taxon	Scientific name	English name	S-rank in park(s)*		
			K	C	F
Mammal	*Lynx canadensis*	Canada lynx		S1S2	S1S2
Mammal	*Lynx rufus gigas*	Bobcat		S4S5	
Mammal	*Martes americana americana*	American marten	S1S2	S1S2	S4S5
Mammal	*Martes pennanti*	Fisher	S3S4		
Mammal	*Myotis lucifugus lucifugus*	Little brown bat			S3S4
Mammal	*Odocoileus virginianus borealis*	white-tailed deer	S4S5	S4S5	S4S5
Mammal	*Peromyscus maniculatus abietorum*	Deer mouse		S4S5	
Mammal	*Procyon lotor lotor*	Raccoon			S4S5
Mammal	*Sorex cinereus acadicus*	Masked shrew		S4S5	
Mammal	*Tamias striatus lysteri*	Eastern chipmunk			S4S5
Mammal	*Tamiasciurus hudsonicus gymnicus*	Red squirrel/Pine squirrel		S4S5	S4S5
Mammal	*Ursus americanus americanus*	Black bear	S4S5	S4S5	S4S5
Mammal	*Vulpes vulpes rubicosa*	Red fox		S4S5	
Tree	*Abies balsamea*	Balsam fir	S4S5	S4S5	S4S5
Tree	*Acer pensylvanicum*	Striped maple		S4S5	
Tree	*Acer rubrum*	Red maple	S4S5	S4S5	S4S5
Tree	*Acer saccharum*	Sugar maple	S4S5	S4S5	S4S5
Tree	*Betula alleghaniensis*	Yellow birch	S4S5	S4S5	S4S5
Tree	*Betula cordifolia*	Mountain paper birch/Heart-leaved birch			S4S5
Tree	*Betula papyrifera*	White birch	S4S5	S4S5	S4S5
Tree	*Fagus grandifolia / Fagus americana*	American beech	S4S5	S4S5	S4S5
Tree	*Larix laricina*	Eastern larch/American larch/Tamarack	S4S5	S4S5	S4S5
Tree	*Ostrya virginiana*	Ironwood	S4S5		
Tree	*Picea glauca*	White spruce	S4S5	S4S5	S4S5
Tree	*Picea mariana*	Black spruce	S4S5	S4S5	S4S5
Tree	*Picea rubens*	Red spruce	S4S5	S4S5	S4S5
Tree	*Pinus resinosa*	Red pine	S4S5	S4S5	S4S5
Tree	*Pinus strobus*	White pine	S4S5	S4S5	S4S5
Tree	*Quercus rubra*	Red oak	S4S5	S4S5	S4S5
Tree	*Tsuga canadensis*	Eastern hemlock	S4S5	S4S5	S4S5
Tree	*Ulmus americana*	American elm		S4S5	

* S-rank refers to Subnational Conservation Status Rank (c.f., Table 3.5.). Species marked with S-rank were targeted for climate change vulnerability assessments in the indicated park(s) (K, Kejimkujik National Park; C, Cape Breton Highlands National Park; F, Fundy National Park).

Appendix 4.3. Estimates of current climate data for the three selected national parks in the Maritimes (average values between 1961 and 1990).

Month	Kejimkujik				Cape Breton Highlands				Fundy			
	Temperature across the park [◦C]	Temperature at a centroid [◦C]	Precipitation across the park [mm]	Precipitation at a centroid [mm]	Temperature across the park [◦C]	Temperature at a centroid [◦C]	Precipitation across the park [mm]	Precipitation at a centroid [mm]	Temperature across the park [◦C]	Temperature at a centroid [◦C]	Precipitation across the park [mm]	Precipitation at a centroid [mm]
1	-5.1	-4.6	144	139	-6.1	-9.8	149	93	-8.9	-10.9	146	133
2	-4.9	-5.0	116	112	-7.0	-10.9	109	110	-8.1	-9.8	103	113
3	-0.7	-1.1	120	110	-3.4	-3.5	115	114	-3.1	-4.9	121	119
4	4.4	4.0	113	105	1.3	1.3	112	101	2.7	-0.1	100	109
5	9.9	9.3	104	94	6.6	7.5	93	81	9.1	6.1	109	112
6	14.9	14.0	96	91	12.1	12.9	99	60	13.8	11.1	103	97
7	18.1	17.1	98	88	16.4	18.5	90	66	17.2	14.5	106	95
8	17.7	16.9	93	80	16.6	19.3	116	65	16.7	13.7	92	108
9	13.5	13.4	101	97	12.5	13.0	111	77	12.2	9.6	95	96
10	8.5	8.6	119	115	7.5	7.8	141	122	7.0	5.0	121	124
11	3.7	4.2	148	139	2.7	2.7	157	118	1.1	0.1	137	133
12	-2.2	-1.8	164	151	-2.8	-4.2	161	141	-6.0	-7.2	161	143
Ann	6.4	6.3	1416	1321	4.7	4.6	1454	1148	4.5	2.3	1393	1381
Win	-4.0		422		-5.2		414		-7.6		406	
Spr	4.5		337		1.4		320		2.8		331	
Sum	16.8		287		15.0		304		15.9		301	
Aut	8.5		368		7.5		409		6.7		353	

Appendix 4.4. Assumed climate-change scenarios of Kejimkujik National Park for Young et al. (2011)'s CCVI program.

	Moderate climate change scenario	Severe climate change scenario
Temperature change	+2.23 to +2.84℃	+4.04 to +4.39℃
AET:PET change	-0.013 to 0.007	-0.053 to -0.033
GDD5 change*	+530	+920
Rationale	It corresponds to a scenario of B1 (2080s) by Climate Wizard Custom (Girvetz et al. 2009) and roughly to a scenario of RCP4.5 50% (2081-2100c) by IPCC (2013).	It corresponds to a scenario of RCP8.5 50% (2081-2100c) by IPCC (2013), which is more drastic change than the conventional A2 scenario (2080s). Specific AET:PET change data are not available for this scenario. However, even the A2 scenario assuming temperature increase of +3.84℃ predicts decrease of AET:PET ratio by 0.036, and therefore we chose AET:PET change of "-0.033 to -0.053" for the severe climate change scenario.

Appendix 4.5. Assumed climate-change scenarios of Cape Breton Highlands National Park for Young et al. (2011)'s CCVI program.

	Moderate climate change scenario	Severe climate change scenario
Temperature change	+1.58 to +2.23℃ (50%) / +2.23 to +2.84℃ (50%)	+4.04 to +4.39℃
AET:PET change	-0.033 to -0.013 (50%) / -0.013 to 0.007 (50%)	-0.053 to -0.033
GDD5 change*	+450	+870
Rationale	It corresponds to B1 (2080s) scenario by Climate Wizard Custom (Girvetz et al. 2009) and roughly to a scenario of RCP4.5 50% (2081-2100c) by IPCC (2013).	It corresponds to a scenario of RCP8.5 50% (2081-2100c) by IPCC (2013), which is more drastic change than a conventional A2 scenario (2080s). Specific AET:PET change data are not available for this scenario. However, even the A2 scenario assuming temperature increase of +3.68℃ predicts decrease of AET:PET ratio by 0.033, and therefore we chose AET:PET change of "-0.033 to -0.053" for the severe climate change scenario.

Appendix 4.6. Assumed climate-change scenarios of Fundy National Park for Young et al. (2011)'s CCVI program.

	Moderate climate change scenario	Severe climate change scenario
Temperature change	+2.23 to +2.84℃	+4.04 to +4.39℃
AET:PET change	-0.013 to 0.007%	-0.033 to -0.013 (50%)/ -0.053 to -0.033 (50%)
GDD5 change*	+480	+830

Rationale	It corresponds to a scenario of B1 (2080s) by Climate Wizard Custom (Girvetz et al. 2009) and roughly to a scenario of RCP4.5 50% (2081-2100c) by IPCC (2013).	It corresponds to a scenario of RCP8.5 50% (2081-2100c) by IPCC (2013), which is similar to a conventional A2 scenario (2080s). Specific AET:PET change data are not available for this scenario. The A2 scenario assuming temperature increase of +4.17℃ predicts decrease of AET:PET ratio by 0.029, and therefore we chose AET:PET change of "-0.033 to -0.013" as well as "-0.053 to -0.033" for the severe climate change scenario. This projection is consistent with the fact that Fundy National Park is less likely to be dry than other parks in Atlantic Canada due to fogs from the Bay of Fundy.

*, GDD5 refers to Growing Degree Days above 5 ℃ (c.f., Appendices 4.7-4.10).

Appendix 4.7: Detail of estimating GDD5 change

There were no available data of future GDD5 of the three targeted parks. Therefore, we tried to estimate future GDD5 of the parks indirectly in two different ways. First, Richards and Daigle (2011) and Dalton et al. (2009) reported future annual temperature as well as future GDD5 in several towns around the parks in three different periods (the 2020s, 2050s, and 2080s). Therefore, we got regression equations between the two variables, annual temperature increase vs. GDD5 increase, from their projection, for three towns (Lunenberg, Cheticamp, and Moncton) respectively. For instance, an equation of "(GDD5 increase) = 209.87×(annual temperature increase) - 16.576" was obtained from the data of Cheticamp, a town situated by Cape Breton Highlands National Park. We then calculated GDD5 increase of each park based on temperature increase of the two assumed climate-change scenarios (Appendices 4.4-4.6) using the equations. So, in the case of Cape Breton Highlands National Park under the severe climate change scenario, GDD5 increase was 209.87×(4.04+4.39)/2 - 16.576 = 868.

Second, to confirm the adequacy of the result of the first method, we used the online program of Climate Change Knowledge Portal (http://climateknowledgeportal.climatewizard.org/) developed by the Nature Conservancy. This tool allows us to estimate GDD10, Growing-Degree Days based on 10°C under SRES-B1 and A2 scenarios in 2081-2100s. For instance, the A2 scenario of Cape Breton Highlands National Park assumes +4.34°C increase on average, which is slightly larger temperature change than the severe climate change scenario in our study. On the other hand, Gordon and Bootsma (1993) gave a well-fitting regression equation between GDD5 and GDD10 ($R^2 = 0.96$) in Atlantic Canada, and therefore we could calculate future GDD5 based on the GDD10 estimated by Climate Change Knowledge Portal. In the case of Cape Breton Highlands National Park, GDD10 was 1,232, and the corresponding GDD5 was 2,258. The difference in GDD5 between past average (1961-1990) vs. 2081-2100 was then 895. This value is slightly higher than the previously obtained GDD5 increase, 868. However, the value of 895 was assuming a slightly more drastic temperature change, as aforementioned, and therefore the two results are mutually consistent with each other.

Finally, for reference, we described the future climate-change scenarios of the three Maritime national parks in comparison with suitable habitats for main tree species in terms of Growing Degree-Days above 5℃ (GDD5) (Appendix 4.11). Herein, the GDD range of each tree species was obtained from a study on effects of climate change on forests in Atlantic Canada (Steenberg et al. 2013). This figure does not consider any non-thermal effects caused by climate change, but still it is convenient to understand impacts of climate change on each tree species in terms of thermal change.

Appendix 4.8. Estimates of Growing-Degree Days based on 5°C (GDD5) in Kejimkujik National Park.

	Moderate climate change scenario	Severe climate change scenario
1) Extrapolation based on the data of Lunenberg reported by Richards and Daigle (2011)		
Assumed temperature increase	+2.5°C	+4.2°C
GDD5 increase	+532	+917
2) Estimation based on GDD10 calculated by Climate Change Knowledge Portal*		
Assumed temperature increase	+2.8°C	+4.6°C
GDD5 increase	+641	+1,106
The current GDD5	1,659	1,659
The future GDD5	2,300	2,765

*, the second approach assumed the more distant future (2081-2100), and therefore the assumed climate-change scenarios are slightly more drastic than those of the first approach. The scenarios of the first approach are corresponding to the two scenarios in the main chapter.

Appendix 4.9. Estimates of Growing-Degree Days based on 5°C (GDD5) in Cape Breton Highlands National Park.

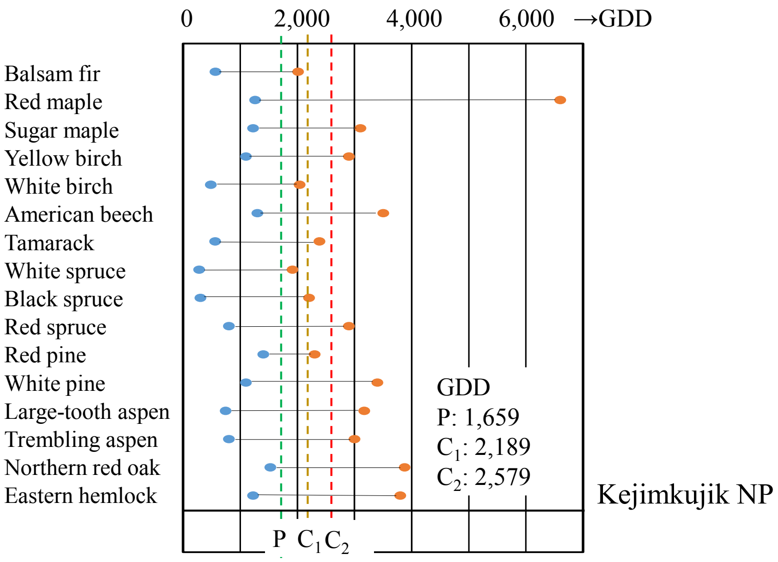
	Moderate climate change scenario	Severe climate change scenario
1) Extrapolation based on the data of Cheticamp reported by Richards and Daigle (2011)		
Assumed temperature increase	+2.2°C	+4.2°C
GDD5 increase	+447	+868
2) Estimation based on GDD10 calculated by Climate Change Knowledge Portal*		
Assumed temperature increase	+2.7°C	+4.3°C
GDD5 increase	+527	+895
The current GDD5	1,364	1,364
The future GDD5	1,891	2,258

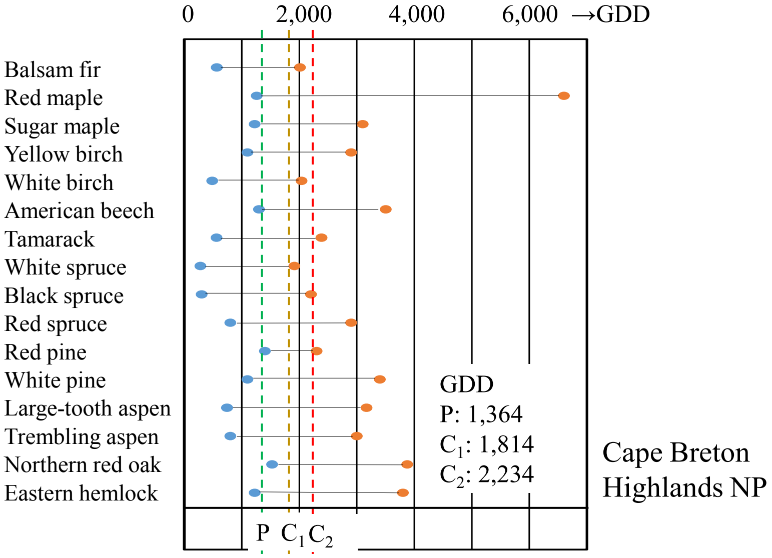
*, the second approach assumed the more distant future (2081-2100), and therefore the assumed climate-change scenarios are slightly more drastic than those of the first approach. The scenarios of the first approach are corresponding to the two scenarios in the main chapter.

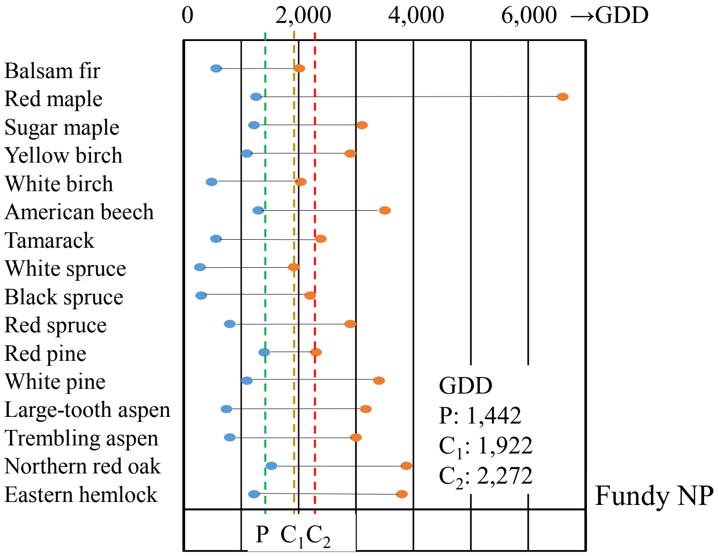
Appendix 4.10. Estimates of Growing-Degree Days based on 5°C (GDD5) in Fundy National Park.

	Moderate climate change scenario	Severe climate change scenario
1) Extrapolation based on the data of Moncton reported by Dalton et al. (2009)		
Assumed temperature increase	+2.5°C	+4.2°C
GDD5 increase	+481	+828
2) Estimation based on GDD10 calculated by Climate Change Knowledge Portal*		
Assumed temperature increase	+3.0°C	+4.8°C
GDD5 increase	+599	+1,043
The current GDD5	1,442	1,442
The future GDD5	2,041	2,485

*, the second approach assumed the more distant future (2081-2100), and therefore the assumed climate-change scenarios are slightly more drastic than those of the first approach. The scenarios of the first approach are corresponding to the two scenarios in the main chapter.


0
2,000
4,000
6,000
→GDD
Balsam fir
Red maple
Sugar maple
Yellow birch
White birch
American beech
Tamarack
White spruce
Black spruce
Red spruce
Red pine
White pine
Large-tooth aspen
Trembling aspen
Northern red oak
Eastern hemlock
GDD
P: 1,659
C_1: 2,189
C_2: 2,579
P C_1 C_2
Kejimkujik NP


0
2,000
4,000
6,000
→GDD
Balsam fir
Red maple
Sugar maple
Yellow birch
White birch
American beech
Tamarack
White spruce
Black spruce
Red spruce
Red pine
White pine
Large-tooth aspen
Trembling aspen
Northern red oak
Eastern hemlock
GDD
P: 1,364
C_1: 1,814
C_2: 2,234
P C_1 C_2
Cape Breton Highlands NP


0
2,000
4,000
6,000
→GDD
Balsam fir
Red maple
Sugar maple
Yellow birch
White birch
American beech
Tamarack
White spruce
Black spruce
Red spruce
Red pine
White pine
Large-tooth aspen
Trembling aspen
Northern red oak
Eastern hemlock
GDD
P: 1,442
C_1: 1,922
C_2: 2,272
P C_1 C_2
Fundy NP

Appendix 4.11. The future climate-change scenarios of the three national parks in comparison with suitable habitats for main tree species in terms of Growing Degree-Days above 5℃ (GDD5). P, Present; C_1, the moderate climate change scenario; C_2, the severe climate change scenario.

Appendix 4.12. Selected subfactors in Young et al. (2011)'s CCVI program (GI, Greatly Increase; Inc, Increase; SI, Somewhat Increase; N, Neutral; SD, Somewhat Decrease; Dec, Decrease; U, Unknown).

