Conserving Alberta's Biodiversity Under a Changing Climate: A Review and Analysis of Adaptation Measures

Richard R. Schneider
Department of Biological Sciences
University of Alberta
Email: rnschnei@ualberta.ca

Prepared for the Biodiversity Management and Climate Change Adaptation Project

June 19, 2014

Corresponding author:
Richard Schneider
Dept. of Biological Sciences
University of Alberta
rnschnei@ualberta.ca

Alberta Biodiversity Monitoring Institute
CW-405 Biological Sciences
University of Alberta
Edmonton, Alberta, Canada T6G 2E9
Phone: (780) 492-6322
E-mail: abmiinfo@ualberta.ca

This report was produced as part of the Biodiversity Management and Climate Change Adaptation Project. This project is led by the Alberta Biodiversity Monitoring Institute, with collaborators from the University of Alberta and the Miistakis Institute. The project receives its core funding from the Climate Change and Emissions Management (CCEMC) Corporation.

Preface:

The Alberta Biodiversity Monitoring Institute (ABMI) is an arm's-length, not-for-profit scientific organization. The primary goal of the ABMI is to provide relevant scientific information on the state of Alberta's biodiversity to support natural resource and land-use decision making in the province.

In the course of monitoring terrestrial and wetland ecosystems across the province, the ABMI has assembled a massive biodiversity database, developed reliable measurement protocols, and found innovative ways to summarize complex ecological information.

The ABMI undertakes focused projects to apply this capacity to specific management challenges, and demonstrate the value of the ABMI's long-term monitoring data to addressing these challenges. In some cases, these applied research projects also evaluate potential solutions to pressing management challenges. In doing so, the ABMI has extended its relevance beyond its original vision.

The ABMI continues to be guided by a core set of principles – we are independent, objective, credible, accessible, transparent and relevant.

This report was produced in support of the ABMI's Biodiversity Management and Climate Change Adaptation project, which is developing knowledge and tools to support the management of Alberta's biodiversity in a changing climate. The views, statements, and conclusions expressed in this report are those of the author and should not be construed as conclusions or opinions of the ABMI. The ABMI is a value-neutral organization committed to the application of high quality science to natural resource management in Alberta.

www.abmi.ca
www.biodiversityandclimate.abmi.ca

Acknowledgements

This report was produced as part of the Biodiversity Management and Climate Change Adaptation Project. This project is led by the Alberta Biodiversity Monitoring Institute, with collaborators from the University of Alberta and the Miistakis Institute. The project receives its core funding from the Climate Change and Emissions Management (CCEMC) Corporation.

I thank the many individuals that provided their perspective and insights into climate change as part of the domain expert interview process (see Appendix 1). I also thank Erin Bayne, Dave Belyea, Shauna-Lee Chai, Dan Farr, Norm Henderson, Steve Kennett, Amy Nixon, Jim Schiek, Brad Stelfox, Harry Stelfox, and Diana Stralberg for their feedback on an earlier version of the manuscript.

Table of Contents

Executive Summary

As a province and a nation we have committed to conserving our native biodiversity. In this discussion paper I examine this goal through the lens of climate change. The intent is to draw attention to issues that need to be addressed and to illustrate options for adapting our current system of biodiversity management to the new realities we face.

The first step in developing effective adaptation measures is to gain a clear understanding of the risk that climate change poses to Alberta's biodiversity. What are we adapting to? The mean annual temperature in Alberta is projected to increase between 2-4 °C by the 2080s, and possibly as high as 6.5 °C under the maximum-change scenario. A small increase in precipitation is expected; however, because of the drying effect of warmer temperatures, soil moisture levels will likely be lower, particularly during summer months. As a result of these climatic changes, ecosystems are expected to shift northwards and upslope.

Although ecological transitions are expected to be widespread, under even the least-change climate scenario, ecological change is not synonymous with the loss of biodiversity. The actual risk to biodiversity depends on net changes in habitat supply, spatial location, and the ability of individual species to accommodate change. The most dramatic declines in habitat supply are expected in the boreal forest, where widespread transition to parkland and grassland ecosystems is likely under moderate to high levels of warming. Ecosystems found at high elevations are also expected to decline in extent, through replacement by ecosystems from below. The species with the lowest capacity for intrinsic adaptation include those with specialized habitat requirements and those with low dispersal ability, among other traits (e.g., amphibians).

Setting conservation objectives

The stated goal of biodiversity conservation is to maintain ecosystem, species and genetic diversity, and the processes that shape them, in the face of human development. Implementing this broad goal in a management setting involves defining, in measureable terms, the original ecological state that is to be maintained through management intervention and protection measures. For ecosystem attributes, the reference state is typically the state of the landscape prior to widespread anthropogenic development. At the species scale, the reference is usually related to historical range and abundance. These reference states represent outcomes we would like to achieve from a primarily ecological perspective. The development of management targets — the biodiversity outcomes that we actually manage for — must also take into account trade-offs among land-use objectives and various constraints.

Our current approach to biodiversity management assumes that anthropogenic disturbance is the only agent of long-term change. The onset of global warming invalidates this assumption. We must now re-examine what it means to maintain biodiversity, and how it can be achieved, in a world of constant change.

A climate-ready interpretation of biodiversity conservation, consistent with its sustainable development origin, can be articulated as: maintain ecosystem structures, patterns, and processes (including species distributions) *as they would be in the absence of human disturbance.* Under this interpretation, conservation efforts would continue to focus, as they always have, on preventing harm from human land uses. In contrast, efforts would not be undertaken to prevent ecological changes resulting from climate change. The rationale is that climatic changes are effectively irreversible once they occur, at least on any time scale relevant to the management of biodiversity, and so must be accepted and adjusted to. This does not diminish the importance of minimizing greenhouse gas emissions as a preventative measure. The context here is different: minimizing the amount of future climate change versus responding to climatic and ecological changes once they occur.

This approach requires a new method for defining conservation objectives. Instead of relying on static historical reference states, objectives need to become dynamic. The report outlines an approach for doing this, based on monitoring the evolving status of patches of unperturbed landscape, such as protected areas.

Maximizing adaptive capacity

Although ecological changes resulting from climate change will generally need to be accepted as the new dynamic norm, management intervention is warranted in the context of adaptation. The aim is not to prevent change, but to ensure that species are able to successfully transition to new climatic environments that arise. This assistance is required because: 1) the vitality and resilience of many species has been reduced due to anthropogenic disturbance, making them less able to withstand climatic variability and less able to shift their range, 2) barriers to movement now exist, including regions where habitat quality has deteriorated, 3) some species may be unable to keep pace with the unusually fast rate of climate change projected under the median to warmest climate scenarios, and 4) non-native species may competitively exclude the movement of native species into new areas. These areas of concern define the scope for management intervention in the context of adaptation.

The available adaptation measures are, for the most part, components of the standard conservation toolkit. The changes lie in the purpose for which the tools are used, and in some cases, the way they are used. A key approach is to reduce anthropogenic stressors in order to improve the general vitality and resilience of species. Fully implementing management strategies designed to minimize the impacts of human disturbances, such as integrated landscape management and cumulative effects management, is paramount. Another strategy is to remove or minimize barriers to movement, for example, by removing the existing anthropogenic footprint through restoration where feasible.

Some species may be unable to effectively track climatic changes, despite efforts to reduce anthropogenic stressors and barriers. It would therefore be helpful to slow the overall rate of regional ecological transitions, to the extent that this is possible, to buy extra time for the species that need it. Active intervention in the form of assisted migration may also be warranted in some cases. These measures are examined in detail in the report, including a discussion of issues related to implementation.

Protected areas

Habitat protection is one of the most frequently cited climate adaptation measures for biodiversity conservation. The rationale is that species will have the greatest capacity to withstand the challenges arising from climate change if they do not also have to contend with the stresses imposed by human disturbances. Well-designed reserve networks, acting as stepping stones, may also facilitate migration along climatic gradients.

Because the amount of land that can be protected is limited by competing land-uses, careful consideration has to be given to how sites are chosen for protection. Under conventional coarse-filter theory, the overriding objective is to represent all major ecosystem types based on their current distributions. With climate change, ecosystem distributions will shift over time, so it may be more appropriate to link representation to variability in the physical environment. A regional system of protected areas that represents the full range of physical environments, including dominant landforms and climatic gradients, is likely to provide protection for most species. Moreover, because the focus is on the "stage" and not the "actors", the system is intrinsically robust to climate change. Connectivity among protected areas, which has always been an important design consideration, will become even more critical with climate change.

The challenge with this approach is in objectively delineating physical environments. It should be reasonable to use the Natural Subregion classification as a first approximation where the boundaries are based on distinct landforms (e.g., Boreal Highlands) or unique soils (e.g., Athabasca Plains). But Subregion boundaries that are based on changes in vegetation (e.g., Lower to Upper Foothills) will require additional analysis.

Fine-filter protection will be especially challenging under climate change. Sites selected for a single species may lose their utility once ecosystems begin to shift. Failures of this type would represent a poor investment of conservation resources, given that the overall amount of land available for protection is limited.

The coarse-filter approach can be augmented by identifying and protecting climatic refugia — habitats that components of biodiversity retreat to or persist in under changing environmental conditions. In one type of application, the objective is to maximize the overall stability of the protected area system by selecting sites that are least likely to change as the climate warms. The refugium concept should be applied in conjunction with the representation of physical landscapes, to avoid gaps in representation (i.e., select physical landscapes first, then climatically stable areas within landscapes).

Planning

Under climate change, the management decision space is more complex and it is harder to forecast management outcomes. These issues are of primary relevance to long-term planning, where the emphasis is on prevention and long-term success rather than response to immediate threats. The planning of conservation activities that are very short-term or reactive in nature should not be greatly affected by climate change, except that the conservation objectives and ecological reference states will need to become dynamic.

Arguably the greatest challenge in incorporating climate change into the planning process is the large degree of uncertainty associated with projections of the future climate and its effects on ecosystem structure and function. The differences among projections are most apparent in the Boreal Natural Region. Under the least-change projection the Boreal will change in character but remain forested, while under the maximum change projection most of the region will eventually transition to a combination of parkland and grassland. The actual outcome is likely to be something between these extremes, but at this point none of the projections can be entirely discounted. The implication is that long-term planning will have to be based on scenario modeling rather than forecasts of future conditions. Four such scenarios are described in the report.

Different approaches are available for incorporating climate scenarios into the planning process. For some simple systems, the raw climate projections may suffice. But in most cases, broader indirect effects, such as the influence of climate on habitat supply, will also need to be incorporated. The most commonly used approach for this purpose is bioclimatic envelope modeling. These models can be used to quickly screen a broad range of species or populations to determine which are most vulnerable to climate change. Detailed analysis of the climate-associated risks for selected species of special interest can also be undertaken using bioclimatic models. Integrated land-use planning requires an additional level of complexity. Not only must the ecological trajectory of the system under climate change be projected, but ecological lags, natural disturbances, and the influence of human land-uses (such as tree planting) must also be incorporated. Modeling approaches capable of this level of integration are described in the report.

Identifying the best management strategy for a given application becomes more complicated under climate change, and new approaches for decision making will be required. Most current planning initiatives use a deterministic approach, where the aim is to identify a suite of management actions that best achieves one or more stated management objectives. The underlying assumption is that forecasts of future conditions under alternative management scenarios are sufficiently reliable to be used as the basis for planning.

Because of climate change, deterministic planning is unlikely to be appropriate for planning horizons that extend past 2050. Ecological projections become increasingly divergent, resulting in ambiguity over which future is to be the target of management optimization. Management solutions that work well for one future may not work well for another. An alternative to deterministic planning is "robust" planning, also known as the "no regrets" approach. The essence of this approach is that planners seek strategies that are most robust in terms of their utility across a range of potential futures, instead of just one. Various methods of robust optimization are discussed in the report.

Bet-hedging is another approach to optimization, which addresses uncertainty by applying multiple strategies simultaneously, in different parts of the landscape. There is much overlap here with the concept of adaptive management, in its broadest sense. The intent is to learn from experience, trying different approaches in different places, and iteratively incorporating lessons into future plans.

Triage is another approach that merits consideration, though its application is contentious. The concern is that triage could change the overall structure of the conservation framework, from a focus on saving all species to one focused on strategically accepting some losses but not others. The appropriate way to think about triage in the context of climate change is in relation to the concept of dynamic conservation objectives. As the climate warms, species are going to shift from their historical range, and we must accept this rather than attempt to prevent it. But acceptance of change does not imply abandonment. Rather, the focus of conservation shifts to facilitating the transition and supporting the species in new areas. Triage is one way of accomplishing this task in a management setting, with an emphasis on making optimal use of limited conservation capacity. The main caveat is that climate change introduces considerable uncertainty into the decision making process, so caution must be exercised before committing to irreversible decisions that may be premature or potentially unwarranted.

The application of these planning concepts to the management of species at risk and coarse-filter conservation is examined in depth in the report. Practical steps for incorporating climate change into existing policies and practices are described, implementation issues are highlighted, and consideration is given to the timing of changes.

Supportive measures

Adaptation and investment in adaptive capacity can be enhanced or constrained by institutional structures and norms. There is an immediate need to incorporate climate change into the legal and policy frameworks supporting conservation, with the initial aim of enabling and promoting preparation across all levels of biodiversity management. In particular, an effort should be made to incorporate climate change into the models used to support the development of regional plans under the *Land-Use Framework*. Another priority is to complete and implement the province's proposed biodiversity framework and to establish additional conservation areas to fill gaps in representation.

In time, more substantive changes will need to be made to the system of conservation management, and land management in general, to accommodate climate change. The main challenge is to develop a system that embraces flexibility while safeguarding against activities that are inconsistent with the aims of conservation and actors seeking to avoid environmental regulation. The whole concept of accountability also needs to be reconsidered. We must be prepared to take risks in the context of adaptive management, and to accept that failures will sometimes occur, while somehow continuing to hold companies and government agencies accountable for the decisions they make and the actions they take. It may be best to begin with pilot projects that can serve as laboratories for identifying and solving the many practical issues that must be dealt with.