Subfactor	Selectable factor values	Notes for assessments targeting the three Maritime National Parks (detail of our protocol)
A (Exposure to local climate change)	-	This section assumes future climate-change scenarios by choosing one or multiple options from given choices of thermal and hydrological changes. Actual selections for the three parks are shown in Appendices 4.4-4.6.
B1 (Exposure to sea level rise)	GI-Inc-SI-N-SD	This subfactor is supposed to be judged based on proportion of area that will be exposed to sea level rise within an assessed range, and therefore species' distribution and projection of sea level rise are recommended for use in determining the factor values (Young et al. 2011). For instance, if 10-49% of species' distribution within an assessed area will be subject to sea level rise, SI should be selected. However, because we could not obtain distribution data for every assessed species within the parks, and because most terrestrial species in the parks are unlikely to be subject to significant (> 10%) sea level rise, a neutral (N) score was chosen for most species. For a few species that are allegedly exposed to sea level rise, both SI and N were chosen to reflect the possible impact.
B2a (Natural barriers)	GI-Inc-SI-N	Barriers outsides national parks should not be reflected in the current assessments, according to expert consultation in Kejimkujik National Park. Thus, we did not reflect geographical isolation effects outside of national parks. However, in Cape Breton Highlands National Park, species currently inhabiting Acadian/boreal forests could migrate to taiga region within the park under climate change. Thus, following Young et al.'s protocol, Inc and SI are selected for such species that can move upwards and can find limited refugium sites. On the other hand, species that are already distributed in taiga region cannot find any refugia and are completely isolated from other populations (which is known as the "mountain island effect" (Oline et al. 2000)). GI and Inc are given for such species. Likewise, the northern part of Fundy National Park is highland in which slopes may hinder migration of species to northern and higher areas in the future. However, the topography is not so steep as as to form a complete barrier. To reflect this partial barrier, SI and N are selected here. Choosing multiple factor values expresses uncertainty of the effect of natural barriers, and are reflected in Monte Carlo simulations in the CCVI assessment. In contrast, species that are distributed within flat sites without any highlands, as in Kejimkujik National Park, have no available refugia/shelter sites around their distributions. Such species should be more vulnerable to climate change than those in sites with greater topographic variation due to lack of adaptation opportunity. This is important especially when assessing species' vulnerability at local scales (e.g., national park), because upward migration is more relevant and effective to species' survival than long-distance poleward migrations. To move to a colder site by 1℃ from a certain place, a species needs to migrate for as long as 145 km in latitude but only 167 m in elevation (Jump et al. 2009). Hence, in the MVA, factor values for species in flat sites are rated more negatively than those in mountainous sites.

B2b (Artificial barriers)	GI-Inc-SI-N	This subfactor measures to which degree artificial barriers could hinder a species' distribution shift in response to climate change (Young et al. 2011). Of a total land area of 5,284ha in Nova Scotia, around 3,900 ha is still covered with forests; however, only 300 ha is dominated by old-growth forests (Mosseler et al. 2003). Likewise, of a total land area of 7,209ha in New Brunswick, around 4,900 ha is still covered with forests, though the area of old-growth forest is not known (Mosseler et al. 2003). Many animals are killed as a direct impact of roads in Nova Scotia (Fudge et al. 2007) and elsewhere (e.g., Yale Conrey and Mills 2001). Also, there are 44 geographically small watersheds, which could be further divided, in Nova Scotia, suggesting that this province is characterized with small drainage units (Kanno and Beazley 2004). Consequently, individuals/populations of freshwater species can move only within limited ranges. Some late- successional tree species have declined by human impacts in Acadian forests (Loo and Ives 2003), but the impacts are relatively light in the national parks due to regulations. Artificial barriers outside parks should not be generally considered according to the expert consultation in Kejimkujik National Park, unless assessed species are wide-ranging and thus require large habitats. Thus, the factor value in this subfactor was determined neutral for most species.
B3 (Predicted impact of land use changes resulting from human responses to climate change)	Inc-SI-N-SD-Dec	Because land uses are not permitted in national parks in general, no land use changes were assumed here regardless of climate change. Thus, the value of Neutral was chosen.
C1 (Dispersal and movement)	GI-Inc-SI-N-SD-Dec	This subfactor measures species' ability to shift its distribution in reponse to climate change without any natural/artificial barriers. For instance, a factor value for the species that disperse their propagules or individuals for 100-1000 m is supposed to be "N", whereas that for 1-10 km is "SD" (Young et al. 2011).
C2ai (Historical thermal niche)	GI-Inc-SI-N-SD	The maximum temperature in the warmest month (July) minus the minimum temperature in the coldest month (January) was 32.9◦C in Kejimkujik National Park according to Climate Wizard Custom (Girvetz et al. 2009), and therefore the factor value of "Neutral" (which corresponds to 31.8◦C - 43.0◦C) was given for all the species in this park. The maximum temperature in the warmest month (August) minus the minimum temperature in the coldest month (February) was 31.3◦C in Cape Breton Highlands National Park according to Climate Wizard Custom (Girvetz et al. 2009), and therefore the factor value of "Somewhat increase vulnerability" (which corresponds to 26.3◦C - 31.8◦C) was given for all the species in this park. The maximum temperature in the warmest month (July) minus the minimum temperature in the coldest month (February) was 36.3◦C in Fundy National Park according to Climate Wizard Custom (Girvetz et al. 2009), and therefore the factor value of "Neutral" (which corresponds to 31.8◦C - 44.0◦C) was given for all the species in this park.

C2aii (Physiological thermal niche)	GI-Inc-SI-N-SD	Physiological thermal niche is the most important subfactor in many CCVAs. There are some southern relic populations since the Hypsi-thermal period, due to a warm condition in Kejimkujik National Park (e.g., Southern flying squirrel; Lavers 2004; Petersen and Stewart 2006). Clayden et al. (2011) documented that the interior of southern Nova Scotia is one of the warmest regions in Eastern Canada with ample precipitation in summer. In contrast, Cape Breton Highlands National Park is situated at a latitudinally and elevationally high position, therefore in a relatively cool condition. Coastal fog in combination with a local cooling effect from the Bay of Fundy have created local refugia for some species (e.g., *Picea rubens*) around Fundy National Park during the mid-Holecene, and even now such microclimates maintain distinctive forest vegetation (Cox et al. 1996; Schauffler and Jacobson 2002; Clayden et al. 2011). Species' distribution and spatial projection of temperature change are recommended for use in determining values of this subfactor (Young et al. 2011), but we could not obtain distribution data for every assessed species within the parks. Therefore, we determined factor values based on other available information. Physiological thermal niche for tree species was determined in terms of not only annual average temperature but also Growing-Degree Days (GDD5: Appendices 4.7-4.11). Thermal conditions in some areas of the parks will likely be beyond of some tree species' tolerances according to GDD5, which would correspond to a factor value of "GI" in the CCVI program. However, longevity of tree species is very high in comparison with that of other taxa, and complete extirpation of these species in the parks by the 2080s is considered unlikely. Therefore, we did not give any tree species a factor value of "GI".
C2bi (Historical hydrological niche)	GI-Inc-SI-N-SD	The concept of this subfactor is similar to that of C2ai (Young et al. 2011), but for water rather than temperature. However, there are no available, precise spatial data on precipitation in the past 50 years for these parks, therefore we refrained from giving values for this subfactor.
C2bii (Physiological hydrological niche)	GI-Inc-SI-N-SD	This subfactor assesses the degree to which a species depends upon specific precipitation/hydrological regimes (Young et al. 2011). Like C2aii, we determined factor values based on available information instead of species' distribution and spatial projection of hydrological change. Clayden et al. (2011) documented that the interior of southern Nova Scotia is one of the warmest regions in eastern Canada with ample precipitation in summer. However, small and shallow waterbodies are at greater risk than large and deep rivers and lakes under climate change. So, the physiological hydrological niches of species depending on small and/or shallow waterbodies with delicate balance between inflow vs. outflow were judged to be vulnerable, while those of species on large and/or deep waterbodies were regarded as somewhat vulnerable. If a species is then insensitive to water level/depth, impacts of climate change on this species was judged as partly 'somewhat vulnerable' and partly 'neutral'. In contrast, Cape Breton Highlands National Park is characterized with a cool and moist climate (Péch 1993). Coastal fog in combination with the local cooling effect of the Bay of Fundy have created local refugia for some species (e.g., *Picea rubens*) around Fundy National Park during the mid-Holecene, and even now such microclimates keep distinctive forest vegetation (i.e., "perhumid forests") (Schauffler and Jacobson 2002; Clayden et al. 2011). Thus, these parks were assumed to remain moist under warmer climates in this vulnerability assessment.

C2c (Dependence on a specific disturbance regime likely to be impacted by climate change)	Inc-SI-N-SD-Dec	This subfactor measures a species' response to specific disturbance regimes, including fires, winds and even pathogen outbreaks (Young et al., 2011). Kejimkujik National Park has experienced many forest fires, particularly prior to the establishment of the park (Wein and Moore 1978; Clayden et al. 2011). Damage from hurricane winds has also influenced forests in and around this park, in the interior of southern Nova Scotia (Clayden et al. 2011). Therefore, we selected any of the available factor values including "Inc", Considering each species' tolerance and/or dependence on distrubances. On the other hand, Cape Breton Highlands National Park has experienced very few forest fires probably because of the climate (Wein and Moore 1979). Péch (1993) reported that the cool and moist climate in Cape Breton Highlands could decompose dead fuels easily even after budworm outbreaks, lowering fire probability. Coastal fog by the Bay of Fundy, especially during the summer season, has reduced the probability of forest fires around Fundy National Park as well (Clayden et al. 2011). Therefore, fire-related vulnerability was judged as either of "SI" or "SD", but not "Inc" or "Dec", for species in these two parks in our assessment.
C2d (Dependence on ice, ice-edge, or snow-cover habitats)	GI-Inc-SI-N	This subfactor focuses on species' dependence on ice/snow-associated habitats (Young et al., 2011). Projection about snowfall seems to be inconsistent among different studies. Generally, snow amount is likely to be decreased in a high GHG emission scenario by the end of the 21st century in southeastern Canada (Peacock 2012). However, Scott and Suffling (2000) proposed that a likely increase of winter precipitation would lead to higher snowfall in Cape Breton Highlands and Fundy National Parks. Richards and Daigle (2011) estimated increased snow days in Lunenberg (near Kejimkujik National Park) and Amherst (near Fundy National Park). However, even though more snow falls, it might melt more quickly under warmer conditions than it presently does. Biologically, snow accumulation may be more important but also more difficult to predict than snowfall amount. Our assessment assumed that changes in snow accumulation would not be substantial in the moderate climate change scenario but that there would be a substantial decrease in accumulation in the severe climate change scenario.
C3 (Restriction to uncommon geological features or derivatives)	Inc-SI-N-SD-Dec	This subfactor focuses on species' dependence on specific soil/substrates, geology, water chemistry, or other physical features (Young et al. 2011). Any features considered in the subfactor of C3 should be abiotic. However, animals are generally tolerant to various physical habitats. Animals that can move for long-distances (e.g., coyotes) may reflect such high tolerance, and therefore scoring for this subfactor was done in consideration of factor values for dispersal/movement (C1). Yet, the two subfactors are not necessarily in parallel with each other. If specific information was available about physical habitats for certain species, such information was prioritized for scoring. Still, all animal species were assessed as "Dec" or "SD", so long as they were not confined to specific geological features or areas. Species of other (non-animal) taxa often have specific requirements for physical habitats (e.g., pH), and thus such information was utilized in the scoring. However, generalist traits to physical habitats does not necessarily increase species' adaptability to climate change (Anacker et al. 2013). For instance, specificity to serpentine soils of plants could be helpful to survive under climate change (Damschen et al. 2012). However, in our current targets (area and species), we did not have such specific combinations (e.g., many serpentine habitats and serpentine plants, as seen in Califorinia). Thus, factor values of "Dec" as well as "SD" are replaced by "N" in the MVA.

C4a (Dependence on other species to generate habitat)	GI-Inc-SI-N	Any assessed species that depend upon other species to generate habitat are considered here (Young et al. 2011). For instance, a species whose habitat is generated by a small number of other species is to be assessed with the factor value of "SI”. However, if these species that generate habitat are adaptable to climate change, the factor value of “SI” is replaced by “SD” in the MVA.
C4b (Dietary versatility (animals only))	GI-Inc-SI-N-SD	This subfactor focuses on diversity of foods for assessed species (Young et al. 2011). For instance, a species that feeds on just a few species from a single guild is supposed to be rated with the factor value of "SI", while an omnivorous species is supposed to be with “SD”. However, if these prey species are adaptable to climate change, the factor value of “SI” is replaced by “SD” in the MVA.
C4c (Pollinator versatility (plants only))	GI-Inc-SI-N	This subfactor measures the degree to which a plant species depends upon specific pollinators to disperse its pollen (Young et al. 2011). If a species depends upon just a single pollinator species, it should be assessed with the factor value of “Inc” here.
C4d (Dependence on other species for propagule dispersal)	GI-Inc-SI-N	This subfactor measures the degree to which a species depends on specific species to disperse its propagules (Young et al. 2011). If a species depends on just a single species to disperse propagules, it is supposed to be assessed with the factor value of “Inc” here.
C4e (Forms part of an interspecific interaction not covered by 4a-d)	Inc-SI-N	This subfactor focuses on interspecific interactions that are needed for an assessed species but not assessed by the subfactors of C4a-C4d (e.g., mutualism) (Young et al. 2011). Hence, Young et al.’s protocol focuses on the potential loss of required interactios, but does not take into account any anticipated negative interspecific interactions. In contrast, in the MVA, any negative interactions that are anticipated with climate change are also incoporated into the assessment here. Note that pathogen outbreaks are supposed to be considered by the subfactor of C2c.
C5a (Measured genetic variation)	Inc-SI-N-SD	This subfactor reflects the relative amount of intra-population genetic variation of assessed species (Young et al. 2011). For instance, if a population retains very low genetic variation in comparison with that of other populations or related species, it is supposed to be rated with the factor value of “Inc” here. Variations at both selectively neutral and non-neutral (quantitative) loci are supposed to be used in the subfactor.
C5b (Occurrence of bottlenecks in recent evolutionary history)	Inc-SI-N	*(use only if C5a is "unknown")*
C6 (Phenological response to changing seasonal temperature and precipitation dynamics)	Inc-SI-N-SD	This subfactor looks at flexibility of species' phenological changes in response to climate change (Young et al. 2011). In other words, species that could more flexibly change their phenology, like migration timing, are considered less vulnerable to climate change. There are few data and publications on phenology in the Maritimes, while phenology changes in response to climate change could be varied among locations (e.g., Butler 2003; Marra et al. 2005). Therefore, we could rarely determine factor values of the subfactor in the current study.

D1 (Documented response to recent climate change)	GI-Inc-SI-N-SD-Dec	This subfactor refers to any actual positive or negative responses of assessed species to already occurring climate change (Young et al. 2011). For instance, if distribution of an assessed species has contracted drastically, the factor value of "GI" is supposed to be chosen (Young et al. 2011). In the Maritime region, such observations have been reported with just few species, and hence we could rarely use the subfactor.
D2 (Modeled future change in population or range size)	GI-Inc-SI-N-SD-Dec	Information about D2 for most plant species could be derived from “Species Climatic Distribution based on Future Climate Scenarios” by Natural Resources Canada (2014). This data was originally produced by McKenney et al. (2007), However, the same research team conducted additional work in 2014 using the latest modeling and climate-change scenarios. Here, we consulted their simulation results assuming RCP 4.5 and 8.5 scenarios with MaxEnt (composite-AR5) (Natural Resources Canada 2014).
D3 (Overlap of modeled future range with current range)	GI-Inc-SI-N	This subfactor is based on the idea that a species whose current range is overlapping with its future range is less vulnerable to climate change than species that have no overlaps between their current and future ranges (Young et al. 2011). Because we could not obtain distribution data for every assessed species within the parks, we did not use the subfactor.
D4 (Occurrence of protected areas in modeled future distribution)	Inc-SI-N	This subfactor refers to percentage of protected areas within each species' future range in the assessed area (Young et al. 2011). Technically, because we are focusing on just national parks, every species' range in the assessed areas should be within the protected areas. So, the factor value should be neutral. However, it means that the subfactor of D4 is not relevant to our current CCVAs. Also, the category D is just an optional input, and hence we did not use the subfactor.

Note: There are 16 subfactors in the category C, though only ten factors need to be assessed to calculate the vulnerability index. Rating of the four subfactors in the category D is considered optional as well. If information in category D (documented and/or modeled responses to climate change) is available, the final index is calculated in consideration of the information. In this study, C2bi, D3, and D4 were not assessed for any species. In the MVA, subfactors indicated by grey cells (C2aii, (C2bii,) C2c, C2d, C4a, and C4e) were used to determine species’ vulnerability/adaptability.

Appendix 4.13. Literature survey steps in climate change vulnerability assessments.

Step no.	Method
1	Searching and scanning up to 50 documents published since 2000 by the keyword combination of “species name” + “national park name”.
2	Searching and scanning up to 50 documents published since 2000 by the keyword combination of “species name” + “region name (Nova Scotia, Cape Breton, or New Brunswick)”.
3	Searching and scanning up to 50 documents published since 2000 by the keyword combination of “species name” + “climate change”.
4	Searching and scanning up to 50 documents published since 2000 by the keyword combination of “species name” + “temperature/thermal”.
5*	If no or few documents were available in the first four searches, similar documents published before 2000 were additionally searched.
6*	To supplement relevant information, searching and scanning additional documents by keyword combinations of “species name” + specific terms (e.g., snow/ice, fire/wind, genetic).

* The last two searches were done only if necessary/applicable.

Appendix 4.14. Vulnerability assessment results by the CCVI (Young et al. 2011) in Kejimkujik National Park under the moderate climate change scenario.

Species were scored on how each factor affects its vulnerability (GI, Greatly Increase; Inc, Increase; SI, Somewhat Increase; N, Neutral; SD, Somewhat Decrease; Dec, Decrease; U, Unknown). Index score was given from either of six possible choices: EV (Extremely Vulnerable), HV (Highly Vulnerable), MV (Moderately Vulnerable), PS (Not Vulnerable/Presumed Stable), IL (Not Vulnerable/Increase Likely), or IE (Insufficient Evidence). The subfactors of C2bi, D3, and D4 are not shown, because they were not rated.