Institutional support is also needed for high-level coordination and facilitation of adaptation efforts. The pursuit of synergistic opportunities among different management sectors is of particular importance, given that funding constraints severely limit the types of adaptation measures available when conservation is the sole objective. The regional planning system under the *Land-use Framework* is well positioned to facilitate this type of coordination. Finally, additional staff and resources for addressing the climate change aspects of policy development, planning, research, and monitoring, will be needed to make substantive progress in terms of adaptation.

A key supportive measure for biodiversity conservation is monitoring. The general aim of such monitoring is to understand how well biodiversity is being maintained as a result of our management of human land uses. Climate change complicates this process because it introduces a second agent of long-term change. Efforts must be made to disentangle changes in biodiversity resulting from human disturbances, from changes resulting from climate change. Monitoring has several additional roles, many of which are new or expanded because of climate change. These include the validation of bioclimatic envelope model projections, the monitoring of protected areas as ecological benchmarks, support for adaptive management, and the surveillance for invasive species. A variety of implementation issues are examined in the report.

Finally, adaptation to climate change will require much additional research, in three main areas: 1) climate projections, 2) ecological responses, and 3) management actions. A summary of research priorities is provided in the report. Efforts will also have to be made to disseminate the knowledge that is gained to managers and decision makers. There is also a pressing need to find clear ways to explain and communicate new climate concepts to the general public. Without an awareness of the impending changes in ecological systems and risks to existing land-use objectives, public and political support for new management approaches may not be forthcoming and there may also be an underinvestment in adaptive capacity.

1. Introduction

As a province and a nation we have committed to conserving our native biodiversity (Environment Canada, 1995; Alberta Sustainable Resource Development, 2008a). In this discussion paper I examine this goal through the lens of climate change. The intent is to draw attention to issues that will need to be addressed, and to illustrate practical options for adapting our current system of biodiversity management to the new realities we face. The report is divided into three main sections: a review of the risks that climate change poses for biodiversity; an examination of how conservation objectives can be defined in a world of constant change; and a review and analysis of adaptation measures, ranging from management actions through to planning and supportive measures.

This paper represents a synthesis of ideas obtained from interviews with domain experts and from the scientific literature. The interviews took place during the summer of 2013 and included 43 individuals with management or research experience relevant to conservation in Alberta, from various government departments, academia, industry, and non-governmental groups (Appendix 1).

The leading edge of management response to climate change in the province, in the context of biodiversity conservation, is in the management of fish, for which climate change represents an immediate threat (Sullivan et al., 2013). Active response to climate change is also very evident in the management of forest genetic resources involving commercial tree species (Gray and Hamann, 2011; Gray et al., 2011; Tree Improvement Alberta, 2012). In other areas of government, and within industry and environmental organizations, management responses to climate change are being contemplated but have not yet been implemented.

In the scientific literature, papers on climate adaptation have increased five-fold over the past decade (Glick et al., 2011). These papers are heavily skewed toward human systems, but literature related to the conservation of biodiversity has also been increasing (Heller and Zavaleta, 2009; West et al., 2009; Poiani et al., 2011; Stein et al., 2013). Until the last few years, adaptation researchers assumed no change in conservation objectives and emphasized general principles rather than discrete actions (Heller and Zavaleta, 2009; Poiani et al., 2011). More recently, papers have become more practical and have begun to explore how climate change might affect what conservation is trying to achieve as opposed to how it achieves its objectives (West et al., 2009; Dunlop et al., 2013; Stein et al., 2013).

2. Understanding the Problem

2.1 Risks Related to Physical Changes

The first step in developing effective adaptation measures is to gain a clear understanding of the threat that climate change poses to Alberta's biodiversity. What is it that we are adapting to? The analysis presented here examines the risks to biodiversity arising from anticipated changes in climate and shifts in ecological distributions, as described in a companion report (Schneider, 2013).

The mean annual temperature in Alberta is projected to increase between 2-4 °C by the 2080s, and possibly as high as 6.5 °C under the maximum-change scenario. Most climate models project a small (< 10%) increase in precipitation. Despite the increase in precipitation, most models predict that Alberta will be substantially drier in the future, particularly during the summer months, because warmer temperatures will increase the rate of moisture loss from soils and vegetation. It is also anticipated that year-to-year variability in climate will increase, including an increase in the occurrence of extreme weather events such as droughts and floods (Kharin et al., 2007). Natural disturbances, such as wildfires and insect outbreaks, are also expected to increase (Balshi et al., 2009). As a result of these changes, ecosystems are expected to shift northwards and upslope (details are provided in Schneider, 2013).

At the ecosystem scale, the assessment of risk must consider the difference between ecological change and the actual loss of biodiversity. The status quo is unlikely to be maintained anywhere in the province, even under the least-change climate scenario. But if ecosystems all simply shift northward, then the only real loss is at the northern boundary of the province. Even in this case, the ecosystems are not truly lost, just shifted to a different jurisdiction. This line of reasoning suggests that climate change may pose more of a threat to our static biodiversity objectives than to biodiversity itself (Dunlop et al., 2013). This is an important concept, which I further explore in Section 3. But the expected changes in ecosystem distribution are more complex than a simple shift northward. A more nuanced understanding of the threat to biodiversity from climate change must take these finer-scale changes in distribution into account (see below).

Individual species will not all respond to climatic changes and ecosystem shifts in the same way. Some will have more capacity to adapt than others, and this must be taken into account when assessing vulnerability at the species scale (Ohlson et al., 2005; Williams et al., 2008). This level of analysis is beyond the scope of this report; however, it is an active area of research and assessments for select Alberta species are starting to become available (Lane et al., 2012; Stralberg and Bayne, 2013; Wellicome et al., 2013; Shank and Nixon, 2014). Some of the general traits that influence the capacity of species to adapt include dispersal ability, physiological tolerance limits, degree of habitat specialization, range size, and rate of reproduction (Malcolm et al., 2002; Williams et al., 2008; Dawson et al., 2011). Also important is the amount of genetic variation within and among populations, as this provides the basis for rapid adaptation without actual evolutionary changes (Davis and Shaw, 2001; Hof et al., 2011). In Alberta, amphibians have been identified as the taxonomic group with the least capacity for accommodating climatic changes (Shank and Nixon, 2014).

2.1.1 The boreal forest

When it comes to net loss of biodiversity, the Boreal Region stands out from other Natural Regions (Schneider 2013). To begin with, the Northern Mixedwood Subregion is expected to disappear completely from the province, even under the least-change scenario. However, as previously noted, related ecosystems will continue to be represented in the Northwest Territories. The Boreal Subarctic is also expected to disappear, though in this case the shift is upward rather than northward. The disappearance of these Subregions will have both positive and negative implications for biodiversity in the province. The biggest loss will be to communities specially adapted to permafrost conditions — many genetically distinct populations, and possibly some species, will be replaced by populations and species adapted to warmer climates. On the positive side, the productivity and overall species diversity of these Subregions will likely increase as their harsh climates moderate. Moreover, under medium to severe warming scenarios, these Subregions are expected to serve as refugia of boreal forest after it is lost in other Subregions.