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Bird	Rusty blackbird	N	N	N	N	Dec	N	N	Inc	N	N	SI-N-SD	SI	SI	N/A	N	N	U	U	SI	Inc	U	MV
Bird	Common loon	N	N	N	N	Dec	N	SI-N	SI	SI	N	SI-N	N	N-SD	N/A	N	N	U	U	U	U	U	PS
Bird	(Eastern) barred Owl	N	N	N	N	Dec	N	N-SD	SI	SI-N	N	SD	SI-N	N	N/A	N	N	SI	N/A	U	U	U	PS
Fish	Brown bullhead	N	SI-N	N	N	SD	N	SD	SI-SD	SI	N	SI-N-SD	N	SD	N/A	N	N	U	U	U	U	U	PS
Fish	White perch	N	SI-N	N	N	Dec	N	SD	N	N	N	SI-N	N	N	N/A	N	N	U	U	U	U	U	PS
Fish	Yellow perch	N	SI-N	N	N	SD-Dec	N	SD	N	SI	N	SI-N	N	N	N/A	N	N	SI	N/A	U	U	U	PS
Fish	Brook trout	N	Inc-SI-N	N	N	Dec	N	SI	SI-N	SI	N	SI-N	SI-N	N	N/A	N	N	U	SI	U	U	SI-N	PS
Mammal	American moose	N	N	SI	N	Dec	N	SI	SI	SD	N	SD-Dec	SI	SI	N/A	N	N	SI	N/A	U	U	SI	PS
Mammal	Coyote	N	N	N	N	Dec	N	N	SI-N	SD	N	Dec	N	SI-SD	N/A	N	N	U	U	U	U	U	IL
Mammal	Beavers	N	SI-N	N	N	SD-Dec	N	N-SD	SI	N-SD	N	SD-Dec	SI-N	SI-N	N/A	N	N	U	U	U	U	U	PS

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Mammal	Porcupine	N	N	N	N	SD	N	N	N	SI-N	N	SD	N	N	N/A	N	N	U	U	U	U	U	PS
Mammal	Southern flying squirrel	N	N	N	N	SD-Dec	N	SD	SI	Inc-SI	N	Dec	SI	SI-SD	N/A	N	N	U	SI	SD	U	U	PS
Mammal	American Marten	N	N	SI	N	SD	N	U	SI-N	Inc	N	SD	SI	SI-SD	N/A	N	N	U	U	U	U	SI	PS
Mammal	Fisher	N	N	N	N	SD	N	N	SI	SI	N	SD	SI-N	SD	N/A	N	N	SI	N/A	U	U	SD	PS
Mammal	white-tailed deer	N	N	N	N	Dec	N	SD	N	SD	N	Dec	N	SI-N	N/A	N	N	U	U	U	U	U	IL
Mammal	Black bear	N	N	SI	N	SD-Dec	N	N	N	SI-SD	N	SD-Dec	SI-N	SI-SD	N/A	N	N	U	U	U	U	U	PS
Tree	Balsam fir	N	N	N	N	N	N	Inc-SI	SI-N	Inc-SD	N	N-SD	N	N/A	N	SI-N	N	U	U	U	U	Inc	MV
Tree	Red maple	N	N	N	N	N	N	N-SD	SI-N	SD	N	SD	N	N/A	SI-N	N	N	U	U	U	U	SD	PS
Tree	Sugar maple	N	N	N	N	N	N	N-SD	SI	SI-N	N	N-SD	N	N/A	SI-N	N	N	SI	N/A	U	U	SI	PS
Tree	Yellow birch	N	N	N	N	N	N	SI-N	SI	Inc-SD	N	N	N	N/A	N	N	N	U	U	U	U	SI	PS
Tree	White birch	N	N	N	N	N-SD	N	Inc-SI	SI-SD	SD	N	N-SD	N	N/A	N	N	N	U	U	U	U	Inc	MV
Tree	American beech	N	N	N	N	SD	N	SD	SI	Inc	N	N	N	N/A	N	SI	N	N	N/A	U	U	SD	PS
Tree	Eastern larch/American larch/Tamarack	N	N	N	N	SI	N	SI	SI	N-SD	N	SD	N	N/A	N	N	N	U	U	U	U	GI	MV
Tree	Ironwood	N	N	N	N	N	N	SD	N-SD	N-SD	N	SD	N	N/A	N	SI-N	N	U	U	U	U	Dec	IL
Tree	White spruce	N	N	N	N	N	N	Inc-SI	SI	SI-N	N	N-SD	N	N/A	N	N	N	U	U	U	U	Inc	MV

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Tree	Black spruce	N	N	N	N	SI-N	N	SI	SI	SI	N	N	N	N/A	N	N	N	U	U	U	U	Inc	MV
Tree	Red spruce	N	N	N	N	N	N	SI	SI-N	SI	N	SD	N	N/A	N	N	SI-N	SD	N/A	U	U	GI	MV
Tree	Red pine	N	N	N	N	SI	N	SI	SI	SD	N	N	N	N/A	N	N	N	SD	N/A	U	U	GI	MV
Tree	White pine	N	N	N	N	N	N	N-SD	SI	SD	N	N-SD	N	N/A	N	N	N	Inc	N/A	U	U	SD	PS
Tree	Red oak	N	N	N	N	N-SD	N	SD	SI	SD	N	N-SD	N	N/A	N	SI-N	N	U	U	U	U	Dec	IL
Tree	Eastern hemlock	N	N	N	N	N	N	N-SD	SI	SI-N	N	N-SD	N	N/A	N	N	N	N	N/A	U	U	SD	PS

Appendix 4.15. Vulnerability assessment results by the CCVI (Young et al. 2011) in Kejimkujik National Park under the severe climate change scenario.

Species were scored on how each factor affects its vulnerability (GI, Greatly Increase; Inc, Increase; SI, Somewhat Increase; N, Neutral; SD, Somewhat Decrease; Dec, Decrease; U, Unknown). Index score was given from either of six possible choices: EV (Extremely Vulnerable), HV (Highly Vulnerable), MV (Moderately Vulnerable), PS (Not Vulnerable/Presumed Stable), IL (Not Vulnerable/Increase Likely), or IE (Insufficient Evidence). The subfactors of C2bi, D3, and D4 are not shown, because they were not rated.

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Bird	Rusty blackbird	N	N	N	N	Dec	N	N	Inc	N	N	SI-N-SD	SI	SI	N/A	N	N	U	U	SI	Inc	U	MV
Bird	Common loon	N	N	N	N	Dec	N	Inc-SI	SI	SI	N	SI-N	SI	N-SD	N/A	N	N	U	U	U	U	U	PS
Bird	(Eastern) barred owl	N	N	N	N	Dec	N	N	SI	SI-N	N	SD	SI-N	N	N/A	N	N	SI	N/A	U	U	U	PS
Fish	Brown bullhead	N	SI-N	N	N	SD	N	SD	SI-SD	SI	N	SI-N-SD	N	SD	N/A	N	N	U	U	U	U	U	IL
Fish	White perch	N	SI-N	N	N	Dec	N	SD	N-SD	N	N	SI-N	N	N	N/A	N	N	U	U	U	U	U	IL
Fish	Yellow perch	N	SI-N	N	N	SD-Dec	N	SD	SI	SI	N	SI-N	N	N	N/A	N	N	SI	N/A	U	U	U	MV/PS
Fish	Brook trout	N	Inc-SI-N	N	N	Dec	N	Inc	SI-N	SI	SI	SI-N	SI-N	N	N/A	N	N	U	SI	U	U	Inc	HV
Mammal	American moose	N	N	SI	N	Dec	N	Inc	SI	SD	SI	SD-Dec	SI	SI	N/A	N	N	SI	N/A	U	U	Inc	HV/MV
Mammal	Coyote	N	N	N	N	Dec	N	N	SI-N	SD	SI	Dec	N	SI-SD	N/A	N	N	U	U	U	U	U	IL
Mammal	Beavers	N	SI-N	N	N	SD-Dec	N	N-SD	SI	SI-SD	N	SD-Dec	SI	SI-N	N/A	N	N	U	U	U	U	U	PS

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Mammal	Porcupine	N	N	N	N	SD	N	N	N	SI-N	N	SD	N	N	N/A	N	N	U	U	U	U	U	PS/IL
Mammal	Southern flying squirrel	N	N	N	N	SD-Dec	N	SD	SI	Inc-SI	N	Dec	SI	SI-SD	N/A	N	N	U	SI	SD	U	U	PS
Mammal	American Marten	N	N	SI	N	SD	N	U	SI-N	Inc	Inc	SD	Inc-SI	SI-SD	N/A	N	N	U	U	U	U	Inc	HV
Mammal	Fisher	N	N	N	N	SD	N	N	SI	SI	N	SD	SI-N	SD	N/A	N	N	SI	N/A	U	U	Dec	IL
Mammal	white-tailed deer	N	N	N	N	Dec	N	SD	N	SD	N	Dec	N	SI-N	N/A	N	N	U	U	U	U	U	IL
Mammal	Black bear	N	N	SI	N	SD-Dec	N	N	N	SI-SD	SI-N	SD-Dec	SI-N	SI-SD	N/A	N	N	U	U	U	U	U	PS
Tree	Balsam fir	N	N	N	N	N	N	Inc	SI-N	Inc-SD	N	N-SD	N	N/A	N	SI-N	N	U	U	U	U	GI	HV/MV
Tree	Red maple	N	N	N	N	N	N	N-SD	SI-N	SD	N	SD	N	N/A	SI-N	N	N	U	U	U	U	N	IL
Tree	Sugar maple	N	N	N	N	N	N	SI	SI	SI-N	Inc-SI	N-SD	N	N/A	SI-N	N	N	SI	N/A	U	U	SI	MV
Tree	Yellow birch	N	N	N	N	N	N	SI	SI	Inc-SD	Inc-SI	N	N	N/A	N	N	N	U	U	U	U	Inc	HV
Tree	White birch	N	N	N	N	N-SD	N	Inc	SI-SD	SD	Inc-SI	N-SD	N	N/A	N	N	N	U	U	U	U	GI	MV
Tree	American beech	N	N	N	N	SD	N	N-SD	SI	Inc	SI	N	N	N/A	N	SI	N	N	N/A	U	U	SD	MV
Tree	Eastern larch/American larch/Tamarack	N	N	N	N	SI	N	Inc	SI	N-SD	N	SD	N	N/A	N	N	N	U	U	U	U	GI	MV
Tree	Ironwood	N	N	N	N	N	N	SD	N-SD	N-SD	N	SD	N	N/A	N	SI-N	N	U	U	U	U	Dec	IL
Tree	White spruce	N	N	N	N	N	N	Inc	SI	SI-N	SI-N	N-SD	N	N/A	N	N	N	U	U	U	U	GI	MV

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Tree	Black spruce	N	N	N	N	SI-N	N	Inc	SI	SI	N	N	N	N/A	N	N	N	U	U	U	U	GI	HV/MV
Tree	Red spruce	N	N	N	N	N	N	SI	SI-N	SI	N	SD	N	N/A	N	N	SI-N	SD	N/A	U	U	GI	MV
Tree	Red pine	N	N	N	N	SI	N	Inc-SI	SI	SD	N	N	N	N/A	N	N	N	SD	N/A	U	U	GI	MV
Tree	White pine	N	N	N	N	N	N	SI-N	SI	SD	N	N-SD	N	N/A	N	N	N	Inc	N/A	U	U	SI	PS
Tree	Red oak	N	N	N	N	N-SD	N	N-SD	SI	SD	N	N-SD	N	N/A	N	SI-N	N	U	U	U	U	Dec	IL
Tree	Eastern hemlock	N	N	N	N	N	N	N-SD	SI	Inc-N	N	N-SD	N	N/A	N	N	N	N	N/A	U	U	Inc	MV

Appendix 4.16. Vulnerability assessment results by the MVA in Kejimkujik National Park under the moderate climate change scenario.

Species were scored on how each factor affects its vulnerability (Inc, Increase; SI, Somewhat Increase; N, Neutral; SD, Somewhat Decrease; Dec, Decrease; U, Unknown). Index score was given from either of six possible choices: HV (Highly Vulnerable), MV (Moderately Vulnerable), PS (Presumed Stable), MA (Moderately Adaptable), HA (Highly Adaptable), and IE (Insufficient Evidence). Underlined cells show factor values that are different from their corresponding values rated by the CCVI. The subfactors of C2bi, D3, and D4 are not shown, because they were not rated.

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Bird	Rusty blackbird	N	N	N	N	Dec	N	N	Inc	N	N	SI-N	SI	Inc-SI	N/A	N	N	U	U	SI	Inc	U	MV
Bird	Common loon	N	N	N	N	Dec	N	SI-N	SI	SI	N	SI-N	SI	N-SD	N/A	N	N	U	U	U	U	U	MV/PS
Bird	(Eastern) barred owl	N	N	N	N	Dec	N	N-SD	SI	SI-N	N	N	SI-N	N	N/A	N	N	SI	N/A	U	U	U	PS
Fish	Brown bullhead	N	SI-N	N	N	SD	N	Dec	SI-SD	SI	N	SI-N	N	SD	N/A	N	N	U	U	U	U	U	MA
Fish	White perch	N	SI-N	N	N	Dec	N	Dec	N	N	N	SI-N	N	N	N/A	N	N	U	U	U	U	U	MA
Fish	Yellow perch	N	SI-N	N	N	SD-Dec	N	SD-Dec	N	SI	N	SI-N	N	N	N/A	N	N	SI	N/A	U	U	U	PS/MA
Fish	Brook trout	N	Inc-SI	N	N	Dec	N	SI	SI-N	SI	N	SI-N	N-SD	N	N/A	N	Inc	U	SI	U	U	SI-N	MV
Mammal	American moose	N	Inc-SI	SI	N	Dec	N	SI	SI	SD	N	N	SI-N-SD	SI	N/A	N	SI	SI	N/A	U	SI	SI	MV
Mammal	Coyote	N	N	N	N	Dec	N	N	SI-N	SD	N	N	N	SI-SD	N/A	N	N	U	U	U	U	U	PS/MA

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Mammal	Beavers	N	SI-N	N	N	SD-Dec	N	N-SD	SI	N-SD	N	N	N-SD	SI-N	N/A	N	N	U	U	U	U	U	PS/MA
Mammal	Porcupine	N	N	N	N	SD	N	N	N	SI-N	N	N	N	N	N/A	N	N	U	U	U	U	U	PS
Mammal	Southern flying squirrel	N	N	N	N	SD-Dec	N	SD-Dec	SI	Inc-SI	N	N	SD-Dec	SI-SD	N/A	N	SI	U	SI	SD	U	U	PS/MA
Mammal	American Marten	N	Inc-SI	SI	N	SD	N	U	SI-N	Inc	N	N	SI	SI-SD	N/A	N	N	U	U	U	U	SI	IE
Mammal	Fisher	N	SI-N	N	N	SD	N	N	SI	SI	N	N	SI-N	SD	N/A	N	N	SI	N/A	U	U	SD	PS
Mammal	white-tailed deer	N	N	N	N	Dec	N	SD	N	SD	N	N	N	N-SD	N/A	N	N	U	U	U	U	U	MA
Mammal	Black bear	N	N	SI	N	SD-Dec	N	N	N	SI-SD	N	N	SI-N	SI-SD	N/A	N	N	U	U	U	U	U	PS/MA
Tree	Balsam fir	N	Inc-SI	N	N	N	N	Inc-SI	SI-N	Inc-SD	N	N	N	N/A	N	SI-N	N	U	U	U	U	Inc	HV/MV
Tree	Red maple	N	N	N	N	N	N	SD-Dec	SI-N	SD	N	N	N	N/A	SI-N	N	N	U	U	U	U	SD	MA
Tree	Sugar maple	N	N	N	N	N	N	N-SD	SI	SI-N	N	N	N	N/A	SI-N	N	N	SI	N/A	U	U	SI	PS/MA
Tree	Yellow birch	N	Inc-SI	N	N	N	N	SI-N	SI	Inc-SD	N	N	N	N/A	N	N	N	U	U	U	U	SI	MV/PS
Tree	White birch	N	Inc-SI	N	N	N-SD	N	Inc-SI	SI-SD	SD	N	N	N	N/A	N	N	N	U	U	U	U	Inc	HV/MV
Tree	American beech	N	N	N	N	SD	N	SD-Dec	SI	Inc	N	N	N	N/A	N	SI	N	N	N/A	U	U	SD	MA
Tree	Eastern larch/American larch/Tamarack	N	Inc-SI	N	N	SI	N	SI	SI	N-SD	N	N	N	N/A	N	N	N	U	U	U	U	Inc	MV

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Tree	Ironwood	N	N	N	N	N	N	SD	N-SD	N-SD	N	N	N	N/A	N	SI-N	N	U	U	U	U	Dec	MA
Tree	White spruce	N	Inc-SI	N	N	N	N	Inc-SI	SI	SI-N	N	N	N	N/A	N	N	N	U	U	U	U	Inc	HV/MV
Tree	Black spruce	N	Inc-SI	N	N	SI-N	SI	SI	SI	SI	N	N	N	N/A	N	N	SI	U	U	U	U	Inc	MV
Tree	Red spruce	N	Inc-SI	N	N	N	N	SI	SI-N	SI	N	N	N	N/A	N	N	SI-N	SD	N/A	U	U	Inc	MV
Tree	Red pine	N	Inc-SI	N	N	SI	N	SI	SI	SD	N	N	N	N/A	N	N	N	SD	N/A	U	U	Inc	MV
Tree	White pine	N	N	N	N	N	N	N-SD	SI	SD	N	N	N	N/A	N	N	N	Inc	N/A	U	U	SD	PS/MA
Tree	Red oak	N	N	N	N	N-SD	N	SD-Dec	SI	SD	N	N	N	N/A	N	SI-N	N	U	U	U	U	Dec	MA/HA
Tree	Eastern hemlock	N	N	N	N	N	N	N-SD	SI	SI-N	N	N	N	N/A	N	N	N	N	N/A	U	U	SD	PS/MA

Appendix 4.17. Vulnerability assessment results by the MVA in Kejimkujik National Park under the severe climate change scenario.

Species were scored on how each factor affects its vulnerability (Inc, Increase; SI, Somewhat Increase; N, Neutral; SD, Somewhat Decrease; Dec, Decrease; U, Unknown). Index score was given from either of six possible choices: HV (Highly Vulnerable), MV (Moderately Vulnerable), PS (Presumed Stable), MA (Moderately Adaptable), HA (Highly Adaptable), or IE (Insufficient Evidence). Underlined cells show factor values that are different from their corresponding values rated by the CCVI. The subfactors of C2bi, D3, and D4 are not shown, because they were not rated.

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Bird	Rusty blackbird	N	N	N	N	Dec	N	N	Inc	N	N	SI-N	SI	Inc-SI	N/A	N	N	U	U	SI	Inc	U	MV
Bird	Common loon	N	N	N	N	Dec	N	Inc-SI	SI	SI	N	SI-N	N	N-SD	N/A	N	N	U	U	U	U	U	MV
Bird	(Eastern) barred Owl)	N	N	N	N	Dec	N	N	SI	SI-N	N-SD	N	SI-N	N	N/A	N	N	SI	N/A	U	U	U	PS
Fish	Brown bullhead	N	SI-N	N	N	SD	N	Dec	SI-SD	SI	N	SI-N	N	SD	N/A	N	N	U	U	U	U	U	HA
Fish	White perch	N	SI-N	N	N	Dec	N	Dec	N-SD	N	N	SI-N	N	N	N/A	N	N	U	U	U	U	U	HA
Fish	Yellow perch	N	SI-N	N	N	SD-Dec	N	SD-Dec	SI	SI	N	SI-N	N	N	N/A	N	N	SI	N/A	U	U	U	MA/HA
Fish	Brook trout	N	Inc-SI	N	N	Dec	N	Inc	SI-N	SI	SI	SI-N	SI-N	N	N/A	N	Inc	U	SI	U	U	Inc	HV
Mammal	American moose	N	Inc-SI	SI	N	Dec	N	Inc	SI	SD	SI	N	SI-N	SI	N/A	N	SI	SI	N/A	U	SI	Inc	HV
Mammal	Coyote	N	N	N	N	Dec	N	N	SI-N	SD	SI	N	N	SI-SD	N/A	N	N	U	U	U	U	U	PS

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Mammal	Beavers	N	SI-N	N	N	SD-Dec	N	N-SD	SI	SI-SD	N-SD	N	SI-N	SI-N	N/A	N	N	U	U	U	U	U	MV/PS
Mammal	Porcupine	N	N	N	N	SD	N	N	N	SI-N	N-SD	N	N	N	N/A	N	N	U	U	U	U	U	PS
Mammal	Southern flying squirrel	N	N	N	N	SD-Dec	N	SD-Dec	SI	Inc-SI	N-SD	N	SD-Dec	SI-SD	N/A	N	SI	U	SI	SD	U	U	MA/HA
Mammal	American Marten	N	Inc-SI	SI	N	SD	N	U	SI-N	Inc	Inc	N	Inc-SI	SI-SD	N/A	N	SI	U	U	U	U	Inc	IE
Mammal	Fisher	N	SI-N	N	N	SD	N	N	SI	SI	SD-Dec	N	Inc-SI	SD	N/A	N	N	SI	N/A	U	U	Dec	MA
Mammal	white-tailed deer	N	N	N	N	Dec	N	SD	N	SD	SD-Dec	N	N	N-SD	N/A	N	N	U	U	U	U	U	MA/HA
Mammal	Black bear	N	N	SI	N	SD-Dec	N	N	N	SI-SD	SI-N	N	SI-N	SI-SD	N/A	N	N	U	U	U	U	U	PS/MA
Tree	Balsam fir	N	Inc-SI	N	N	N	N	Inc	SI-N	Inc-SD	N	N	N	N/A	N	SI-N	N	U	U	U	U	Inc	HV
Tree	Red maple	N	N	N	N	N	N	SD-Dec	SI-N	SD	SD	N	N	N/A	SI-N	N	N	U	U	U	U	N	HA
Tree	Sugar maple	N	Inc-SI	N	N	N	N	SI	SI	SI-N	Inc-SI	N	N	N/A	SI-N	N	N	SI	N/A	U	U	SI	MV/PS
Tree	Yellow birch	N	Inc-SI	N	N	N	N	SI	SI	Inc-SD	Inc-SI	N	N	N/A	N	N	N	U	U	U	U	Inc	MV
Tree	White birch	N	Inc-SI	N	N	N-SD	N	Inc	SI-SD	SD	Inc-SI	N	N	N/A	N	N	N	U	U	U	U	Inc	HV
Tree	American beech	N	N	N	N	SD	N	N-SD	SI	Inc	SI	N	N	N/A	N	SI	N	N	N/A	U	U	SD	PS/MA
Tree	Eastern larch/American larch/Tamarack	N	Inc-SI	N	N	SI	N	Inc	SI	N-SD	N	N	N	N/A	N	N	N	U	U	U	U	Inc	HV

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Tree	Ironwood	N	N	N	N	N	N	Dec	N-SD	N-SD	N	N	N	N/A	N	SI-N	N	U	U	U	U	Dec	HA
Tree	White spruce	N	Inc-SI	N	N	N	N	Inc	SI	SI-N	SI-SD	N	N	N/A	N	N	N	U	U	U	U	Inc	HV
Tree	Black spruce	N	Inc-SI	N	N	SI-N	SI	Inc	SI	SI	N	N	N	N/A	N	N	N	U	U	U	U	Inc	HV
Tree	Red spruce	N	Inc-SI	N	N	N	N	SI	SI-N	SI	N	N	N	N/A	N	N	SI-N	SD	N/A	U	U	Inc	HV/MV
Tree	Red pine	N	Inc-SI	N	N	SI	N	Inc-SI	SI	SD	N	N	N	N/A	N	N	N	SD	N/A	U	U	Inc	HV
Tree	White pine	N	Inc-SI	N	N	N	N	SI-N	SI	SD	N	N	N	N/A	N	N	N	Inc	N/A	U	U	SI	PS
Tree	Red oak	N	N	N	N	N-SD	N	N-SD	SI	SD	N	N	N	N/A	N	SI-N	N	U	U	U	U	Dec	MA/HA
Tree	Eastern hemlock	N	N	N	N	N	N	N-SD	SI	Inc-N	N	N	N	N/A	N	N	N	N	N/A	U	U	Inc	MV/PS

Appendix 4.18. Vulnerability assessment results by the CCVI (Young et al. 2011) in Cape Breton Highlands National Park under the moderate climate change scenario.

Species were scored on how each factor affects its vulnerability (GI, Greatly Increase; Inc, Increase; SI, Somewhat Increase; N, Neutral; SD, Somewhat Decrease; Dec, Decrease; U, Unknown). Index score was given from either of six possible choices: EV (Extremely Vulnerable), HV (Highly Vulnerable), MV (Moderately Vulnerable), PS (Not Vulnerable/Presumed Stable), IL (Not Vulnerable/Increase Likely), or IE (Insufficient Evidence). The subfactors of C2bi, D3, and D4 are not shown, because they were not rated.

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Bird	Bicknell's thrush	N	N	N	N	Dec	SI	GI-Inc	N	SD	N	SD-Dec	SI	N	N/A	N	N	U	U	U	U	U	PS
Bird	Hermit thrush	N	N	N	N	Dec	SI	N	SI-N	SI-N	N	Dec	SI-N	SD	N/A	N	N	U	U	U	U	U	PS/IL
Bird	Chimney swift	N	N	N	N	Dec	SI	SD	SI-N	SI-SD	N	Dec	N	SI	N/A	N	N	U	U	U	U	U	PS
Bird	Olive-sided flycatcher	N	N	N	N	Dec	SI	N	SI-N	SI-SD	N	Dec	SI	N	N/A	N	N	U	U	U	U	U	PS
Bird	Blue jay	N	N	N	N	Dec	SI	SD	N	SI-N	N	Dec	SI-N	SD	N/A	N	N	U	U	U	U	U	IL
Bird	Spruce grouse	N	N	N	N	N	SI	N	SI	SD	N	SD	SI	SI-N	N/A	N	N	U	U	U	U	U	PS
Bird	Boreal chickadee	N	N	N	N	SD-Dec	SI	U	N	SI	N	SD-Dec	N	SD	N/A	N	N	U	U	U	SI	U	PS
Bird	Gray jay	N	N	N	N	SD	SI	Inc-SI	N	SI	N	SD	SI-N	SD	N/A	N	N	U	U	U	U	U	PS
Bird	American redstart	N	N	N	N	Dec	SI	N	U	N-SD	N	Dec	N	N	N/A	N	N	U	U	U	U	U	IL

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Bird	Greater yellowlegs	SI-N	N	N	N	Dec	SI	Inc-SI	SI-N	N	N	N-SD	N	N	N/A	N	N	U	U	U	U	U	PS
Bird	American robin	N	N	N	N	Dec	SI	N	SI-N	SD	N	Dec	N	SD	N/A	N	N	U	U	U	U	U	IL
Bird	Red-eyed vireo	N	N	N	N	Dec	SI	SD	N	SI-N	N	Dec	N	SD	N/A	N	N	U	U	U	U	U	IL
Bird	Canada warbler	N	N	N	N	Dec	SI	U	SI	SI-SD-Dec	N	Dec	N	SI-N	N/A	N	N	U	U	U	U	U	PS
Fish	American eel	N	Inc-SI	N	N	Dec	SI	SD	SI-N	N	N	SD	N	N-SD	N/A	N	N	U	U	U	U	U	PS
Fish	Atlantic salmon	N	Inc-SI	N	N	Dec	SI	N-SD	SI	SI-SD	N	N	N	N	N/A	N	N	SI-N	N/A	U	U	U	PS
Mammal	Western moose	N	GI-Inc-SI-N	N	N	Dec	SI	SI-N	N	N-SD	N	N	SI	SI	N/A	N	N	N-SD	N/A	U	U	U	PS
Mammal	Coyote	N	N	N	N	Dec	SI	N-SD	SI-N	SD	N	Dec	N	SI-SD	N/A	N	N	U	U	U	U	U	IL
Mammal	Snowshoe hare	N	N	N	N	Dec	SI	N-SD	SI-N	SI-SD	N	Dec	SI	SI-N	N/A	N	N	U	U	U	U	U	PS
Mammal	Canadian lynx	N	N	N	N	Dec	SI	U	SD	SI-SD	N	Dec	SI-N	Inc-SI	N/A	N	N	U	U	U	SI-N	SI	PS
Mammal	Bobcat	N	N	N	N	Dec	SI	N	N	N	N	Dec	N	SI	N/A	N	N	Inc	N/A	U	N-SD	U	PS
Mammal	American marten	N	N	SI	N	SD	SI	U	SI-N	SI-SD	N	SD	SI	SI-SD	N/A	N	N	Inc	N/A	U	U	SI	PS

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Mammal	White-tailed deer	N	N	N	N	Dec	SI	SD	N	SI-SD	N	Dec	SI	SI-N	N/A	N	N	U	U	U	U	U	PS
Mammal	Deer mouse	N	N	N	N	N	SI	N-SD	SD	SI-N	N	SD-Dec	SI-N	N-SD	N/A	N	N	U	U	U	U	U	PS
Mammal	Masked shrew	N	N	N	N	U	SI	N-SD	SI	N-SD	N	SD-Dec	SI-N	N	N/A	N	N	U	U	U	U	U	PS
Mammal	Red squirrel/Pine squirrel	N	N	N	N	N	SI	U	N	SI	N	SD	SI	N-SD	N/A	N	N	U	U	U	U	U	PS
Mammal	Black bear	N	N	SI	N	SD-Dec	SI	N	N	SI-SD	N	SD-Dec	SI-N	SI-SD	N/A	N	N	U	U	U	U	U	PS
Mammal	Red fox	N	N	N	N	Dec	SI	N	N	SD	N	N	N	SD	N/A	N	N	U	U	U	U	U	IL
Tree	Balsam fir	N	Inc-SI	SI	N	N	SI	SI-N	SI-N	SI-SD	N	SI-N	N	N/A	N	SI-N	N	U	U	U	U	SI	MV
Tree	Striped maple	N	Inc-SI	N	N	N	SI	N-SD	SI-N	SI	N	N	N	N/A	U	N	N	U	U	U	U	Dec	IL
Tree	Red maple	N	Inc-SI	N	N	N	SI	SD	SI-N	SD	N	SD	N	N/A	SI-N	N	N	U	U	U	U	Dec	IL
Tree	Sugar maple	N	Inc-SI	N	N	N	SI	SD	SI	SI-N	N	N	N	N/A	SI-N	N	N	Inc	N/A	U	U	Dec	PS/IL
Tree	Yellow birch	N	Inc-SI	N	N	N	SI	SI-SD	SI	SI-SD	N	SI-N	N	N/A	N	N	N	U	U	U	U	N	PS
Tree	White birch	N	Inc-SI	N	N	N-SD	SI	SI-N	SI-SD	SD	N	N-SD	N	N/A	N	N	N	U	U	U	U	N	PS

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Tree	American beech	N	Inc-SI	N	N	SD	SI	SD	SI	SI	N	SI-N	N	N/A	N	SI	N	U	U	U	U	Dec	IL
Tree	Eastern larch/American larch/Tamarack	N	GI-Inc-SI	N	N	SI	SI	SI-N	SI	N-SD	N	SD	N	N/A	N	N	N	U	U	U	U	SI	PS
Tree	White spruce	N	Inc-SI	N	N	N	SI	SI-N	SD	SI-N	N	N-SD	N	N/A	N	N	N	U	U	U	U	SI	PS
Tree	Black spruce	N	Inc-SI	N	N	SI-N	SI	SI-N	SI	SI	N	SI-N	N	N/A	N	N	N	U	U	U	U	SI	MV
Tree	Red spruce	N	Inc-SI	N	N	N	SI	N-SD	SI-N	SI	N	N	N	N/A	N	N	SI-N	U	U	U	U	SD	PS
Tree	Red pine	N	Inc-SI	N	N	SI	SI	N-SD	SI	SD	N	N	N	N/A	N	N	N	U	U	U	U	Dec	IL
Tree	White pine	N	Inc-SI	N	N	N	SI	SD	SI	SD	N	N-SD	N	N/A	N	N	N	U	U	U	U	SD	PS
Tree	Red oak	N	Inc-SI	N	N	N-SD	SI	SD	SI	SD	N	N-SD	N	N/A	N	SI-N	N	U	U	U	U	Dec	IL
Tree	Eastern hemlock	N	Inc-SI	N	N	N	SI	SD	N	SI	N	N	N	N/A	N	N	N	SI-N	N/A	U	U	Dec	IL
Tree	American elm	N	Inc-SI	N	N	N	SI	SD	SI	SD	U	N-SD	N	N/A	N	N	N	U	U	U	U	Dec	IL

Appendix 4.19. Vulnerability assessment results by the CCVI (Young et al. 2011) in Cape Breton Highlands National Park under the severe climate change scenario.

Species were scored on how each factor affects its vulnerability (GI, Greatly Increase; Inc, Increase; SI, Somewhat Increase; N, Neutral; SD, Somewhat Decrease; Dec, Decrease; U, Unknown). Index score was given from either of six possible choices: EV (Extremely Vulnerable), HV (Highly Vulnerable), MV (Moderately Vulnerable), PS (Not Vulnerable/Presumed Stable), IL (Not Vulnerable/Increase Likely), or IE (Insufficient Evidence). The subfactors of C2bi, D3, and D4 are not shown, because they were not rated.

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Bird	Bicknell's thrush	N	N	N	N	Dec	SI	GI-Inc	N	SD	N	SD-Dec	Inc-SI	N	N/A	N	N	U	U	U	U	U	HV/MV
Bird	Hermit thrush	N	N	N	N	Dec	SI	N	SI-N	SI-N	N	Dec	SI-N	SD	N/A	N	N	U	U	U	U	U	IL
Bird	Chimney swift	N	N	N	N	Dec	SI	SD	SI-N	SI-SD	N	Dec	N	SI	N/A	N	N	U	U	U	U	U	IL
Bird	Olive-sided flycatcher	N	N	N	N	Dec	SI	N	SI-N	SI-SD	N	Dec	Inc-SI	N	N/A	N	N	U	U	U	U	U	PS
Bird	Blue jay	N	N	N	N	Dec	SI	SD	N	SI-N	N	Dec	SI-N	SD	N/A	N	N	U	U	U	U	U	IL
Bird	Spruce grouse	N	N	N	N	N	SI	N	SI	SD	N	SD	Inc-SI	SI-N	N/A	N	N	U	U	U	U	U	PS
Bird	Boreal chickadee	N	N	N	N	SD-Dec	SI	U	N	SI	N	SD-Dec	N	SD	N/A	N	N	U	U	U	SI	U	PS
Bird	Gray jay	N	N	N	N	SD	SI	Inc-SI	N	SI	N	SD	SI-N	SD	N/A	N	N	U	U	U	U	U	PS
Bird	American redstart	N	N	N	N	Dec	SI	N	U	N-SD	N	Dec	N	N	N/A	N	N	U	U	U	U	U	IL

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Bird	Greater yellowlegs	SI-N	N	N	N	Dec	SI	Inc-SI	SI-N	N	N	N-SD	N	N	N/A	N	N	U	U	U	U	U	PS
Bird	American robin	N	N	N	N	Dec	SI	N	SI-N	SD	N	Dec	N	SD	N/A	N	N	U	U	U	U	U	IL
Bird	Red-eyed vireo	N	N	N	N	Dec	SI	SD	N	SI-N	N	Dec	N	SD	N/A	N	N	U	U	U	U	U	IL
Bird	Canada warbler	N	N	N	N	Dec	SI	U	SI	SI-SD-Dec	N	Dec	N	SI-N	N/A	N	N	U	U	U	U	U	IL
Fish	American eel	N	Inc-SI	N	N	Dec	SI	SD	SI-N	N	N	SD	N	N-SD	N/A	N	N	U	U	U	U	U	IL
Fish	Atlantic salmon	N	Inc-SI	N	N	Dec	SI	N-SD	SI	SI-SD	N	N	N	N	N/A	N	N	SI-N	N/A	U	U	U	PS
Mammal	Western moose	N	GI-Inc-SI-N	N	N	Dec	SI	Inc-SI	N	N-SD	N	N	SI	SI	N/A	N	N	N-SD	N/A	U	U	U	MV
Mammal	Coyote	N	N	N	N	Dec	SI	N-SD	SI-N	SD	SI	Dec	N	SI-SD	N/A	N	N	U	U	U	U	U	IL
Mammal	Snowshoe hare	N	Inc-SI	N	N	Dec	SI	N-SD	SI-N	SI-SD	Inc-N	Dec	SI	SI-N	N/A	N	N	U	U	U	U	U	PS
Mammal	Canadian lynx	N	Inc-SI	N	N	Dec	SI	U	SD	SI-Dec	Inc	Dec	SI-N	Inc-SI	N/A	N	N	U	U	U	SI-N	Inc	MV
Mammal	Bobcat	N	N	N	N	Dec	SI	N	N	N	N	Dec	N	SI	N/A	N	N	Inc	N/A	U	N-SD	U	PS
Mammal	American marten	N	Inc-SI	SI	N	SD	SI	U	SI-N	SI-Dec	Inc	SD	Inc-SI	SI-SD	N/A	N	N	Inc	N/A	U	U	Inc	HV

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Mammal	White-tailed deer	N	N	N	N	Dec	SI	SD	N	SI-SD	N	Dec	SI	SI-N	N/A	N	N	U	U	U	U	U	IL
Mammal	Deer mouse	N	N	N	N	N	SI	N-SD	SD	SI-N	N	SD-Dec	SI-N	N-SD	N/A	N	N	U	U	U	U	U	PS
Mammal	Masked shrew	N	N	N	N	U	SI	N-SD	SI	N-SD	N	SD-Dec	SI-N	N	N/A	N	N	U	U	U	U	U	PS
Mammal	Red squirrel/Pine squirrel	N	N	N	N	N	SI	U	N	SI	N	SD	Inc-SI	N-SD	N/A	N	N	U	U	U	U	U	PS
Mammal	Black bear	N	N	SI	N	SD-Dec	SI	N	N	SI-SD	SI-N	SD-Dec	SI-N	SI-SD	N/A	N	N	U	U	U	U	U	MV
Mammal	Red fox	N	N	N	N	Dec	SI	N	N	SD	N	N	N	SD	N/A	N	N	U	U	U	U	U	IL
Tree	Balsam fir	N	Inc-SI	SI	N	N	SI	Inc-SI	SI-N	Inc-SI-Dec	N	SI-N	N	N/A	N	SI-N	N	U	U	U	U	GI	HV
Tree	Striped maple	N	Inc-SI	N	N	N	SI	SI-N	SI-N	SI	SI-N	N	N	N/A	U	N	N	U	U	U	U	Dec	PS
Tree	Red maple	N	Inc-SI	N	N	N	SI	SD	SI-N	SD	N	SD	N	N/A	SI-N	N	N	U	U	U	U	SD	PS
Tree	Sugar maple	N	Inc-SI	N	N	N	SI	SD	SI	SI-N	Inc-SI	N	N	N/A	SI-N	N	N	Inc	N/A	U	U	Dec	MV
Tree	Yellow birch	N	Inc-SI	N	N	N	SI	SI-SD	SI	SI-SD	Inc-SI	SI-N	N	N/A	N	N	N	U	U	U	U	SI	HV
Tree	White birch	N	Inc-SI	N	N	N-SD	SI	Inc	SI-SD	Dec	Inc-SI	N-SD	N	N/A	N	N	N	U	U	U	U	GI	HV/MV

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Tree	American beech	N	Inc-SI	N	N	SD	SI	SD	SI	SI	SI	SI-N	N	N/A	N	SI	N	U	U	U	U	Dec	PS
Tree	Eastern larch/American larch/Tamarack	N	GI-Inc-SI	N	N	SI	SI	Inc-SI	SI	N-SD	N	SD	N	N/A	N	N	N	U	U	U	U	GI	HV
Tree	White spruce	N	Inc-SI	N	N	N	SI	Inc-SI	SD	SI-N	SI-N	N-SD	N	N/A	N	N	N	U	U	U	U	GI	HV/MV
Tree	Black spruce	N	Inc-SI	N	N	SI-N	SI	Inc-SI	SI	SI	N	SI-N	N	N/A	N	N	N	U	U	U	U	GI	HV
Tree	Red spruce	N	Inc-SI	N	N	N	SI	SI-N	SI-N	SI	N	N	N	N/A	N	N	SI-N	U	U	U	U	GI	HV
Tree	Red pine	N	Inc-SI	N	N	SI	SI	SI-N	SI	SD	N	N	N	N/A	N	N	N	U	U	U	U	GI	MV
Tree	White pine	N	Inc-SI	N	N	N	SI	N-SD	SI	SD	N	N-SD	N	N/A	N	N	N	U	U	U	U	SD	PS
Tree	Red oak	N	Inc-SI	N	N	N-SD	SI	SD	SI	SD	N	N-SD	N	N/A	N	SI-N	N	U	U	U	U	Dec	IL
Tree	Eastern hemlock	N	Inc-SI	N	N	N	SI	N-SD	N	SI	N	N	N	N/A	N	N	N	SI-N	N/A	U	U	Dec	PS
Tree	American elm	N	Inc-SI	N	N	N	SI	SD	SI	SI-SD	U	N-SD	N	N/A	N	N	N	U	U	U	U	Dec	PS/IL

Appendix 4.20. Vulnerability assessment results by the MVA in Cape Breton Highlands National Park under the moderate climate change scenario.