Elsewhere in the Boreal Region the biggest threat to biodiversity is in the Central Mixedwood Subregion, which is uniquely vulnerable. The Climate Moisture Index in this Subregion is near the tipping point that differentiates forested from non-forested systems (Hogg, 1994; Hogg and Hurdle, 1995). In addition, the Climate Moisture Index is relatively uniform across much of the boreal plain, which means that very large areas can be affected by relatively small changes in climate (Schneider, 2013).

Unless there is a substantial increase in precipitation, which does not appear likely, then the least-change scenario for the Central Mixedwood is a transition to Dry Mixedwood. This involves a progressive loss of the spruce component of upland forests, leading to increasing dominance by deciduous stands. Such a change would result in a loss of structural diversity and a decline in species dependent on spruce and mixedwood forest features (Hobson and Bayne, 2000). An increase in fire and insect related mortality is also expected, which would reduce the amount of old-growth forest on the landscape (Nelson et al., 2011). Under the median to maximum-change scenarios these changes occur earlier and the Central Mixedwood eventually transitions to a combination of parkland and grassland ecosystem types. These changes will take time to manifest and even under the maximum-change scenario the expectation for the end of the century is a patchy transitional forest, not a grassland. In any event, the long-term prospects for forest-dependent species currently residing the Central Mixedwood are generally poor.

The loss of Central Mixedwood from its current location will be offset to some degree by an expansion of Central Mixedwood into the Northern Mixedwood and the Boreal Highlands. But given the relative sizes of the Subregions involved, the net result will be a net loss in area for the Central Mixedwood. Old-growth forest habitat[1] will be particularly at risk because it cannot be regenerated quickly. Normally, old-growth stands are produced through the natural aging of 60 to 80-year-old stands scattered throughout the forest landscape. Generating it de novo in areas that today are still largely overlain with permafrost is another matter entirely. The implication is that there could be a severe bottleneck for old-growth flora and fauna during the period between when their habitat is lost in the Central Mixedwood due to climate change and forest harvesting, and when it becomes re-established in new Subregions. Under the hottest climate scenarios it is doubtful that boreal old-growth forest would re-establish anywhere in the province.

2.1.2 Other Subregions

Under the least-change to median scenarios the net effects of climate change on most other Subregions are expected to be neutral or positive. The greatest potential gains are in grassland, parkland and deciduous forest ecosystems, which are all expected to expand at the expense of the

[1] In boreal mixedwood forest stands, old-growth characteristics begin to appear after approximately 80 years.

boreal mixedwood forest. Given that 75% of Alberta's species at risk are located in the Grasslands Region (Alberta Sustainable Resource Development, 2008a), an expansion of grassland ecosystems may have positive implications for biodiversity conservation in the province.

Near-term benefits to grassland species will be limited by the fact that the Central Parkland, directly north of the existing grasslands, has almost entirely been converted to agriculture. While this area may soon be exposed to a grassland climate, the prospects for increasing amounts of native grassland habitat here are low. Rather than abandoning the rich soils of the Central Parkland, farmers will likely adapt to drier conditions with crops that can be harvested earlier (e.g., winter wheat), or have low moisture requirements (e.g., dry pea and chickpea), or can be supported through dry periods with irrigation and water conservation measures (Lemmen and Warren, 2004; Sauchyn et al., 2009).

Better opportunities for range expansion by grassland species exist in northern areas. Scattered grasslands already exist along the Peace River lowlands, all the way to Wood Buffalo National Park, and these are expected to be the initial foci of grassland expansion. Migration distance will be a challenge for some southern species; however, a large proportion of the Northern Fescue flora is already present in the Grande Prairie area (Moss, 1952). Competition from non-native species may also present a challenge to migrating species (see 2.2.1).

The main exception to the generally positive outlook described above is the Alpine Subregion. As with the Boreal Subarctic, the Alpine is expected to be replaced by ecosystems from below, while being unable to move much higher itself. Given the harsh climatic conditions at high elevation, the rate of change may be relatively slow compared with other regions.

Biodiversity declines may also occur as a result of the progressive drying of prairie wetlands, which have a large ecological role in southern Alberta landscapes in terms of maintaining biodiversity. Losses of wetlands in the south should be offset by gains in the north, as peatlands decompose and convert to marshes and open water. The problem is that peatland conversion is subject to significant lag effects, whereas falling water levels in the south can occur quickly in the face of warm and dry conditions. This could lead to a bottleneck for prairie wetland species. Migration distance may be an issue as well, for some species.

Under the maximum-change climate scenario the patterns of change will initially be the same as described above. But it is very difficult to know what the net effects on biodiversity will be by the end of the century. Extirpation of species due to climate change does not seem likely, other than in high elevation sites, because scattered remnants of earlier ecosystems should persist in some parts of the landscape[2]. But significant declines in the abundance are possible, particularly for species with limited adaptive capacity. More generally, unanticipated ecological outcomes are likely to arise under maximum levels of warming.

[2]I refer here to extirpation directly attributable to climate change. Extirpation from other causes, particularly habitat loss, remains a real possibility for some species.

2.2 Interaction with Human Land Uses

The species that exist in Alberta today are the survivors of several glacial cycles, suggesting that they have the capacity for adapting to substantial changes in climate (Dawson et al., 2011; Hof et al., 2011). There is reason to believe, however, that the current episode of climate change represents a greater threat to Alberta's native species than climatic changes that have occurred in the past. Although species do have an intrinsic ability to respond to climate change, this adaptive capacity has limits. There is a concern that many species may be unable to keep pace with the rapid rate of climate change projected under the median to maximum-change climate scenarios (Noss, 2001; Malcolm et al., 2002). Furthermore, the ability of species to effectively respond to climate change may be compromised by the effects of human land uses (Davis and Shaw, 2001; Noss, 2001; Hof et al., 2011; Staudt et al., 2013).

2.2.1 Impediments to migration

One effect of anthropogenic disturbance of the landscape is that it may impede the ability of species to shift their range, resulting in climate vulnerability that would not otherwise exist. The problem is not so much physical barriers to movement, though these exist in a few areas, but the widespread deterioration in habitat quality that has occurred over the past century. Instead of robust populations primed to expand into new areas, many populations are smaller and less viable than they might otherwise be because of human activities occurring in their current range. The burrowing owl and ferruginous hawk, which are on the northern edge of their range in Alberta, are examples. Instead of slowly expanding northward in response to a warming climate, both species are contracting southward towards their core range in the United States (Todd, 2005; Downey, 2006).

Anthropogenic disturbance of the landscape may not only hamper the ability of populations to leave existing areas, it may also reduce the ability of populations to become successfully established in new areas. Just because the climate of a new area becomes suitable does not mean that the land will be suitable in all other respects as well. The example of agricultural conversion in the Central Parkland has already been mentioned, reducing the potential for northward expansion of Northern Fescue species. In the north, there is a concern that non-native grasses that have been planted along roadways and on seismic lines will become widespread under a warmer and drier climate, resulting in a competitive barrier to the influx of native grass species and associated biota (Sumners and Archibold, 2007; Galatowitsch et al., 2009).

2.2.2 Changing land-use objectives

Another risk to Alberta's biodiversity is the potential of climate change to alter human land-use objectives and policies. The risk is greatest in the Green Zone, which is comprised of publicly owned forested lands where agriculture is prohibited. Industrial activities are permitted in the Green Zone, but restrictions are in place that are intended to maintain native biodiversity (Alberta Sustainable Resource Development, 2006). For example, forestry companies must reforest stands after harvest using local genetic stock, and areas disturbed by petroleum development must be restored after use. Although the cumulative impact of industrial disturbances has reduced the ecological integrity of the Green Zone, particularly over the past few decades, it is relatively pristine when compared to the White Zone.

In the White Zone, native ecosystems have been extensively replaced by agricultural systems designed to harness as much of the productive capacity of the land as possible for the purpose of growing food. The native prairie that remains is mostly in the southeast of the province, where insufficient moisture and poor soils preclude cultivation. Even here, the current ecosystems, dedicated to cattle grazing, are substantially different from the native prairie that existed prior to settlement (Sutter and Brigham, 1998). It is unsurprising that 75% of Alberta's species at risk reside in the White Zone and that most species extirpations since European settlement have happened here (Alberta Sustainable Resource Development, 2008a).

As the climate warms, it is all but inevitable that the agricultural community will begin to promote the conversion of Green Zone land to agricultural use. Examples can already be found today. Writing about the implications of climate change in Saskatchewan, Carr et al. (2004) wrote: "It may be possible to open up new agricultural areas north of Prince Albert. These areas are too cold now, but as the length of the growing season increases, perhaps the present boreal plain can be made the new breadbasket of the country." Although agricultural expansion would provide obvious societal benefits, such as jobs and food production, it represents a serious threat to the conservation of native biodiversity. This is especially true if the transition to agriculture involves the privatization of public land, because the government retains little ability to ensure the maintenance of biodiversity once land is in private hands.

Another potential threat to biodiversity in the Green Zone is that, as the climate warms, resource companies in the region may demand concessions with respect to operating rules designed to maintain biodiversity (Carr et al., 2004). Companies may argue that such restrictions are unwarranted, given the overriding effect that climate change is likely to have on local species. But the amount of ecological change that will result from climate change is uncertain, and it would be imprudent to accept biodiversity losses now on the basis of worst-case projections of what might happen in the distant future. Furthermore, it is the transition, not the end state that is important in this case. Species will actually need more protection from industrial disturbance, not less, to ensure that they have the capacity to effectively respond to the demands that climate change will place on them, including the need to migrate to new areas (Noss, 2001). That said, if and when climate change begins to affect the economic viability of the forest industry, through increased fire and insect damage, reforestation failure, and deteriorating winter harvest conditions, demands for intensive short-rotation plantations may become a matter of survival for forestry companies (Johnston et al., 2010; Woods et al., 2010).

3. Setting Conservation Objectives

Climate change complicates the achievement of conventional conservation objectives in ways that make it necessary to re-examine their relationship to the underlying motivating principles (Camacho et al., 2010). The challenge is to find a way to adapt our objectives to the new reality posed by climate change, without losing fidelity to the public values and norms that underlie our current approach to biodiversity conservation (Hobbs et al., 2009). Gaining clarity around our conservation objectives is a critical prerequisite for developing and implementing meaningful adaptation measures (Camacho et al., 2010; Dunlop et al., 2013).

In the following sections I review the current approach to setting conservation objectives and outline three alternative approaches for responding to climate change. These approaches were formulated to maximize their heuristic value. In practice I would expect that parts of all three approaches might be utilized in combination or at different points in time. The main intent is to identify meaningful options and to highlight key issues that need to be considered when changes are contemplated.

3.1 The Current Approach to Conservation

Our current system of biodiversity management can be traced back to the 1960s and 1970s, when widespread awareness of environmental issues began to affect public policy. It was recognized that the global drive for economic development was endangering the biosphere, and by extension, the quality of life of future generations. The solution, articulated in the report of the World Commission on Environment and Development (1987), was the concept of sustainable development, in which human activities are structured to meet today's needs without compromising the future. The concept of sustainable development provided the context within which the *United Nations Convention on Biological Diversity* and the *Canadian Biodiversity Strategy* were developed (Nations, 1992; Environment Canada, 1995). Alberta is a signatory to the *Canadian Biodiversity Strategy* and, along with other Canadian jurisdictions, has agreed to use the *Strategy* as a guide for actions to conserve biodiversity (Government of Alberta, 2013).

What this historical perspective indicates is that, while the goal of conservation is to maintain biodiversity, the management context is that of sustainable development and the need to balance competing land-use objectives. Consequently, there is a need to distinguish between conservation objectives — the outcomes we would like to achieve from a primarily ecological perspective — and management targets, which are the biodiversity outcomes that we actually manage for, after trade-offs among land-use objectives and various constraints are taken into account. This section of the report deals specifically with conservation objectives; management targets are discussed later, in the context of planning (Section 4.3).

The stated goal of conservation is to maintain ecosystem, species and genetic diversity, and the processes that shape them, in the face of human development (Environment Canada, 1995). Implementing this broad goal in a management setting involves defining, in measureable terms, the original ecological state that is to be maintained through management intervention and protection measures. I will use the term Ecological Reference State (ERS) to refer to this form of conservation objective.

ERSs are generally defined using biodiversity proxies, because we have neither the knowledge nor the capacity to individually assess all species, let alone all unique genotypes. These proxies are comprised of indicator species and ecosystem attributes that are selected to represent the biota of a given area (Hunter et al., 1988; Steenberg et al., 1998). Species of special interest, particularly those at risk of extinction, are usually managed directly, and not by proxy.

For ecosystem attributes, the ERS is typically the state of the landscape prior to widespread anthropogenic development (Landres et al., 1999; Millar et al., 2007; Keane et al., 2009). These ERSs are location-specific, because ecosystem type varies across the landscape. At the species scale, the ERS is usually based on historical range and abundance. However, historical status may no longer be relevant for species that are nearing extinction. For these species, an estimate of the minimum population size required for long-term viability may be used to represent the desired conservation outcome (Environment Canada, 2013). It is recognized that ecosystem attributes and species abundance naturally fluctuate from year to year because of disturbances such as wildfire and short-term fluctuations in climate. Therefore, ERSs may be expressed in terms of the range of natural variability rather than a point estimate.