Species were scored on how each factor affects its vulnerability (Inc, Increase; SI, Somewhat Increase; N, Neutral; SD, Somewhat Decrease; Dec, Decrease; U, Unknown). Index score was given from either of six possible choices: HV (Highly Vulnerable), MV (Moderately Vulnerable), PS (Presumed Stable), MA (Moderately Adaptable), HA (Highly Adaptable), or IE (Insufficient Evidence). Underlined cells show factor values that are different from their corresponding values rated by the CCVI. The subfactors of C2bi, D3, and D4 are not shown, because they were not rated.

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Bird	Bicknell's thrush	N	N	N	N	Dec	SI	Inc	N	SD	N	N	SI	N	N/A	N	N	U	U	U	U	U	HV/MV
Bird	Hermit thrush	N	N	N	N	Dec	SI	N	SI-N	SI-N	N	N	SI-N	SD	N/A	N	N	U	U	U	U	U	PS
Bird	Chimney swift	N	N	N	N	Dec	SI	SD	SI-N	SI-SD	N	N	N	SI	N/A	N	N	U	U	U	U	U	PS/MA
Bird	Olive-sided flycatcher	N	N	N	N	Dec	SI	N	SI-N	SI-SD	N	N	SI	N	N/A	N	N	U	U	U	U	U	MV/PS
Bird	Blue jay	N	N	N	N	Dec	SI	SD	N	SI-N	N	N	N-SD	SD	N/A	N	N	U	U	U	U	U	MA
Bird	Spruce grouse	N	N	N	N	N	SI	N	SI	SD	N	N	SI	SI-N	N/A	N	N	U	U	U	U	U	MV/PS
Bird	Boreal chickadee	N	N	N	N	SD-Dec	SI	U	N	SI	N	N	N	SD	N/A	N	SI	U	U	U	SI	U	IE
Bird	Gray jay	N	N	N	N	SD	SI	Inc-SI	N	SI	N	N	SI-N	SD	N/A	N	N	U	U	U	U	U	MV/PS
Bird	American redstart	N	N	N	N	Dec	SI	N	U	N-SD	N	N	N	N	N/A	N	N	U	U	U	U	U	PS/MA

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Bird	Greater yellowlegs	SI-N	N	N	N	Dec	SI	Inc-SI	SI-N	N	N	N	N	N	N/A	N	N	U	U	U	U	U	MV/PS
Bird	American robin	N	N	N	N	Dec	SI	N	SI-N	SD	N	N	N	SD	N/A	N	N	U	U	U	U	U	PS/MA
Bird	Red-eyed vireo	N	N	N	N	Dec	SI	SD	N	SI-N	N	N	SD	SD	N/A	N	N	U	U	U	U	U	PS/MA
Bird	Canada warbler	N	N	N	N	Dec	SI	U	SI	SI-SD-Dec	N	N	N-SD	SI-N	N/A	N	N	U	U	U	U	U	IE
Fish	American eel	N	SI	N	N	Dec	SI	SD	SI-N	N	N	N	N	N-SD	N/A	N	N	U	U	U	U	U	PS/MA
Fish	Atlantic salmon	N	SI	N	N	Dec	SI	N-SD	SI	SI-SD	N	N	N	N	N/A	N	N	SI-N	N/A	U	U	U	PS/MA
Mammal	Western moose	N	Inc-SI-N	N	N	Dec	SI	SI-N	N	N-SD	N	N	SI-N-SD	SI	N/A	N	SI	N-SD	N/A	U	U	U	MV/PS
Mammal	Coyote	N	N	N	N	Dec	SI	N-SD	SI-N	SD	N	N	N	SI-SD	N/A	N	N	U	U	U	U	U	PS/MA
Mammal	Snowshoe hare	N	N	N	N	Dec	SI	N-SD	SI-N	SI-SD	N	N	SI	SI-N	N/A	N	N	U	U	U	U	U	PS/MA
Mammal	Canadian lynx	N	N	N	N	Dec	SI	U	SD	SI-SD	N	N	SI-N	Inc-SI	N/A	N	N	U	U	U	SI-N	SI	IE
Mammal	Bobcat	N	N	N	N	Dec	SI	N	N	N	N	N	N	SI	N/A	N	N	Inc	N/A	U	N-SD	U	PS
Mammal	American marten	N	N	SI	N	SD	SI	U	SI-N	SI-SD	N	N	SI	SI-SD	N/A	N	N	Inc	N/A	U	U	SI	IE

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Mammal	White-tailed deer	N	N	N	N	Dec	SI	SD	N	SI-SD	N	N	SD	N-SD	N/A	N	N	U	U	U	U	U	MA
Mammal	Deer mouse	N	N	N	N	N	SI	N-SD	SD	SI-N	N	N	SI-N	N-SD	N/A	N	SI	U	U	U	U	U	PS/MA
Mammal	Masked shrew	N	N	N	N	U	SI	N-SD	SI	N-SD	N	N	SI-N	SD	N/A	N	N	U	U	U	U	U	PS/MA
Mammal	Red squirrel/Pine squirrel	N	N	N	N	N	SI	U	N	SI	N	N	SI	N-SD	N/A	N	N	U	U	U	U	U	IE
Mammal	Black bear	N	N	SI	N	SD-Dec	SI	N	N	SI-SD	N	N	SI-N	SD	N/A	N	N	U	U	U	U	U	PS/MA
Mammal	Red fox	N	N	N	N	Dec	SI	N	N	SD	N	N	N	SD	N/A	N	N	U	U	U	U	U	PS/MA
Tree	Balsam fir	N	SI-N	SI	N	N	SI	SI-N	SI-N	SI-SD	N	SI-N	N	N/A	N	SI-N	N	U	U	U	U	SI	MV/PS
Tree	Striped maple	N	SI-N	N	N	N	SI	N-SD	SI-N	SI	N	N	N	N/A	U	N	N	U	U	U	U	Dec	PS/MA
Tree	Red maple	N	SI-N	N	N	N	SI	SD	SI-N	SD	N	N	N	N/A	SI-N	N	N	U	U	U	U	Dec	MA
Tree	Sugar maple	N	SI-N	N	N	N	SI	SD-Dec	SI	SI-N	N	N	N	N/A	SI-N	N	N	Inc	N/A	U	U	Dec	MA
Tree	Yellow birch	N	SI-N	N	N	N	SI	SI-SD	SI	SI-SD	N	SI-N	N	N/A	N	N	N	U	U	U	U	N	PS/MA
Tree	White birch	N	SI-N	N	N	N-SD	SI	SI-N	SI-SD	SD	N	N	N	N/A	N	N	N	U	U	U	U	N	MV

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Tree	American beech	N	SI-N	N	N	SD	SI	SD	SI	SI	N	SI-N	N	N/A	N	SI	N	U	U	U	U	Dec	MA
Tree	Eastern larch/American larch/Tamarack	N	Inc-SI	N	N	SI	SI	SI-N	SI	N-SD	N	N	N	N/A	N	N	N	U	U	U	U	SI	MV/PS
Tree	White spruce	N	SI-N	N	N	N	SI	SI-N	SD	SI-N	N	N	N	N/A	N	N	N	U	U	U	U	SI	MV/PS
Tree	Black spruce	N	SI-N	N	N	SI-N	SI	SI-N	SI	SI	N	SI-N	N	N/A	N	N	SI	U	U	U	U	SI	MV
Tree	Red spruce	N	SI-N	N	N	N	SI	N-SD	SI-N	SI	N	N	N	N/A	N	N	SI-N	U	U	U	U	SD	PS
Tree	Red pine	N	SI-N	N	N	SI	SI	N-SD	SI	SD	N	N	N	N/A	N	N	N	U	U	U	U	Dec	MA
Tree	White pine	N	SI-N	N	N	N	SI	Dec-SD	SI	SD	N	N	N	N/A	N	N	N	U	U	U	U	SD	MA
Tree	Red oak	N	SI-N	N	N	N-SD	SI	Dec	SI	SD	N	N	N	N/A	N	SI-N	N	U	U	U	U	Dec	MA/HA
Tree	Eastern hemlock	N	SI-N	N	N	N	SI	SD-Dec	N	SI	N	N	N	N/A	N	N	N	SI-N	N/A	U	U	Dec	MA
Tree	American elm	N	SI-N	N	N	N	SI	Dec	SI	SD	U	N	N	N/A	N	N	N	U	U	U	U	Dec	MA/HA

Appendix 4.21. Vulnerability assessment results by the MVA in Cape Breton Highlands National Park under the severe climate change scenario.

Species were scored on how each factor affects its vulnerability (Inc, Increase; SI, Somewhat Increase; N, Neutral; SD, Somewhat Decrease; Dec, Decrease; U, Unknown). Index score was given from either of six possible choices: HV (Highly Vulnerable), MV (Moderately Vulnerable), PS (Presumed Stable), MA (Moderately Adaptable), HA (Highly Adaptable), or IE (Insufficient Evidence). Underlined cells show factor values that are different from their corresponding values rated by the CCVI. The subfactors of C2bi, D3, and D4 are not shown, because they were not rated.

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Bird	Bicknell's thrush	N	N	N	N	Dec	SI	Inc	N	SD	N	N	Inc-SI	N	N/A	N	N	U	U	U	U	U	HV
Bird	Hermit thrush	N	N	N	N	Dec	SI	N	SI-N	SI-N	N	N	SI-N	SD	N/A	N	N	U	U	U	U	U	MV/PS
Bird	Chimney Swift	N	N	N	N	Dec	SI	SD	SI-N	SI-SD	N	N	N	SI	N/A	N	N	U	U	U	U	U	MA
Bird	Olive-sided Flycatcher	N	N	N	N	Dec	SI	N	SI-N	SI-SD	N	N	Inc-SI	N	N/A	N	N	U	U	U	U	U	MV
Bird	Blue jay	N	N	N	N	Dec	SI	SD	N	SI-N	N-SD	N	N-SD	SD	N/A	N	N	U	U	U	U	U	MA/HA
Bird	Spruce grouse	N	N	N	N	N	SI	N	SI	SD	N-SD	N	Inc-SI	SI-N	N/A	N	N	U	U	U	U	U	MV
Bird	Boreal chickadee	N	N	N	N	SD-Dec	SI	U	N	SI	N-SD	N	N	SD	N/A	N	SI	U	U	U	SI	U	IE
Bird	Gray jay	N	N	N	N	SD	SI	Inc-SI	N	SI	N-SD	N	SI	SD	N/A	N	N	U	U	U	U	U	HV/MV
Bird	American redstart	N	N	N	N	Dec	SI	N	U	N-SD	N	N	N	N	N/A	N	N	U	U	U	U	U	PS/MA

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Bird	Greater yellowlegs	SI-N	N	N	N	Dec	SI	Inc-SI	SI-N	N	N	N	N	N	N/A	N	N	U	U	U	U	U	MV/PS
Bird	American robin	N	N	N	N	Dec	SI	N	SI-N	SD	N	N	N	SD	N/A	N	N	U	U	U	U	U	PS/MA
Bird	Red-eyed vireo	N	N	N	N	Dec	SI	SD	N	SI-N	N	N	SD	SD	N/A	N	N	U	U	U	U	U	MA
Bird	Canada warbler	N	N	N	N	Dec	SI	U	SI	SI-SD-Dec	N	N	N-SD	SI-N	N/A	N	N	U	U	U	U	U	IE
Fish	American eel	N	SI	N	N	Dec	SI	SD	SI-N	N	N-SD	N	N	N-SD	N/A	N	N	U	U	U	U	U	MA
Fish	Atlantic salmon	N	SI	N	N	Dec	SI	N-SD	SI	SI-SD	N-SD	N	N	N	N/A	N	N	SI-N	N/A	U	U	U	MA
Mammal	Western moose	N	Inc-SI-N	N	N	Dec	SI	Inc-SI	N	N-SD	N	N	SI-N	SI	N/A	N	SI	N-SD	N/A	U	U	U	MV
Mammal	Coyote	N	N	N	N	Dec	SI	N-SD	SI-N	SD	SI	N	N	SI-SD	N/A	N	N	U	U	U	U	U	PS/MA
Mammal	Snowshoe hare	N	SI	N	N	Dec	SI	N-SD	SI-N	SI-SD	Inc-SD	N	SI	SI-N	N/A	N	N	U	U	U	U	U	MV/PS
Mammal	Canadian lynx	N	SI	N	N	Dec	SI	U	SD	SI-Dec	Inc	N	SI-N	Inc-SI	N/A	N	SI	U	U	U	SI-N	Inc	IE
Mammal	Bobcat	N	N	N	N	Dec	SI	N	N	N	Dec	N	N	SI	N/A	N	N	Inc	N/A	U	N-SD	U	MA
Mammal	American marten	N	SI	SI	N	SD	SI	U	SI-N	SI-Dec	Inc	N	Inc-SI	SI-SD	N/A	N	SI	Inc	N/A	U	U	Inc	IE

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Mammal	White-tailed deer	N	N	N	N	Dec	SI	SD	N	SI-SD	SD-Dec	N	SD	N-SD	N/A	N	N	U	U	U	U	U	MA/HA
Mammal	Deer mouse	N	N	N	N	N	SI	N-SD	SD	SI-N	N	N	SI-N	N-SD	N/A	N	Inc	U	U	U	U	U	PS/MA
Mammal	Masked shrew	N	N	N	N	U	SI	N-SD	SI	N-SD	N	N	SI-N	SD	N/A	N	N	U	U	U	U	U	PS/MA
Mammal	Red squirrel/Pine squirrel	N	N	N	N	N	SI	U	N	SI	N-SD	N	Inc-SI	N-SD	N/A	N	N	U	U	U	U	U	IE
Mammal	Black bear	N	N	SI	N	SD-Dec	SI	N	N	SI-SD	SI-N	N	SI-N	SD	N/A	N	N	U	U	U	U	U	PS/MA
Mammal	Red fox	N	N	N	N	Dec	SI	N	N	SD	SD	N	N	SD	N/A	N	N	U	U	U	U	U	MA
Tree	Balsam fir	N	SI-N	SI	N	N	SI	Inc-SI	SI-N	Inc-SI-Dec	N	SI-N	N	N/A	N	SI-N	N	U	U	U	U	Inc	HV/MV
Tree	Striped maple	N	SI-N	N	N	N	SI	SI-N	SI-N	SI	SI-N	N	N	N/A	U	N	N	U	U	U	U	Dec	MV/PS
Tree	Red maple	N	SI-N	N	N	N	SI	Dec	SI-N	SD	SD	N	N	N/A	SI-N	N	N	U	U	U	U	SD	HA
Tree	Sugar maple	N	SI-N	N	N	N	SI	SD-Dec	SI	SI-N	Inc-SI	N	N	N/A	SI-N	N	N	Inc	N/A	U	U	Dec	PS/MA
Tree	Yellow birch	N	SI-N	N	N	N	SI	SI-SD	SI	SI-SD	Inc-SI	SI-N	N	N/A	N	N	N	U	U	U	U	SI	MV/PS
Tree	White birch	N	SI-N	N	N	N-SD	SI	Inc	SI-SD	Dec	Inc-SI	N	N	N/A	N	N	N	U	U	U	U	Inc	HV/MV

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Tree	American beech	N	SI-N	N	N	SD	SI	Dec	SI	SI	SI	SI-N	N	N/A	N	SI	N	U	U	U	U	Dec	MA
Tree	Eastern larch/American larch/Tamarack	N	Inc-SI	N	N	SI	SI	Inc-SI	SI	N-SD	N	N	N	N/A	N	N	N	U	U	U	U	Inc	MV
Tree	White spruce	N	SI-N	N	N	N	SI	Inc-SI	SD	SI-N	SI-SD	N	N	N/A	N	N	N	U	U	U	U	Inc	HV/MV
Tree	Black spruce	N	SI-N	N	N	SI-N	SI	Inc-SI	SI	SI	N	SI-N	N	N/A	N	N	N	U	U	U	U	Inc	HV/MV
Tree	Red spruce	N	SI-N	N	N	N	SI	SI-N	SI-N	SI	N	N	N	N/A	N	N	SI-N	U	U	U	U	Inc	MV
Tree	Red pine	N	SI-N	N	N	SI	SI	SI-N	SI	SD	N	N	N	N/A	N	N	N	U	U	U	U	Inc	MV/PS
Tree	White pine	N	SI-N	N	N	N	SI	N-Dec	SI	SD	N	N	N	N/A	N	N	N	U	U	U	U	SD	MA
Tree	Red oak	N	SI-N	N	N	N-SD	SI	Dec	SI	SD	N	N	N	N/A	N	SI-N	N	U	U	U	U	Dec	HA
Tree	Eastern hemlock	N	SI-N	N	N	N	SI	N-Dec	N	SI	N	N	N	N/A	N	N	N	SI-N	N/A	U	U	Dec	MA
Tree	American elm	N	SI-N	N	N	N	SI	Dec	SI	SI-SD	U	N	N	N/A	N	N	N	U	U	U	U	Dec	MA/HA

Appendix 4.22. Vulnerability assessment results by the CCVI (Young et al. 2011) in Fundy National Park under the moderate climate change scenario.

Species were scored on how each factor affects its vulnerability (GI, Greatly Increase; Inc, Increase; SI, Somewhat Increase; N, Neutral; SD, Somewhat Decrease; Dec, Decrease; U, Unknown). Index score was given from either of six possible choices: EV (Extremely Vulnerable), HV (Highly Vulnerable), MV (Moderately Vulnerable), PS (Not Vulnerable/Presumed Stable), IL (Not Vulnerable/Increase Likely), or IE (Insufficient Evidence). The subfactors of C2bi, D3, and D4 are not shown, because they were not rated.