Although a degree of year-to-year variability may be incorporated into the ERS, the only acknowledged agent of long-term change is anthropogenic disturbance. Indeed, managing these disturbances and their ecological effects is the central focus of most conservation efforts (Glick et al., 2011). The advent of global warming requires a fundamental shift in thinking because natural systems are now subjected to two agents of change. Furthermore, while conservation managers are able to exert (some) control over human activities within their jurisdiction they have no control over the global climate (despite the fact that global warming is itself anthropogenic in origin).

The upshot is that our current system of biodiversity conservation, which defines conservation objectives on the basis of static spatially-defined ERSs, will become untenable as ecosystems and species shift in response to climatic change. The challenge is to reimagine what the goal of maintaining biodiversity means and how it can be achieved in a world of constant change (Camacho et al., 2010; Dunlop et al., 2013).

3.2 Approach A: Continue Using Static Conservation Objectives

3.2.1 Rationale for maintaining the status quo

Although static ERSs will eventually cease to be relevant as a result of climate change, they are still serviceable today. Moreover, there are several reasons for maintaining the existing ERSs, at least for the time being (Keane et al., 2009). Any discussion about how and when conservation objectives should change needs to take into account the many reasons for keeping things as they are (Hagerman and Satterfield, 2013; Tam and McDaniels, 2013). For advocates of proactive adaptation, the reasons for maintaining the status quo represent points of resistance that must be understood and addressed.

Scientific uncertainty. Although little doubt remains about the overall trajectory of global warming, there is considerable uncertainty regarding the amount and rate of change. There is also uncertainty about how species and ecological systems will respond to changes in climate. Some managers and decision makers may choose to delay responding to climate change until empirical evidence of ecosystem change validates some of the model predictions and provides some indication of which of the various climate scenarios is most likely to be realized.

Capacity limitations. Because of capacity limitations, managers are often forced to focus on the most pressing issues and are unable to provide much attention to issues (such as climate change) that do not pose an immediate threat and which are subject to considerable uncertainty (Hodgson et al., 2009; Magness et al., 2012). This being the case, the allocation of financial support and staff time to adaptation measures may be limited, effectively precluding adaptation measures that are costly to implement (at least in the near term). A shortage of technical expertise related to climate change is also an issue.

Resistance to change. Humans have a natural tendency to resist change (Magness et al., 2012; Hagerman and Satterfield, 2013). In the context of climate change, individuals that have dedicated their careers to the current system of biodiversity conservation may not easily accept that the objectives must change (Poiani et al., 2011). Within the public sphere, there may be scepticism about government and industry motives for change.

Lack of an alternative. Static ERSs cannot be abandoned until a viable alternative is available. We are only now beginning to consider what this alternative might look like. A key challenge is finding something that is as objective and resistant to discretionary interpretation as references that are based on historical status (Camacho et al., 2010). It will take some time before the options are fully developed and debated and even longer before actual changes in policy are made.

Political inertia. The conservation of biodiversity is only one of many objectives that land managers are asked to achieve. Many of these objectives are in conflict with each other, necessitating political trade-off decisions. The trade-off decisions that have been made over the years often reflect hard-fought battles between opposing interests. Reopening these decisions to accommodate climate change has complex political ramifications — we are opening the proverbial "can of worms." The environmental community may be particularly resistant to such change, not because it is opposed to climate adaptation per se, but because it is concerned that industry will be given a free hand under the guise of increased flexibility (Camacho et al., 2010; Hagerman et al., 2010a). Another cause of political inertia is that adaptation to climate change involves novel management approaches and limited predictability concerning outcomes. Managers may hesitate moving in this direction given a political culture that has been slow to accept the reality of climate change and that is not accepting of failure (Hagerman et al., 2010b).

3.2.2 Problems with maintaining the status quo

Although continued use of static ERSs is viable in the near-term, it is not a long-term solution in the face of global warming (Millar et al., 2007; West et al., 2009; Stein et al., 2013). Efforts to maintain the status quo will become increasingly expensive and fundamentally misdirected as ecosystems shift in response to climate change. Mostly likely, static ERSs will simply be ignored once they fade from reality.

There are two concerns with maintaining the status quo that require immediate attention. First, there is a danger that continued adherence to a static management framework will impede progress in preparing for the future. The preparatory steps that will be required to accommodate climate change will take many years of effort. The paradigm shift in forest management that began in the early 1990s, taking us from sustained yield forestry to integrated land management and the emulation of natural disturbances, has taken over two decades and is still not complete. If we hope to have the scientific knowledge and the institutional system in place to accommodate climate change once large-scale ecosystem changes begin to occur, we need to start preparing now. Such preparations can begin even while static ERSs continue to be used, through a high-level directive mandating climate readiness as an additional objective at all levels of biodiversity management.

A second problem with strict adherence to static ERSs is that it positions the ecological effects of climate change as a threat that must be resisted, rather than an externality that must be adapted to (Dunlop et al., 2013). In some cases, slowing the pace of ecological change through resistance measures may be helpful, giving species the time they need to adapt. But in other cases, efforts at resisting change may be maladaptive in the long-term or will divert scarce conservation resources away from where they would do more good (Choi, 2007; Dunlop et al., 2013; Hamann and Aitken, 2013).

The management of Arctic grayling provides an example. Most populations of Arctic grayling in the southern parts of their range are in decline as a result of rising water temperatures, in combination with other factors (Walker, 2005). Under a static approach to conservation, increasing effort should be devoted to these southern populations because they are most at risk. An alternative perspective is that the decline in southern populations reflects a shift in range, and instead of trying to prevent this change, conservation efforts should be redirected farther north, where they will provide the greatest long-term benefit .

Another example where a focus on historical ERSs is maladaptive is reclamation and reforestation that involves the planting of genetic stock that is poorly suited to the anticipated future climate (Harris et al., 2006; Choi, 2007; Hamann and Aitken, 2013).

In practice, the transition away from static conservation objectives is likely to be gradual and will depend to a certain extent on how quickly ecological changes actually occur. Managers involved in situations where resisting climatic change is clearly futile or maladaptive are likely to make ad hoc adjustments to existing conservation objectives at an early stage. Such bottom-up adjustments may constitute the initial phase of climate change adaptation, preceding broader shifts in provincial policy. However, to avoid the unintended outcomes and lack of accountability that may arise with an ad hoc system, efforts to develop formal climate-ready conservation objectives should be developed as quickly as possible.

3.3 Approach B: Make the Current System Dynamic

3.3.1 The meaning of biodiversity conservation under climate change

The stated goal of biodiversity conservation is to maintain ecosystem, species and genetic diversity (Environment Canada, 1995). The key to interpreting this goal in the context of climate change is the word "maintain". One perspective is that "maintain" implies the preservation of a specific ecological state. However, as described in Section 3.1, our system of biodiversity management was motivated by a desire for conservation, not preservation. That is, the intent was to protect the natural environment from the deleterious effects of human activities, not to prevent change per se.

A climate-ready interpretation of biodiversity conservation that reflects this original intent can be articulated as: maintain ecosystem structures, patterns, and processes (including species distributions) *as they would be in the absence of human disturbance*. Under this interpretation, conservation efforts would continue to focus, as they always have, on preventing harm from human land uses. In contrast, ecological changes resulting from climate change would generally be treated as natural phenomena, and efforts would not be undertaken to prevent these kinds of changes. Management intervention would, however, be warranted in the context of adaptation, to ensure that species are able to successfully adjust to new climatic environments despite barriers to movement and other constraints (see Section 4).

The reason for treating all climatic and associated ecological changes as natural phenomena, despite the anthropogenic origins of global warming, is simply that they are unlikely to be reversed once they occur, at least not on any time scale relevant to the management of biodiversity (Archer and Brovkin, 2008; Craig, 2010). Once the climate changes it will represent a new normal that we will have to accept and adjust to (like it or not). This does not diminish the importance of minimizing greenhouse gas emissions as a preventative measure. The context here is different: minimizing the amount of future climate change versus responding to climatic and ecological changes once they occur.

3.3.2 Defining dynamic reference states

The climate-ready interpretation of biodiversity conservation requires a new approach to defining ERSs. These reference points should continue to provide reliable quantitative descriptions of the ecological patterns and species distributions that would exist in the absence of anthropogenic disturbance. But, because global warming will cause ecological patterns to shift over time, the ERSs must be dynamic. That is, they must be continually updated in order to represent what the unperturbed state of the landscape would be at the current time, not what it was in the past.

Dynamic ERSs can be defined using a combination of monitoring and modeling. The basic idea is to monitor patches of unperturbed landscape across the entire province and then use models to interpolate the data and generate projections for the entire landscape (Wiersma, 2005). Ideally, the patches of native landscape would be representative of the full range of ecosystems in the province and would be large enough to maintain natural processes including natural disturbance regimes (Leroux et al., 2007). They would also be in a reasonably pristine state and not subject to significant edge effects from human activities in the adjacent working landscape (Wiersma, 2005). The larger sites in our existing system of protected areas fulfill most of these requirements; however, the distribution of large parks is heavily skewed to the Rocky Mountains and the northeast corner of the province, leaving major gaps in representation. To some extent, these gaps are addressed by smaller natural areas and sites that are only partially protected. These include range lands in southeast Alberta, the Suffield National Wildlife area, smaller parks, and the forest stands comprising the provincial permanent sample plot system.

Defining dynamic ERSs for individual species of special interest will require additional effort, particularly for those that exist at low densities. One issue is that the level of detail provided by landscape-level monitoring may be insufficient for the management of these species. This can be addressed through dedicated species-specific monitoring, which already exists for many species at risk. A greater challenge will be determining the "natural" range of a species after ecosystem patterns have shifted as a result of climate change. The observed distribution of a species at that time may not be a good guide, particularly if the species has an abundance that is lower than it should be, or if it has a low rate of migration (possibly because of anthropogenic barriers). In this case, habitat selection models could be used to provide an estimate of the distribution of high-quality habitat on the landscape.

The transition to dynamic ERSs will take time, as several steps are involved. First, policy direction must be provided that enables and supports a dynamic approach to conservation. Next, a system of monitoring sites that are minimally affected by anthropogenic disturbance (i.e., benchmark areas) needs to be in place. The main issue here is filling gaps in ecosystem representation within the current provincial system of protected areas. This could be accomplished through the establishment of additional large conservation areas under the regional planning process, as was done in the Lower Athabasca Regional Plan (Government of Alberta, 2012). Efforts aimed at coordinating and enhancing the provincial permanent sample plot system are also warranted (Alberta Environment and Sustainable Resource Development, 2013). Finally, our current system of biodiversity monitoring will need to be modified, as described in Section 4.4.2.

3.4 Approach C: Devise New Conservation Objectives

3.4.1 Objectives based on ecosystem function

Because the composition of ecosystems is destined to change under climate change, some conservation biologists advocate for a focus on ecosystem function rather than structure (Hagerman et al., 2010b; Glick et al., 2011; Prober and Dunlop, 2011; Dunlop et al., 2013; Stein et al., 2013). This is not a prominent view, and was not expressed by any of the domain experts I interviewed in Alberta, but it merits discussion. The basic idea is to replace site-specific structural targets with broader objectives such as maintaining "a functional landscape" or "ecosystem health". Though these objectives are rather vague, the approach is basically consistent with the fundamental goal of biodiversity conservation, which I have suggested is to prevent harm to natural systems from human disturbances. The challenge lies in its practical application.

The main problem is that our ability to measure and interpret ecosystem function is quite limited. We have a basic understanding of a few fundamental ecosystem processes, such as natural disturbance regimes, ecosystem productivity, predator-prey dynamics, and nutrient cycling. But a composite description of an ecosystem on the basis of these processes would be very coarse. Furthermore, the link to species diversity is quite tenuous. Individual species could easily be lost from the system without being detected by any of the available measures of ecosystem function (Schwartz et al., 2000; Lyons et al., 2005; ter Steege et al., 2013). For example, it is highly unlikely that the loss of sage grouse or whooping cranes would have any detectable effect on ecosystem function at all. This suggests that an ecosystem function approach to conservation is not well aligned with the basic goal of biodiversity conservation, which is to maintain all species, not just some.

Another concern is that objectives such as maintaining "a functional landscape" or "ecosystem health" do not reflect the public's main interest in conservation, which is focused on high-profile species. Furthermore, functional objectives are inherently ambiguous and malleable, and as such, represent a slippery slope (Srivastava and Vellend, 2005; Camacho et al., 2010). Lacking an explicit connection to native species, there is a danger that ecosystem objectives associated with economic gains will come to dominate at the expense of attributes associated with economic costs (Hagerman et al., 2010b). This process has been referred to as the commodification of nature (McCauley, 2006; Gomez-Baggethun and Ruiz-Perez, 2011).

Although using ecosystem function as the basis for conservation does not appear to be a viable alternative to conservation on the basis of structural attributes, functional objectives do have a role in biodiversity management. It has long been recognized that species objectives cannot be achieved unless attention is also paid to broader ecosystem processes, such as maintaining natural disturbance regimes and nutrient flows (Bennett et al., 2009; McGregor et al., 2011). Therefore, efforts to better describe and understand ecosystem function and to integrate functional objectives into biodiversity management are warranted. Functional objectives may one day transition from a supportive role to a primary role in management if the structural approach becomes unworkable because of extreme warming.

3.4.2 Maximizing biodiversity

Another management approach that might be considered in the face of high levels of warming is to abandon ERSs entirely. We would instead rely on the knowledge base that has accumulated over the years on the requirements species have for maintaining viability and on the mechanisms by which human disturbances present a risk to species. When decisions are be made in the context of resource development or land-use planning, the objective for biodiversity could be to maximize the ability of species and ecosystems to survive and adapt (Craig, 2010; Lindenmayer et al., 2010). This approach is inherently climate-ready because the focus is on minimizing harm, regardless of the past or current state of the ecosystem.

The weakness in this approach is that biological systems are highly complex, and the linkage between management intent (e.g., maximizing biodiversity) and actual outcomes is often tenuous.