		Sea level	Natl barriers	Anth barriers	CC migration	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Bird	Great blue heron	SI-N	N	N	N	Dec	N	N	SI	N	N	N-Dec	N	N	N/A	N	N	U	U	U	U	U	PS
Bird	Ruffed grouse	N	N	N	N	SD-Dec	N	N	SI-N	SD-Dec	N	SD-Dec	SI-N	SI-SD	N/A	N	N	U	U	U	U	U	PS
Bird	Hermit thrush	N	N	N	N	Dec	N	N	SI-N	SI-N	N	Dec	SI-N	SD	N/A	N	N	U	U	U	U	U	IL
Bird	Semi-palmated plover	SI-N	N	N	N	Dec	N	U	SI-N	N	N	N-Dec	N	N	N/A	N	SI-N	U	U	U	U	U	PS
Bird	Pileated woodpecker	N	N	SI	N	SD-Dec	N	N	SI-N	SI	N	SD-Dec	SI	SI-N	N/A	N	N	U	U	U	U	U	PS
Bird	Peregrine falcon	N	N	N	N	Dec	N	N	SI-SD	SI-N	N	Dec	N	SI-N	N/A	N	N	U	U	U	U	U	PS
Bird	Dark-eyed Junco	N	N	N	N	Dec	N	N-SD	N	SD	N	Dec	N	SD	N/A	N	N	U	U	U	U	U	IL
Bird	White-winged crossbill	N	N	N	N	Dec	N	N	SD	SI-N	N	Dec	SI-N	SI-SD	N/A	N	N	U	U	U	U	U	PS/IL
Fish	American eel	N	SI	SI	N	Dec	N	SD	SI-N	N	N	SI-SD	N	N-SD	N/A	N	N	U	U	U	U	U	PS

		Sea level	Natl barriers	Anth barriers	CC migration	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Fish	Atlantic salmon	N	Inc-SI	SI	N	Dec	N	U	SI	SI-SD	N	N-SD	N	N	N/A	N	N	Inc-N	N/A	U	U	U	PS
Fish	Brook trout	N	Inc	SI	N	Dec	N	SI-N	SI-N	SI-N	N	N-SD	SI-N	N	N/A	N	N	SI-N	N/A	U	U	U	PS
Mammal	American moose	N	N	SI	N	Dec	N	SI-N	SI	SD	N	Dec	SI	SI	N/A	N	N	N	N/A	U	U	U	PS
Mammal	Eastern coyote	N	N	N	N	Dec	N	N-SD	SI-N	SD	N	Dec	N	SI-SD	N/A	N	N	U	U	U	U	U	IL
Mammal	Beavers	N	SI-N	SI-N	N	SD-Dec	N	N-SD	SI-N	SD	N	SD-Dec	SI-N	SI-N	N/A	N	N	U	U	U	U	U	PS
Mammal	Northern flying squirrel	N	N	SI	N	SD	N	N	SI-N	Inc-SI	N	SD	SI-N	N-SD	N/A	N	N	U	U	U	U	U	PS
Mammal	Snowshoe hare	N	N	N	N	Dec	N	N-SD	SI-N	N-SD	N	Dec	SI	N	N/A	N	N	U	U	U	U	U	IL
Mammal	Canadian lynx	N	N	N	N	Dec	N	U	SD	SI-SD	N	Dec	SI-N	Inc-SI	N/A	N	N	U	U	U	GI-Inc	SI	MV
Mammal	American marten	N	N	Inc-SI	N	SD	N	U	SI-N	SI	N	SD	SI	SI-SD	N/A	N	N	U	U	U	U	SI	PS
Mammal	Little brown bat	N	N	N	N	Dec	N	SD	SI	SI-N	N	SD-Dec	SI-N	N	N/A	N	N	U	U	U	U	U	PS
Mammal	white-tailed deer	N	N	N	N	Dec	N	SD	N	SI-SD	N	Dec	N	SI-N	N/A	N	N	U	U	U	U	U	IL
Mammal	Raccoon	N	N	N	N	SD-Dec	N	N-SD	SI	N	N	SD-Dec	SI-N	SD	N/A	N	N	U	U	U	U	U	PS

		Sea level	Natl barriers	Anth barriers	CC migration	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Mammal	Eastern chipmunk	N	N	N	N	N	N	N-SD	N-SD	SI-N	N	SD	SI-N	SI-SD	N/A	N	N	U	U	U	U	U	PS
Mammal	Red squirrel/Pine squirrel	N	N	N	N	N	N	U	N	SI	N	SD	SI	N-SD	N/A	N	N	U	U	U	U	U	PS
Mammal	Black bear	N	N	SI	N	SD-Dec	N	N	N	SI-SD	N	SD-Dec	SI-N	SI-SD	N/A	N	N	SI-N	U	U	U	U	PS
Tree	Balsam fir	N	SI-N	N	N	N	N	SI-N	SI-N	SI-N	N	N	N	N/A	N	SI-N	N	U	U	U	U	Inc	MV
Tree	Red maple	N	SI-N	N	N	N	N	SD	SI-N	SD	N	SD	N	N/A	SI-N	N	N	U	U	U	U	SD	PS
Tree	Sugar maple	N	SI-N	N	N	N	N	SD	SI	SI-N	N	N-SD	N	N/A	SI-N	N	N	N	N/A	U	U	SI	PS
Tree	Yellow birch	N	SI-N	N	N	N	N	N-SD	SI	SI-SD	N	N	N	N/A	N	N	N	U	U	U	U	SI	PS
Tree	Mountain paper birch	N	SI-N	N	N	N-SD	N	U	SI-N	N-SD	N	SI	N	N/A	N	N	N	U	U	U	U	U	PS
Tree	White birch	N	SI-N	N	N	N-SD	N	SI-N	SI-SD	SD	N	N	N	N/A	N	N	N	U	U	U	U	SI	PS
Tree	American beech	N	SI-N	N	N	SD	N	SD	SI	SI	N	N	N	N/A	N	SI	N	U	U	U	U	N	PS
Tree	Eastern larch/American larch/Tamarack	N	SI-N	N	N	SI	N	SI-N	SI	N-SD	N	SD	N	N/A	N	N	N	N	N/A	U	U	Inc	MV
Tree	White spruce	N	SI-N	N	N	N	N	SI-N	SD	SI-N	N	N-SD	N	N/A	N	N	N	N	N/A	U	U	Inc	MV
Tree	Black spruce	N	SI-N	N	N	SI-N	N	SI-N	SI	SI	N	N	N	N/A	N	N	N	U	U	U	U	Inc	MV

		Sea level	Natl barriers	Anth barriers	CC migration	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Tree	Red spruce	N	N	N	N	N	N	N-SD	SI-N	Inc	N	N	N	N/A	N	N	SI-N	U	N/A	U	U	SI	PS
Tree	Red pine	N	N	N	N	SI	N	N-SD	SI	SD	N	N	N	N/A	N	N	N	SD	N/A	U	U	SI	PS
Tree	White pine	N	N	N	N	N	N	SD	SI	SD	N	N-SD	N	N/A	N	N	N	U	U	U	U	SD	PS
Tree	Red oak	N	N	N	N	N-SD	N	SD	SI	SD	N	N-SD	N	N/A	N	SI-N	N	U	U	U	U	Dec	IL
Tree	Eastern hemlock	N	N	N	N	N	N	SD	SI	SI	N	N-SD	N	N/A	N	N	N	SI	N/A	U	U	N	PS

Appendix 4.23. Vulnerability assessment results by the CCVI (Young et al. 2011) in Fundy National Park under the severe climate change scenario.

Species were scored on how each factor affects its vulnerability (GI, Greatly Increase; Inc, Increase; SI, Somewhat Increase; N, Neutral; SD, Somewhat Decrease; Dec, Decrease; U, Unknown). Index score was given from either of six possible choices: EV (Extremely Vulnerable), HV (Highly Vulnerable), MV (Moderately Vulnerable), PS (Not Vulnerable/Presumed Stable), IL (Not Vulnerable/Increase Likely), or IE (Insufficient Evidence). The subfactors of C2bi, D3, and D4 are not shown, because they were not rated.

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Bird	Great blue heron	SI-N	N	N	N	Dec	N	N	SI	N	N	N-Dec	N	N	N/A	N	N	U	U	U	U	U	PS/IL
Bird	Ruffed grouse	N	N	N	N	SD-Dec	N	N	SI-N	SD-Dec	Inc-SI	SD-Dec	SI-N	SI-SD	N/A	N	N	U	U	U	U	U	PS
Bird	Hermit thrush	N	N	N	N	Dec	N	N	SI-N	SI-N	N	Dec	SI-N	SD	N/A	N	N	U	U	U	U	U	IL
Bird	Semi-palmated plover	SI-N	N	N	N	Dec	N	U	SI-N	N	N	N-Dec	N	N	N/A	N	SI-N	U	U	U	U	U	PS/IL
Bird	Pileated wood-pecker	N	N	SI	N	SD-Dec	N	N	SI-N	SI	N	SD-Dec	SI	SI-N	N/A	N	N	U	U	U	U	U	MV
Bird	Peregrine falcon	N	N	N	N	Dec	N	N	SI-SD	SI-N	N	Dec	N	SI-N	N/A	N	N	U	U	U	U	U	IL
Bird	Dark-eyed Junco	N	N	N	N	Dec	N	N-SD	N	SD	N	Dec	N	SD	N/A	N	N	U	U	U	U	U	IL
Bird	White-winged crossbill	N	N	N	N	Dec	N	N	SD	SI-N	N	Dec	SI-N	SI-SD	N/A	N	N	U	U	U	U	U	IL
Fish	American eel	N	SI	SI	N	Dec	N	SD	SI-N	N	N	SI-SD	N	N-SD	N/A	N	N	U	U	U	U	U	PS/IL

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Fish	Atlantic salmon	N	Inc-SI	SI	N	Dec	N	U	SI	SI-SD	N	N-SD	N	N	N/A	N	N	Inc-N	N/A	U	U	U	MV
Fish	Brook trout	N	Inc	SI	N	Dec	N	Inc-SI	SI-N	SI-N	SI	N-SD	SI-N	N	N/A	N	N	SI-N	N/A	U	U	U	HV/MV
Mammal	American moose	N	N	SI	N	Dec	N	Inc-SI	SI	SD	SI	Dec	SI	SI	N/A	N	N	N	N/A	U	U	U	PS
Mammal	Eastern coyote	N	N	N	N	Dec	N	N-SD	SI-N	SD	SI	Dec	N	SI-SD	N/A	N	N	U	U	U	U	U	IL
Mammal	Beavers	N	SI-N	SI-N	N	SD-Dec	N	N-SD	SI-N	SD	N	SD-Dec	SI	SI-N	N/A	N	N	U	U	U	U	U	PS
Mammal	Northern flying squirrel	N	N	SI	N	SD	N	N	SI-N	Inc-SI	N	SD	SI-N	N-SD	N/A	N	N	U	U	U	U	U	PS
Mammal	Snowshoe hare	N	N	N	N	Dec	N	N-SD	SI-N	N-SD	Inc-N	Dec	SI	N	N/A	N	N	U	U	U	U	U	IL
Mammal	Canadian lynx	N	N	N	N	Dec	N	U	SD	SI-SD	Inc	Dec	SI-N	Inc-SI	N/A	N	N	U	U	U	GI-Inc	Inc	MV
Mammal	American marten	N	N	Inc-SI	N	SD	N	U	SI-N	SI	Inc	SD	Inc-SI	SI-SD	N/A	N	N	U	U	U	U	Inc	HV
Mammal	Little brown bat	N	N	N	N	Dec	N	SD	SI	SI-N	N	SD-Dec	SI-N	N	N/A	N	N	U	U	U	U	U	IL
Mammal	white-tailed deer	N	N	N	N	Dec	N	SD	N	SI-SD	N	Dec	N	SI-N	N/A	N	N	U	U	U	U	U	IL
Mammal	Raccoon	N	N	N	N	SD-Dec	N	N-SD	SI	N	N	SD-Dec	SI-N	SD	N/A	N	N	U	U	U	U	U	IL

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Mammal	Eastern chipmunk	N	N	N	N	N	N	N-SD	N-SD	SI-N	SI-N	SD	SI-N	SI-SD	N/A	N	N	U	U	U	U	U	PS
Mammal	Red squirrel/Pine squirrel	N	N	N	N	N	N	U	N	SI	N	SD	Inc-SI	N-SD	N/A	N	N	U	U	U	U	U	PS
Mammal	Black bear	N	N	SI	N	SD-Dec	N	N	N	SI-SD	SI-N	SD-Dec	SI-N	SI-SD	N/A	N	N	SI-N	U	U	U	U	MV
Tree	Balsam fir	N	SI-N	N	N	N	N	Inc-SI	SI-N	SI-N	N	N	N	N/A	N	SI-N	N	U	U	U	U	GI	MV
Tree	Red maple	N	SI-N	N	N	N	N	SD	SI-N	SD	N	SD	N	N/A	SI-N	N	N	U	U	U	U	SI	IL
Tree	Sugar maple	N	SI-N	N	N	N	N	SD	SI	SI-N	Inc-SI	N-SD	N	N/A	SI-N	N	N	N	N/A	U	U	SI	MV/PS
Tree	Yellow birch	N	SI-N	N	N	N	N	N-SD	SI	SI-SD	Inc-SI	N	N	N/A	N	N	N	U	U	U	U	Inc	MV
Tree	Mountain paper birch	N	SI-N	N	N	N-SD	N	U	SI-N	N-SD	Inc-SI	SI	N	N/A	N	N	N	U	U	U	U	U	MV
Tree	White birch	N	SI-N	N	N	N-SD	N	Inc	SI-SD	SD	Inc-SI	N	N	N/A	N	N	N	U	U	U	U	GI	MV
Tree	American beech	N	SI-N	N	N	SD	N	SD	SI	SI	SI	N	N	N/A	N	SI	N	U	U	U	U	SI	MV/PS
Tree	Eastern larch/American larch/Tamarack	N	SI-N	N	N	SI	N	Inc-SI	SI	N-SD	N	SD	N	N/A	N	N	N	N	N/A	U	U	GI	MV
Tree	White spruce	N	SI-N	N	N	N	N	Inc-SI	SD	SI-N	SI-N	N-SD	N	N/A	N	N	N	N	N/A	U	U	GI	MV
Tree	Black spruce	N	SI-N	N	N	SI-N	N	Inc-SI	SI	SI	N	N	N	N/A	N	N	N	U	U	U	U	GI	HV/MV

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Tree	Red spruce	N	SI-N	N	N	N	N	SI-N	SI-N	Inc	N	N	N	N/A	N	N	SI-N	U	N/A	U	U	GI	MV
Tree	Red pine	N	SI-N	N	N	SI	N	SI-N	SI	SD	N	N	N	N/A	N	N	N	SD	N/A	U	U	GI	MV
Tree	White pine	N	SI-N	N	N	N	N	N-SD	SI	SD	N	N-SD	N	N/A	N	N	N	U	U	U	U	SI	PS/IL
Tree	Red oak	N	SI-N	N	N	N-SD	N	SD	SI	SD	N	N-SD	N	N/A	N	SI-N	N	U	U	U	U	Dec	IL
Tree	Eastern hemlock	N	SI-N	N	N	N	N	N-SD	SI	Inc	N	N-SD	N	N/A	N	N	N	SI	N/A	U	U	Inc	MV

Appendix 4.24. Vulnerability assessment results by the MVA in Fundy National Park under the moderate climate change scenario.

Species were scored on how each factor affects its vulnerability (Inc, Increase; SI, Somewhat Increase; N, Neutral; SD, Somewhat Decrease; Dec, Decrease; U, Unknown). Index score was given from either of six possible choices: HV (Highly Vulnerable), MV (Moderately Vulnerable), PS (Presumed Stable), MA (Moderately Adaptable), HA (Highly Adaptable), or IE (Insufficient Evidence). Underlined cells show factor values that are different from their corresponding values rated by the CCVI. The subfactors of C2bi, D3, and D4 are not shown, because they were not rated.

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Bird	Great blue heron	SI-N	N	N	N	Dec	N	N	SI	N	N	N	N	N	N/A	N	N	U	U	U	U	U	PS
Bird	Ruffed grouse	N	N	N	N	SD-Dec	N	N	SI-N	SD-Dec	N	N	SI-N	SI-SD	N/A	N	N	U	U	U	U	U	PS/MA
Bird	Hermit thrush	N	N	N	N	Dec	N	N	SI-N	SI-N	N	N	SI-N	SD	N/A	N	N	U	U	U	U	U	PS
Bird	Semi-palmated plover	SI-N	N	N	N	Dec	N	U	SI-N	N	N	N	N	N	N/A	N	SI-N	U	U	U	U	U	IE
Bird	Pileated wood-pecker	N	N	SI	N	SD-Dec	N	N	SI-N	SI	N	N	SI	SI-N	N/A	N	N	U	U	U	U	U	PS
Bird	Peregrine falcon	N	N	N	N	Dec	N	N	SI-SD	SI-N	N	N	N	SI-N	N/A	N	N	U	U	U	U	U	PS
Bird	Dark-eyed Junco	N	N	N	N	Dec	N	N-SD	N	SD	N	N	N	SD	N/A	N	N	U	U	U	U	U	PS/MA
Bird	White-winged crossbill	N	N	N	N	Dec	N	N	SD	SI-N	N	N	SI-N	SI-SD	N/A	N	N	U	U	U	U	U	MV/PS

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Fish	American eel	N	SI	SI	N	Dec	N	SD	SI-N	N	N	SI-N	N	N-SD	N/A	N	N	U	U	U	U	U	PS/MA
Fish	Atlantic salmon	N	SI	SI	N	Dec	N	U	SI	SI-SD	N	N	N	N	N/A	N	N	Inc-N	N/A	U	U	U	IE
Fish	Brook trout	N	SI	SI	N	Dec	N	SI-N	SI-N	SI-N	N	N	N-SD	N	N/A	N	N	SI-N	N/A	U	U	U	MV/PS
Mammal	American moose	N	N	SI	N	Dec	N	SI-N	SI	SD	N	N	SI-N-SD	SI	N/A	N	SI	N	N/A	U	U	U	MV/PS
Mammal	Eastern coyote	N	N	N	N	Dec	N	N-SD	SI-N	SD	N	N	N	SI-SD	N/A	N	N	U	U	U	U	U	PS/MA
Mammal	Beavers	N	SI-N	SI-N	N	SD-Dec	N	N-SD	SI-N	SD	N	N	N-SD	SI-N	N/A	N	N	U	U	U	U	U	PS/MA
Mammal	Northern flying squirrel	N	N	SI	N	SD	N	N	SI-N	Inc-SI	N	N	SI-N-SD	N-SD	N/A	N	SI	U	U	U	U	U	MV/PS
Mammal	Snowshoe hare	N	N	N	N	Dec	N	N-SD	SI-N	N-SD	N	N	SI	N	N/A	N	N	U	U	U	U	U	PS/MA
Mammal	Canadian lynx	N	N	N	N	Dec	N	U	SD	SI-SD	N	N	SI-N	Inc-SI	N/A	N	N	U	U	U	Inc	SI	IE
Mammal	American marten	N	N	Inc-SI	N	SD	N	U	SI-N	SI	N	N	SI	SI-SD	N/A	N	N	U	U	U	U	SI	IE
Mammal	Little brown bat	N	N	N	N	Dec	N	SD	SI	SI-N	N	N	SI-N	N	N/A	N	N	U	U	U	U	U	PS/MA

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Mammal	white-tailed deer	N	N	N	N	Dec	N	SD	N	SI-SD	N	N	N	N-SD	N/A	N	N	U	U	U	U	U	MA
Mammal	Raccoon	N	N	N-SD	N	SD-Dec	N	N-SD	SI	N	N	N	SD	SD	N/A	N	N	U	U	U	U	U	PS/MA
Mammal	Eastern chipmunk	N	N	N	N	N	N	N-SD	N-SD	SI-N	N	N	SD	SD	N/A	N	N	U	U	U	U	U	PS/MA
Mammal	Red squirrel/Pine squirrel	N	N	N	N	N	N	U	N	SI	N	N	SI	N-SD	N/A	N	N	U	U	U	U	U	IE
Mammal	Black bear	N	N	SI	N	SD-Dec	N	N	N	SI-SD	N	N	SI-N	SD	N/A	N	N	SI-N	U	U	U	U	PS/MA
Tree	Balsam fir	N	SI-N	N	N	N	N	SI-N	SI-N	SI-N	N	N	N	N/A	N	SI-N	N	U	U	U	U	Inc	MV
Tree	Red maple	N	SI-N	N	N	N	N	SD	SI-N	SD	N	N	N	N/A	SI-N	N	N	U	U	U	U	SD	MA
Tree	Sugar maple	N	SI-N	N	N	N	N	SD-Dec	SI	SI-N	N	N	N	N/A	SI-N	N	N	N	N/A	U	U	SI	MA/HA
Tree	Yellow birch	N	SI-N	N	N	N	N	N-SD	SI	SI-SD	N	N	N	N/A	N	N	N	U	U	U	U	SI	PS/MA
Tree	Mountain paper birch	N	SI-N	N	N	N-SD	N	U	SI-N	N-SD	N	SI	N	N/A	N	N	N	U	U	U	U	U	IE
Tree	White birch	N	SI-N	N	N	N-SD	N	SI-N	SI-SD	SD	N	N	N	N/A	N	N	N	U	U	U	U	SI	MV
Tree	American beech	N	SI-N	N	N	SD	N	SD	SI	SI	N	N	N	N/A	N	SI	N	U	U	U	U	N	MA
Tree	Eastern larch/American larch/Tamarack	N	SI-N	N	N	SI	N	SI-N	SI	N-SD	N	N	N	N/A	N	N	N	N	N/A	U	U	Inc	MV/PS

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Tree	White spruce	N	SI-N	N	N	N	N	SI-N	SD	SI-N	N	N	N	N/A	N	N	N	N	N/A	U	U	Inc	MV/PS
Tree	Black spruce	N	SI-N	N	N	SI-N	N	SI-N	SI	SI	N	N	N	N/A	N	N	SI	U	U	U	U	Inc	MV
Tree	Red spruce	N	SI-N	N	N	N	N	N-SD	SI-N	Inc	N	N	N	N/A	N	N	SI-N	U	N/A	U	U	SI	MV/PS
Tree	Red pine	N	SI-N	N	N	SI	N	N-SD	SI	SD	N	N	N	N/A	N	N	N	SD	N/A	U	U	SI	MA
Tree	White pine	N	SI-N	N	N	N	N	SD-Dec	SI	SD	N	N	N	N/A	N	N	N	U	U	U	U	SD	MA
Tree	Red oak	N	SI-N	N	N	N-SD	N	Dec	SI	SD	N	N	N	N/A	N	SI-N	N	U	U	U	U	Dec	MA/HA
Tree	Eastern hemlock	N	SI-N	N	N	N	N	SD-Dec	SI	SI	N	N	N	N/A	N	N	N	SI	N/A	U	U	N	PS/MA

Appendix 4.25. Vulnerability assessment results by the MVA in Fundy National Park under the severe climate change scenario.

Species were scored on how each factor affects its vulnerability (Inc, Increase; SI, Somewhat Increase; N, Neutral; SD, Somewhat Decrease; Dec, Decrease; U, Unknown). Index score was given from either of six possible choices: HV (Highly Vulnerable), MV (Moderately Vulnerable), PS (Presumed Stable), MA (Moderately Adaptable), HA (Highly Adaptable), or IE (Insufficient Evidence). Underlined cells show factor values that are different from their corresponding values rated by the CCVI. The subfactors of C2bi, D3, and D4 are not shown, because they were not rated.

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Bird	Great blue heron	SI-N	N	N	N	Dec	N	N	SI	N	N-SD	N	N	N	N/A	N	N	U	U	U	U	U	PS
Bird	Ruffed grouse	N	N	N	N	SD-Dec	N	N	SI-N	SD-Dec	Inc-SI	N	SI	SI-SD	N/A	N	N	U	U	U	U	U	MV/PS
Bird	Hermit thrush	N	N	N	N	Dec	N	N	SI-N	SI-N	N	N	SI-N	SD	N/A	N	N	U	U	U	U	U	MV/PS
Bird	Semi-palmated plover	SI-N	N	N	N	Dec	N	U	SI-N	N	N	N	N	N	N/A	N	SI-N	U	U	U	U	U	IE
Bird	Pileated woodpecker	N	N	SI	N	SD-Dec	N	N	SI-N	SI	N	N	SI	SI-N	N/A	N	N	U	U	U	U	U	MV/PS
Bird	Peregrine falcon	N	N	N	N	Dec	N	N	SI-SD	SI-N	N-SD	N	N	SI-N	N/A	N	N	U	U	U	U	U	PS
Bird	Dark-eyed Junco	N	N	N	N	Dec	N	N-SD	N	SD	N-SD	N	N	SD	N/A	N	N	U	U	U	U	U	MA
Bird	White-winged crossbill	N	N	N	N	Dec	N	N	SD	SI-N	N-SD	N	SI-N	SI-SD	N/A	N	N	U	U	U	U	U	MV

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Fish	American eel	N	SI	SI	N	Dec	N	SD	SI-N	N	N-SD	SI-N	N	N-SD	N/A	N	N	U	U	U	U	U	MA
Fish	Atlantic salmon	N	SI	SI	N	Dec	N	U	SI	SI-SD	N-SD	N	N	N	N/A	N	N	Inc-N	N/A	U	U	U	IE
Fish	Brook trout	N	SI	SI	N	Dec	N	Inc-SI	SI-N	SI-N	SI	N	SI-N	N	N/A	N	SI-N	SI-N	N/A	U	U	U	HV/MV
Mammal	American moose	N	N	SI	N	Dec	N	Inc-SI	SI	SD	SI	N	SI-N	SI	N/A	N	SI	N	N/A	U	U	U	MV
Mammal	Eastern coyote	N	N	N	N	Dec	N	N-SD	SI-N	SD	SI	N	N	SI-SD	N/A	N	N	U	U	U	U	U	PS/MA
Mammal	Beavers	N	SI-N	SI-N	N	SD-Dec	N	N-SD	SI-N	SD	N-SD	N	SI-N	SI-N	N/A	N	N	U	U	U	U	U	MV/PS
Mammal	Northern flying squirrel	N	N	SI	N	SD	N	N	SI-N	Inc-SI	N	N	SI-N	N-SD	N/A	N	SI	U	U	U	U	U	MV
Mammal	Snowshoe hare	N	N	N	N	Dec	N	N-SD	SI-N	N-SD	Inc-SD	N	SI	N	N/A	N	N	U	U	U	U	U	MV/PS
Mammal	Canadian lynx	N	N	N	N	Dec	N	U	SD	SI-SD	Inc	N	SI-N	Inc-SI	N/A	N	SI	U	U	U	Inc	Inc	IE
Mammal	American marten	N	N	Inc-SI	N	SD	N	U	SI-N	SI	Inc	N	Inc-SI	SI-SD	N/A	N	SI	U	U	U	U	Inc	IE
Mammal	Little brown bat	N	N	N	N	Dec	N	SD	SI	SI-N	N	N	SI-N	N	N/A	N	N	U	U	U	U	U	PS/MA

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Mammal	white-tailed deer	N	N	N	N	Dec	N	SD	N	SI-SD	SD-Dec	N	N	N-SD	N/A	N	N	U	U	U	U	U	MA/HA
Mammal	Raccoon	N	N	N-SD	N	SD-Dec	N	N-SD	SI	N	N-SD	N	SD	SD	N/A	N	N	U	U	U	U	U	MA
Mammal	Eastern chipmunk	N	N	N	N	N	N	N-SD	N-SD	SI-N	SI-N	N	SD	SD	N/A	N	N	U	U	U	U	U	MA
Mammal	Red squirrel/Pine squirrel	N	N	N	N	N	N	U	N	SI	N-SD	N	Inc-SI	N-SD	N/A	N	N	U	U	U	U	U	IE
Mammal	Black bear	N	N	SI	N	SD-Dec	N	N	N	SI-SD	SI-N	N	SI-N	SD	N/A	N	N	SI-N	U	U	U	U	PS/MA
Tree	Balsam fir	N	SI-N	N	N	N	N	Inc-SI	SI-N	SI-N	N	N	N	N/A	N	SI-N	N	U	U	U	U	Inc	HV/MV
Tree	Red maple	N	SI-N	N	N	N	N	Dec	SI-N	SD	SD	N	N	N/A	SI-N	N	N	U	U	U	U	SI	HA
Tree	Sugar maple	N	SI-N	N	N	N	N	SD-Dec	SI	SI-N	Inc-SI	N	N	N/A	SI-N	N	N	N	N/A	U	U	SI	MA
Tree	Yellow birch	N	SI-N	N	N	N	N	N-SD	SI	SI-SD	Inc-SI	N	N	N/A	N	N	N	U	U	U	U	Inc	MV/PS
Tree	Mountain paper birch	N	SI-N	N	N	N-SD	N	U	SI-N	N-SD	Inc-SI	SI	N	N/A	N	N	N	U	U	U	U	U	IE
Tree	White birch	N	SI-N	N	N	N-SD	N	Inc	SI-SD	SD	Inc-SI	N	N	N/A	N	N	N	U	U	U	U	Inc	HV
Tree	American beech	N	SI-N	N	N	SD	N	Dec	SI	SI	SI	N	N	N/A	N	SI	N	U	U	U	U	SI	MA
Tree	Eastern larch/American larch/Tamarack	N	SI-N	N	N	SI	N	Inc-SI	SI	N-SD	N	N	N	N/A	N	N	N	N	N/A	U	U	Inc	MV

		Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	historical thermal niche	physiological thermal niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	**Index score**
Group	Species	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bii	C2c	C2d	C3	C4a	C4b	C4c	C4d	C4e	C5a	C5b	C6	D1	D2	
Tree	White spruce	N	SI-N	N	N	N	N	Inc-SI	SD	SI-N	SI-SD	N	N	N/A	N	N	N	N	N/A	U	U	Inc	HV/MV
Tree	Black spruce	N	SI-N	N	N	SI-N	N	Inc-SI	SI	SI	N	N	N	N/A	N	N	N	U	U	U	U	Inc	HV/MV
Tree	Red spruce	N	SI-N	N	N	N	N	SI-N	SI-N	Inc	N	N	N	N/A	N	N	SI-N	U	N/A	U	U	Inc	HV
Tree	Red pine	N	SI-N	N	N	SI	N	SI-N	SI	SD	N	N	N	N/A	N	N	N	SD	N/A	U	U	Inc	MV/PS
Tree	White pine	N	SI-N	N	N	N	N	N-Dec	SI	SD	N	N	N	N/A	N	N	N	U	U	U	U	SI	MA
Tree	Red oak	N	SI-N	N	N	N-SD	N	Dec	SI	SD	N	N	N	N/A	N	SI-N	N	U	U	U	U	Dec	HA
Tree	Eastern hemlock	N	SI-N	N	N	N	N	N-Dec	SI	Inc	N	N	N	N/A	N	N	N	SI	N/A	U	U	Inc	PS/MA

Appendix 4.26. Vulnerability/adaptability of species common to the three national parks under the severe climate change scenario.

Taxon	English Name	Park name	CCVI	MVA
Mammal	American moose*	Kejimkujik	HV/MV	HV
	Western moose*	Cape Breton Highlands	MV	MV
	American moose*	Fundy	PS	MV
Mammal	Coyote	Kejimkujik	IL	PS
		Cape Breton Highlands	IL	PS/MA
		Fundy	IL	PS/MA
Mammal	American marten	Kejimkujik	HV	IE
		Cape Breton Highlands	HV	IE
		Fundy	HV	IE
Mammal	White-tailed deer	Kejimkujik	IL	MA/HA
		Cape Breton Highlands	IL	MA/HA
		Fundy	IL	MA/HA
Mammal	Black bear	Kejimkujik	PS	PS/MA
		Cape Breton Highlands	MV	PS/MA
		Fundy	MV	PS/MA
Tree	Balsam fir	Kejimkujik	HV/MV	HV
		Cape Breton Highlands	HV	HV/MV
		Fundy	MV	HV/MV
Tree	Red maple	Kejimkujik	IL	HA
		Cape Breton Highlands	PS	HA
		Fundy	IL	HA
Tree	Sugar maple	Kejimkujik	MV	MV/PS
		Cape Breton Highlands	MV	PS/MA
		Fundy	MV/PS	MA
Tree	Yellow birch	Kejimkujik	HV	MV
		Cape Breton Highlands	HV	MV/PS
		Fundy	MV	MV/PS
Tree	White birch	Kejimkujik	MV	HV
		Cape Breton Highlands	HV/MV	HV/MV
		Fundy	MV	HV
Tree	American beech	Kejimkujik	MV	PS/MA
		Cape Breton Highlands	PS	MA
		Fundy	MV/PS	MA
Tree	Eastern larch/American larch/Tamarack	Kejimkujik	MV	HV
		Cape Breton Highlands	HV	MV
		Fundy	MV	MV
Tree	White spruce	Kejimkujik	MV	HV
		Cape Breton Highlands	HV/MV	HV/MV
		Fundy	MV	HV/MV
Tree	Black spruce	Kejimkujik	HV/MV	HV
		Cape Breton Highlands	HV	HV/MV
		Fundy	HV/MV	HV/MV
Tree	Red spruce	Kejimkujik	MV	HV/MV
		Cape Breton Highlands	HV	MV
		Fundy	MV	HV
Tree	Red pine	Kejimkujik	MV	HV
		Cape Breton Highlands	MV	MV/PS
		Fundy	MV	MV/PS
Tree	White pine	Kejimkujik	PS	PS
		Cape Breton Highlands	PS	MA
		Fundy	PS/IL	MA
Tree	Red oak	Kejimkujik	IL	MA/HA
		Cape Breton Highlands	IL	HA
		Fundy	IL	HA

Tree	Eastern hemlock	Kejimkujik	MV	MV/PS
		Cape Breton Highlands	PS	MA
		Fundy	MV	PS/MA

*, the American moose and the western moose are different at the sub-species level.
Every species that showed contrasting responses to climate change between/among the parks was shown in grey cells.

Appendix 4.27. Percentage of species in each class of vulnerability in the CCVI for the three national parks in the Maritimes (under the severe climate change scenario).

Taxon	Kejimkujik	Cape Breton Highlands	Fundy	Total
No. of species (including double/triple counts)	31	43	39	113
Highly Vulnerable (HV)	15%	17%	5%	12%
Moderately Vulnerable (MV)	35%	15%	38%	29%
Presumably Stable (PS)	23%	38%	23%	29%
Increase Likely (IL)	27%	29%	33%	30%

Appendix 4.28. Percentage of species in each class of vulnerability in the MVA for the three national parks in the Maritimes (under the severe climate change scenario).

Taxon	Kejimkujik	Cape Breton Highlands	Fundy	Total
No. of species* (including double/triple counts)	30	38	33	101
Highly Vulnerable (HV)	28%	9%	12%	16%
Moderately Vulnerable (MV)	17%	28%	29%	25%
Presumably Stable (PS)	22%	17%	23%	20%
Moderately Adaptable (MA)	13%	37%	29%	27%
HighlyAdaptable (HA)	20%	9%	8%	12%

*, the gap in number of species between the CCVI (Appendix 4.20) and the MVA (Appendix 4.21) is number of the species that were not judged due to information constraint.

Appendix 4.29. Suggested adaptation opportunities by species and approaches in Kejimukujik National Park.

[Relevant subfactor] Literature-based adaptation opportunities	Source	Comments/feedbacks from expert consultation
American moose		
Adaptation opportunities by physical approaches		
[C2bii] Protecting total areas/number of waterbodies (as summer shelters) (e.g., creating artificial wetlands as compensation for loss of natural wetlands)	Gomer (1999), Parker (2003), Dou et al. (2013)	· Wetlands may be shrinking or at least drying. · It might be possible to create wetlands on the edge of water bodies.
Adaptation opportunities by protecting and/or increasing other species		
[C2bii/C4a] Increasing beavers by increasing aspen trees to create wetlands	Parker (2003)	· Most of our wetlands are surrounded by black spruce, but not broadleaf trees. We will move towards an aspen-free forest with climate change. The pathway of aspen-beaver-moose is unlikely to be valid for the landscape in Kejimkujik National Park.
[C4a] Protecting coniferous woods (or mixed woods) with enough canopies as summer shelters	Gomer (1999), Parker (2003), Broders et al. (2012)	(c.f.) adaptation opportunities for red spruce (Appendix 4.31) · Mature forest cover habitat is the most limiting habitat feature for moose in Nova Scotia.
Adaptation opportunities by removing or controling other species		
[C4e] Controlling deer populations (to protect moose from *P. tenuis*)	Robinson et al. (2010)	· Lowering deer population has been implemented in other parks, but they are not necessarily for managing moose.
Others		
		· I think the issue is genetic or something we can't necessarily control. · Mitigation may be to relieve other stresses on the population. · If one subfactor is so dominant, there's almost no point mitigating the other factors.
American marten		
Adaptation opportunities by physical approaches		
[C2c] Preventing accidental fires (e.g., keeping fireproof belts)	Banfield (1976)	
Adaptation opportunities by protecting and/or increasing other species		
[C4a] Protecting balsam fir and the black spruce	Banfield (1976)	(c.f.) adaptation opportunities for red spruce (Appendix 4.31)
Adaptation opportunities by removing or controling other species		

[C4e] Controlling the competing species, fisher	Krohn (2012)	· The fisher is almost rare. Both fisher and marten have weak numbers (e.g., 1-2 sightings/year for marten).

Brook trout		
Adaptation opportunities by physical approaches		
[C2aii] Protecting the Mountain Lake as a refugium	Corbett (2003)	· The dam pulled out of Cole Rail Lake could become a refugium for brook trout. Overhang from trees species (e.g., hemlock, pines, red maple) over the water might allow water to stay cool. · Bowater has 30 m no-cut, while the province only has 20 m. Perhaps should ask the province to implement Bowater 30m standards (or greater) outside of Kejimkujik National Park.
[C2c] Preventing accidental fires (e.g., keeping fireproof belts)	Isaak et al. (2010)	
[C2c/C2d] Buffering snowmelt (e.g., snow fences)	Lindstrom and Hubert (2004), Wenger et al. (2011)	· This would only work for a wind-blown environment, not an environment with trees. (c.f.) Snow fence was suggested as one of adaptation measure to climate change by Cross et al. (2012) for cutthroat trout in Greater Yellowstone Ecosystem in the USA.
Adaptation opportunities by removing or controling other species		
[C4e] Eradicating non-native competing species, rainbow trout, which could flourish with snow decline	Bivens (1984) and Wenger et al. (2011)	· Brook trout is threatened by bass and chain pickerel rather than rainbow trout in Kejimkujik National Park. · However, it is hard to remove bass or pickerel. Unlimited recreational take (fishing) is under consideration, but it is Department of Fisheries and Aquaculture of Nova Scotia jurisdiction.

Appendix 4.30. Suggested adaptation opportunities by species and approaches in Cape Breton Highlands National Park.

[Relevant subfactor] Literature-based adaptation opportunities	Source	Comments/feedbacks from expert consultation
Bicknell's thrush		
Adaptation opportunities by protecting and/or increasing other species		
[C4e] Protecting balsam fir and similar coniferous species	Lambert et al. (2005), Rimmer et al. (2005a), de Boer (2008)	· Parks Canada (Cape Breton Highlands National Park) is doing some restoration work over the next four years to restore forest (aka Bicknell's thrush habitat). (c.f.) adaptation opportunities for red spruce (Appendix 4.31)

Adaptation opportunities by removing or controling other species

[C2c] Keeping moose-free areas (e.g., moose fences)	Parks Canada (2010c)	· Scrubby krummholz spruces and dense regeneration of balsam fir-white birch after budworm (e.g. Christmas mountains in New Brunswick) are the two main habitat types of Bicknell's thrush. I agree with keeping areas with low moose numbers (not necessarily moose free) to help keep forest dense and bring back forest faster. The entire centre of the park has turned from forest to grassland and has become barrier to their movement. There's a high number of stems trying to grow under the grass already. In terms of feasibility, one option is to make fences, remove moose from inside that area, and then keep building fences outwards. Yet, it is still expensive and requires a lot of moose harvesting. · As well, there's no food source – snowshoe hare completely beneath snow cover. · We have a large exclosure on Skyline trail over five hectares, which includes 10-15 pairs of thrush. As well, we remove moose with Mi'gmaq harvest. · Yet, a problem in Gros Morne and Terra Nova is that the hunting has to continue without end if there are no natural predators. · It would take at least 25 years to recover forests after moose exclusion.
Others		
The strictest regulation around identified nests or habitats of the species.	Parks Canada (2010c)	· Monte Point is best Bicknell habitat and there are no restrictions. Thus, it might not be necessary to restrict people's movements. Rather than it, more important challenge is to create nesting habitat than to impose any restrictions (this is a national park for heck's sake). (c.f.) A similar idea was suggested as a sole adaptation measure to climate change by Gomer (1999) for bird species in Kejimkujik National Park.
American marten		
Adaptation opportunities by protecting and/or increasing other species		
[C4a] Protecting balsam fir and the black spruce	Banfield (1976)	*(See the table of Bicknell's thrush)* · The conservation of marten is also done through replacing grassland with woodland.
Adaptation opportunities by removing or controling other species		

[C2c] Keeping moose-free areas (e.g., moose fences)	Bridgland et al. (2007), Parks Canada (2010c)	*(See the table of Bicknell's thrush)*
[C4e] Controlling the competing species, fisher	Krohn (2012)	· There are few fishers in Cape Breton Highlands. There's been three or four in Margaree Valley, but that's all. I don't think fishers will expand with better temperatures, due to an island effect. · Fisher is a northern species, and therefore it will not do better with warmer temperatures. Bringing fishers into the park might be good, because they fill much the same niche.
Others		
[C5a] Artificial inflow of different alleles to prevent inbreeding depressions while increase population resilience	Scott (2001), Nova Scotia American Marten Recovery Team (2006)	· This option has been already done. Parks Canada moved martens from a few locations in northern New Brunswick to Cape Breton Highlands National Park. There was minor residual population first after reintroduction in 2006. · Big question mark. Parks Canada does not know how successful the reintroduction was. Parks Canada introduced 100-115 individuals (between 2007 and 2009/10) into the park and south of the park (e.g. Whycocomagh Provincial Park).

Appendix 4.31. Suggested adaptation opportunities by species and approaches in Fundy National Park.

[Relevant subfactor] Literature-based adaptation opportunities	Source	Comments/feedbacks from expert consultation
Red spruce		
Adaptation opportunities by physical approaches		
[C2c] Protecting deep ravines as refugia from winds	Clayden et al. (2011)	· I don't think we're near risking that level of structural integrity. For example, trails are not likely to influence the potential for wind damage. · We need to protect the ravines around (outside) Fundy National Park.
Adaptation opportunities by protecting and/or increasing other species		
[C2c] Using chemical insecticides with just a few mature red spruces to tackle spruce bark beetle	Jenkins et al. (2014)	· One requirement for chemical control is that there should be no alternative to the chemical. · Before we jump to using pesticides, the understory is a last resort. In British Columbia and Alaska, pesticides did not control infestation of bud worms.

[C2c] Making use of wood-peckers (three-toed woodpeckers in particular) to tackle spruce bark beetle	Fayt et al. (2005)	· In addition to artificial nests, snag protection may be helpful to increase wood-peckers. · Black-backs woodpeckers response to fire more strongly than three-toed woodpeckers, which respond more to bark beetle.
Adaptation opportunities by removing or controling other species		

[C4a/C4e] Removing other trees/shrubs around red spruces		·For Fundy National Park, red spruce is a key piece of current *Ecological Integrity*. If this integiry continues until the 2080s, "editing" or "thinning" to favour red spruce as opposed to balsam fir or other competitors has merits.
Others		
Genetic assisted colonization. Seeds and/or seedlings collected from more southern populations than the park are more likely to hold genes that are adaptive to warm environments. Therefore, if red spruce shows noticeably decline in the parks, Parks Canada may need to introduce such adaptive lineages from outsides (e.g., Kejimkujik National Park) to make the species resilient to climate change.	Shoo et al. (2013)	· If red spruce doesn't belong there in the 2080s, maybe that is the right way.
	Brook trout	
Adaptation opportunities by physical approaches		
[C2aii] Seeking for potential refugium sites	Parks Canada (2010d)	· We can't be proactive, as far as there is no temperature problem to address in Fundy National Park. Currently, stream water is at optimal conditions. · In contrast, if there is a tributary that was an important spawning ground, you could limit fishing access.
[C2c] Preventing accidental fires (e.g., keeping fireproof belts)	Isaak et al. (2010)	
[C2c/C2d] Buffering snowmelt (e.g., snow fences)	Lindstrom and Hubert (2004), Wenger et al. (2011)	(c.f.) Snow fence was suggested as one of adaptation measure to climate change by Cross et al. (2012) for cutthroat trout in Greater Yellowstone Ecosystem in the USA.
Adaptation opportunities by removing or controling other species		
[C4e] Eradicating a non-native competing species, rainbow trout, which will flourish with snow decline	Bivens (1984), Wenger et al. (2011)	· If invasive species show up in large numbers, intervention might be needed. I don't think the intervention conflicts with Parks Canada's policies. · Roe bags is a method to attract rainbow trout.

		· Natural barriers for brook trout are potentially also natural barriers to invasive species. So, removing natural barriers may lead to spread of invasive species.
American marten		
Adaptation opportunities by physical approaches		

[C2c] Preventing accidental fires (e.g., measures written in the fire management plan in Fundy National Park)	Banfield (1976)	
Adaptation opportunities by protecting and/or increasing other species		
[C4a] Protecting balsam fir and black spruce	Banfield (1976), Betts et al. (2003), Godbout and Ouellet (2010)	(c.f.) adaptation opportunities for red spruce (Appendix 4.31)
Adaptation opportunities by removing or controling other species		
[C4e] Controlling the competing species, fisher	Krohn (2012)	· It is unknown at what level fisher becomes so hyper-abundant that it jeopardizes marten. From a policy perspective, fisher problem is not as serious as moose in Cape Breton Highlands or Gros Morne national parks. Hence, for now, intervention by the option
Others		
		· Land use outside of the park becomes more important for species with large home ranges like marten.

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Appendix 5.1. Expert consultation about methodology of the CCVI and the MVA

A one-day expert consultation meeting was held in each park in autumn 2014. Eight, seven and 12 experts respectively participated in meetings in Kejimkujik, Cape Breton Highlands, and Fundy National Parks. The consulted experts included mainly park staff from each national park but also a few external experts. Each consultation meeting began with a brief explanation about our research. Subsequently, intensive discussion ensued about the vulnerability of this subset of species. Through comparing results of the CCVI and the MVA, we also got comments on CCVA methodology from the experts. Hereafter, main comments were shown with a name of a park where each advice was given.

(1) Opportunities and challenges of the CCVI

• Importance of the process rather than the output
Even if a species in two different parks has a same ranking, it could be attributed to two different reasons. [Cape Breton Highlands]

• Weighting
The overall averaging is invalid with qualitative classes. [Cape Breton Highlands]
Standardization is good, but you can only go so far. Maybe weighting should differ for different groups or kingdoms. [Fundy]

• Possibility of redundancy/ among subfactors
We have many trait variables (in the CCVI), which are equally weighted. It seems it could be highly redundant. [Fundy]

• Sensitivity analysis
A sensitivity analysis goes a long way in assessing the validity of our arbitrary quantifications (CCVI). A solid sensitivity analysis would be good back up for arguing for or against using the CCVI, depending on the results. [Fundy]

• The subfactor of disturbance includes too many impacts
This category should be broken down. [Kejimkujik]
Pathogen outbreaks or similar events, such as damages by beetles on red spruce, should be present under the sub-factor of interspecific interactions (C4) rather than disturbance (C2c). Disturbance implies a habitat issue rather than a predation issue, while damage by beetle is predation. [Fundy]

(2) Opportunities and challenges of the MVA

• Importance of the process rather than the output
I think the strength of an exercise like the MBA is the details, not the end class. [Cape Breton Highlands]

• Weighting
The real strength to the MVA approach is that it is transparent. However, the weightings were not transparent yet. That needs to be better characterized. [Fundy]

(3) Comparison between the CCVI and the MVA

• Scale issue
Depending on whether we are looking at a national park or a national scale, the preferred method goes from less standardized (MVA) to more standardized (CCVI). If the MVA

includes reasoned argumentation, it is an interpretation that is hard to standardize across places and people. [Fundy]

- Complementarity between the two approaches

When you try to assess something complex, doing two or three exercises, like in the case of the CCVI and the MVA, can be useful. Looking at results side by side is very useful. In reality, some people think quantitatively, and others think qualitatively. I cannot recommend just one. I recommend doing both. [Fundy]

Appendix 5.2. Suggested challenges and solutions about Climate Change Vulnerability Index developed by Young et al. (2011).

Study	Target	Place	Raised concern/question by each study	Suggested solution by each study
Dubois et al. (2011)	Wildlife	Florida in the USA	Requiring other complimentary assessments: Because the CCVI focuses on climate change vulnerability without consideration of population size and distribution range. Sensitivity to input information: Output quality of the CCVI assessment could be highly varied depending on input information (i.e., availability and accuracy of input information).	- Other assessments about species' general status need to be used simultaneously with the CCVI for management and conservation. - Used information for determining each factor value should be explicitly documented so that the information is transparent and able to be updated in the future.
Schlesinger et al. (2011)	Wildlife	New York in the USA	Lack of consideration of climate-induced changes in life-history traits: For instance, the Blanding turtle may be influenced by warming, which could tilt sex ratio of this species. Yet, the species' vulnerability is assessed without consideration of skewed sex ratio by the CCVI. Excessive influences of some irrelevant subfactors: For instance, lack of dispersal barriers may have led some cold-adapted species to be judged as invulnerable to climate change. This might be a misjudgment.	
Sperry and Hayden (2011)	Wildlife	The USA	Sensitivity to spatial scales of assessed area: Changes in scales of assessed areas (i.e., variations in the subfactor of historical hydrological niche) could influence final assessment results (the CCVI) drastically. Lack of consideration of stochastic events: Increase in stochastic events like droughts are not fully incorporated into the current assessment protocol.	- Paying attention to effects of factor values of historical hydrological niche may be helpful (e.g., sensitivity analysis). - Even though impacts of stochastic events are partly reflected in the subfactor of disturbance, but the impacts should be articulated more.
Anacker et al. (2013)	Rare plants	California in the USA	Time-consuming: Eight hours were needed on average to conduct the CCVI assessment for each species.	- Focusing target species may be possible by preparing a large species list based on rarity and population demographics.

			- Using other assessment methods (e.g., assessing vulnerability based on habitat connectivity).
		<u>Specificity and vulnerability</u>: There is not enough agreement about contributions of specificity to species' vulnerability. For instance, it is unclear whether or not soil endemics are more vulnerable to climate change than soil generalists.	- Soil specificity may be just a kind of natural barriers.
		<u>Lack of consideration of mating system</u>: Selfing or out-crossing should be taken into account when assessing plant species' vulnerability.	- New versions of the CCVI program could be offered for plant species as well as animal species separately.
		<u>Factor values to choose without information</u>: The current program recommends assessors to choose neutral score when relevant information is unavailable.	- Choosing "unknown" score may be better than choosing "neutral" one, when relevant information is lacking.
		<u>Lack of consideration of species interactions</u>: The CCVI does not consider impacts of invasive alien species and/or diseases, some of which may expand their distributions in response to climate change.	
Hameed et al. (2013)	Point Reyes National Seashore in the USA	<u>Lack of spatial information in output</u>: Although managers are often interested in spatial information (e.g., which areas should be protected), scoring methods including the CCVI do not give such spatial information.	*- Species distribution modeling should be used for areas at large-scales (distance order > 200-2,000 km), while scoring methods like the CCVI should be used for areas at small-scales (distance order < 200-2,000 km) (Rowland et al. 2011).*
		<u>Unapplicability for some species</u>: Scoring methods including the CCVI are not applicable for marine, invasive, and migratory species.	
		<u>Lack of consideration of species interactions</u>: The CCVI does not consider impacts of most interspecific interactions.	

Ring et al. (2013)	Plants	New Jersey in the USA	Sensitivity to spatial scales of assessed area: When assessed areas are small, variability in projected and historical climate changes is generally limited. Thus, influences of such variability are hard to reflect on species' vulnerability.	- Future CCVI program could allow users to define categories of future climate change scenarios in consideration of each assessment area's scale.
			Unclear algorithm of the CCVI calculation: The current CCVI program does not allow users to know to which degree each subfactor contributes to species' vulnerability.	- Transparency and flexibility (i.e., user-defined weighting) should be given for the algorithm, like the Element Rank Calculator developed by NatureServe (2009).
Small-Lorenz et al. (2013)	Migratory birds	-	Unapplicability for some species: Although climate change vulnerability of migratory bird species could be evaluated separately among breeding, non-breeding and/or migration sites, the vulnerability cannot be comprehensively assessed.	- Migration (e.g., migratory connectivity) should be considered.
Lankford et al. (2014)	Wildlife	The western USA	Lack of consideration of seasonality: Seasonal variations in species' distributions and traits (behaviors) are not incorporated into the current assessment protocol.	- Seasonality should be considered.
Still et al. (2015)	Rare plants	The western USA	Coarse resolution of climate data: ClimateWizard data, which are supposed to used in the CCVI, are coarse (~12 km), and hence they cannot reflect microclimates in topographically complicated areas.	- Assessing vulnerability based on species distribution models (SDMs) with fine resolutions may compensate for the shortcoming of the CCVI.
			Unavaiability of information to input: Some information to input in the CCVI is unavailable particularly with rare species (e.g., genetic variations and phonological responses to climate change).	- For instance, morphology of assessed species and/or information on closely related species may be helpful to infer pollinators and dispersal modes of the assessed species (note that this is not a best way but a compensatory way).

Wright et al. (2015)	Reptiles and amphibians	California in the USA	Difficulty of incorporating modelled species' responses to climate change: Discretizing results of future habitat simulations (the subfactor of D2) and incorporating them into the CCVI ranking are challenging. As well, species distribution models (SDMs), like the ecological niche modelling, are so precise that combinations of small changes in models (GCMs), climate change scenarios (RCPs) and other simulation modes could much influence final outputs of the simulations.	- Trying a wide variety of modelling choice and compare ranking results among the different choices.

Appendix 5.3 Further opportunities to develop CCVAs

Although previous CCVAs have always focused on vulnerable species, these assessments could also give us some clues regarding which species are highly adaptable to climate change. Potentially adaptable species will be important in two ways. First, some of them can be important components in new ecosystems under a changing climate, sustaining ecological functions, ecological services, and landscape beauty. Considering overwhelmingly rapid condition changes, new approaches are required for managing protected areas, other than just restoring historically dominant species (Hobbs et al. 2011). In other words, it could be necessary to make use of some new adaptable species to maintain ecosystem functions and services as well as landscape beauty. As with "intervention ecology", a similar idea was proposed: some new species can be regarded as important components in new climates (Hobbs et al. 2011; Schlaepfer et al. 2011).

Second, some other adaptable species, like invasive alien species, can be harmful for other pre-existing species. Particularly, competing with other native species will be problematic. In this sense, adaptability and harmfulness of these new plant species are sometimes called "weediness" or "weed risk", and a number of weed risk assessments (WRAs) have recently been developed (Pheloung et al. 1999; McClay et al. 2010). Likewise, recently, a pest risk assessment tool has been developed to assess which mammal and bird species are likely to spread their distributions and become harmful to other native species (Biosecurity South Australia 2010).

Beaumont et al. (2014) argued that impacts of climate change should be incorporated into the WRAs, indicating a possibility of designing comprehensive scoring systems of all species that could be threatened or spread by climate change. Previous studies including Beaumont et al. (2014) have never mentioned similarities and possibility of integration between CCVAs and WRAs/pest risk assessments, though future CCVAs could include the viewpoint of these assessments (i.e., possibility of species' prosperity under climate change). Yet, WRAs/pest risk assessments also have the weaknesses of algorithmic approaches that we explored above (Kumschick and Richardson 2013), and therefore qualitative reinterpretation will be necessary even if comprehensive risk scoring methods are developed.

Appendix 5.4. Definitions of classes by the MVA.

Class	Note
HV	Highly Vulnerable: Abundance and/or range extent within geographical area assessed likely to decrease significantly by 2080s.
MV	Moderately Vulnerable: Abundance and/or range extent within geographical area assessed likely to decrease by 2080s.
PS	Not Vulnerable/Presumed Stable: Available evidence does not suggest that abundance and/or range extent within the geographical area assessed will change (increase/decrease) substantially by 2080. Actual range boundaries may change.
MA	Moderately Adaptable: Available evidence suggests that abundance and/or range extent within geographical area assessed is likely to adapt to climate change and moderately increase by 2080s.
HA	Highly Adaptable: Abundance and/or range extent within geographical area assessed likely to increase significantly by 2080s. Some of them could be important species that maintain ecosystem functions, and some of them could be devastating for other pre-existing species.
IE	Insufficient Evidence: Available information about a species' vulnerability is inadequate to judge species' vulnerability.

Appendix 5.5 How to deal with less relevant subfactors to species' vulnerability in the MVA

Information on the subfactors that are listed without the symbol of "*" in Table 5.1 was not considered in principle. This is because, for instance, historical thermal niche (C2ai) may not be significantly relevant to species' vulnerability/adaptability (see the previous subsection of (ii) combinatorial algorithm for details). As well, high dispersal ability (C1) (e.g., movement for the order of $10^1 \sim 10^2$ km or more), which could be beyond scales of protected areas, may be relevant to species' adaptation to climate change at wide scales (e.g., national or provincial scales), but not protected area scales. Rather, species that have high dispersal ability may migrate outsides protected areas where they were originally distributed, and in such cases these species do not persist under climate change in the same areas.

However, if there is specifically relevant information in these subfactors, such information were also taken into account to discuss the vulnerability/adaptability in the MVA. For instance, if a certain species is almost extirpated specifically due to genetic problems (e.g., past bottleneck or strong inbreeding depression), the subfactor of C5a (measured genetic variation) should be considered to determine vulnerability of the species. Yet, small intra-population genetic variation does not necessarily lead to species' vulnerability, because natural selection could have possibly lowered the variation while increasing the frequency of alleles adaptive to a warm climate. In this regard, determining vulnerability/adaptability by the MVA is highly context-dependent.

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Electronic supplements (species-specific assessment sheets)

The supplements are species-specific CCVA sheets including factor values, rationales for the values, reasoned argumentation of the MVA, and lists of additional references. The supplements are available at DalSpace.