Furthermore, management plans are rarely optimal from a biodiversity perspective because of trade-offs with other land-use objectives. A conservation approach that does not formally track ecological status over time, so that adjustments can be made when needed, is likely to lead to gradual declines in biodiversity that are never fully appreciated. Finally, in the absence of a defined reference, biodiversity losses resulting from anthropogenic disturbances in one period can become accepted as the new norm in subsequent time periods.

4. Adaptation Measures

The previous section focused on high-level conservation objectives that serve as proxies for our fundamental conservation goals. The adaptation literature also includes objectives that are operational in nature, serving as the means to an end, rather than an end in themselves. These types of objectives, which exist lower down in the conservation objective hierarchy, are considered here, as part of the discussion of adaptation measures.

The aim of adaptation measures is to help species successfully transition to new climatic environments that arise, much as they would in the absence of human disturbance of the landscape (Craig, 2010). Although species do have the intrinsic capacity to adapt to large changes in climate (Dawson et al., 2011), assistance is needed because: 1) the vitality and resilience of many species has been reduced due to anthropogenic disturbance, making them less able to withstand climatic variability and less able to shift their range, 2) barriers to movement now exist, including regions where habitat quality has deteriorated, 3) some species may be unable to keep pace with the unusually fast rate of climate change projected under the median to warmest climate scenarios, and 4) non-native species may competitively exclude the movement of native species into new areas (Dawson et al., 2011). These areas of concern define the scope for management intervention in the context of adaptation.

The available adaptation measures are, for the most part, components of the standard conservation toolkit (Noss, 2001; Hunter et al., 2010; Lindenmayer et al., 2010; Hagerman and Satterfield, 2013). The changes lie in the purpose for which the tools are used, and in some cases, the way they are used.

4.1 Protected Areas

Habitat protection is one of the most frequently cited climate adaptation measures for biodiversity conservation (Hannah et al., 2007; Heller and Zavaleta, 2009; Hodgson et al., 2009). The underlying rationale is that species will have the greatest capacity to withstand the challenges arising from climate change if they do not also have to contend with the stresses imposed by human disturbances. Well-designed reserve networks, acting as stepping stones, may also facilitate migration along climatic gradients. Protected areas also serve as ecological control areas, helpful in determining the effects of human activities on the managed landscape and for differentiating anthropogenic effects from climatic effects (Wiersma, 2005). Finally, protected areas have additional roles that, while not directly related to conservation, should be considered when developing climate adaptation measures. In particular, protected areas are used for recreation, the preservation of wilderness, and for scientific research.

4.1.1 Coarse-filter application

Because the amount of land that can be protected is limited by competing land-uses, careful consideration has to be given to how sites are chosen for protection. Under conventional coarse-filter theory, the overriding objective is to represent all major ecosystem types based on their current distributions (Margules and Pressey, 2000; Watson et al., 2011). Climate change presents a challenge to this approach in that the ecosystems selected for protection are likely to shift from their current (protected) locations under even the least-change climate scenarios (Lemieux and Scott, 2005; Schneider, 2013).

One potential response is to abandon the concept of permanent protected areas in favour of moveable sites that track their respective ecosystems across the landscape. However, except for existing parks, most of Alberta's lands have been allocated to some form of resource development. If protected areas were to move it would mean that existing sites, which have been kept largely pristine, would have to be exchanged for sites that have been subjected to many decades of resource development or agricultural use. This would violate the central premise of protection. In theory, the new sites could be restored once protected, but the cost and time required to unwind the legacy of decades of anthropogenic disturbance, and to decommission the extensive infrastructure that exists, make this unrealistic, especially considering that the new sites would themselves only be protected temporarily. A system of moveable protected areas would also be extremely complex to manage. Decisions would continually have to be made about when to move sites, where they should move to, and there would be a never-ending series of negotiations with individuals and companies that hold rights to sites identified for future protection.

An alternative response to climate change is to reconsider the concept of representation. Rather than focusing directly on ecosystems, which present a moving target, site selection could be based on representing important forms of variability in the physical environment. A regional system of protected areas that represents the full range of physical environments, including dominant landforms and climatic gradients, is likely to provide protection for most species (Hunter et al., 1988; Anderson and Ferree, 2010; Beier and Brost, 2010; Game et al., 2011). Moreover, because the focus is on the "stage" and not the "actors", the system is intrinsically robust to climate change (Anderson and Ferree, 2010; Beier and Brost, 2010; Game et al., 2011; Groves et al., 2012).

The challenge with this approach is in objectively delineating physical environments. The Natural Region and Subregion classification, which has supported protected area planning in the province for many years, provides a useful starting point (Natural Regions Committee, 2006). However, this classification is only partially based on physical features; it also incorporates dominant vegetation types and other landscape attributes (Fig. 1a). The Physiographic Regions of Alberta map (Fig. 1b) is an alternative, but in this case latitudinal gradients in temperature and regional differences in precipitation patterns, which have important biotic implications, are not captured.

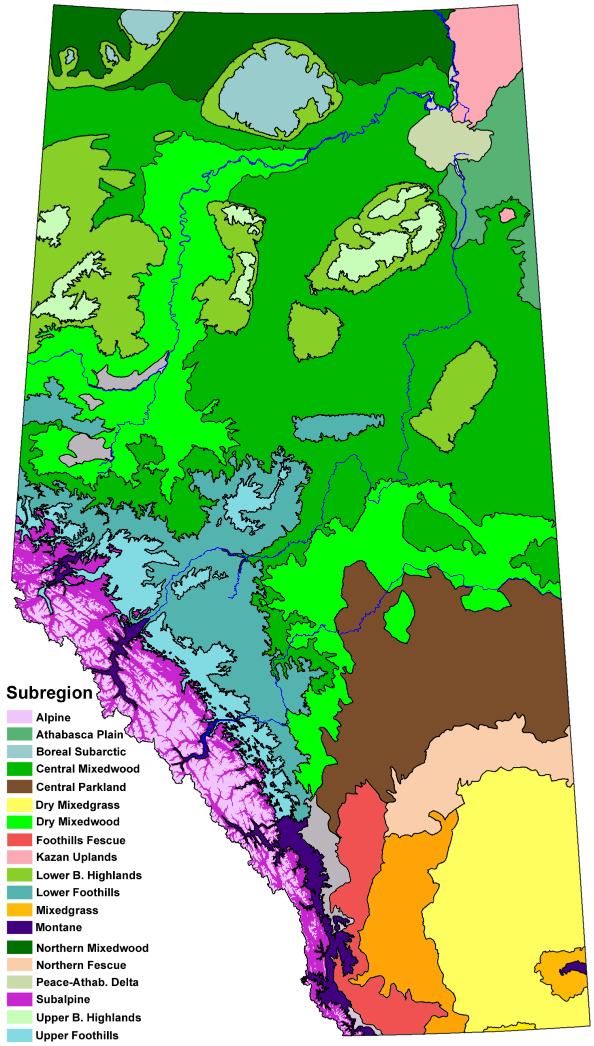

Fig. 1a. The Natural Regions and Subregions of Alberta.

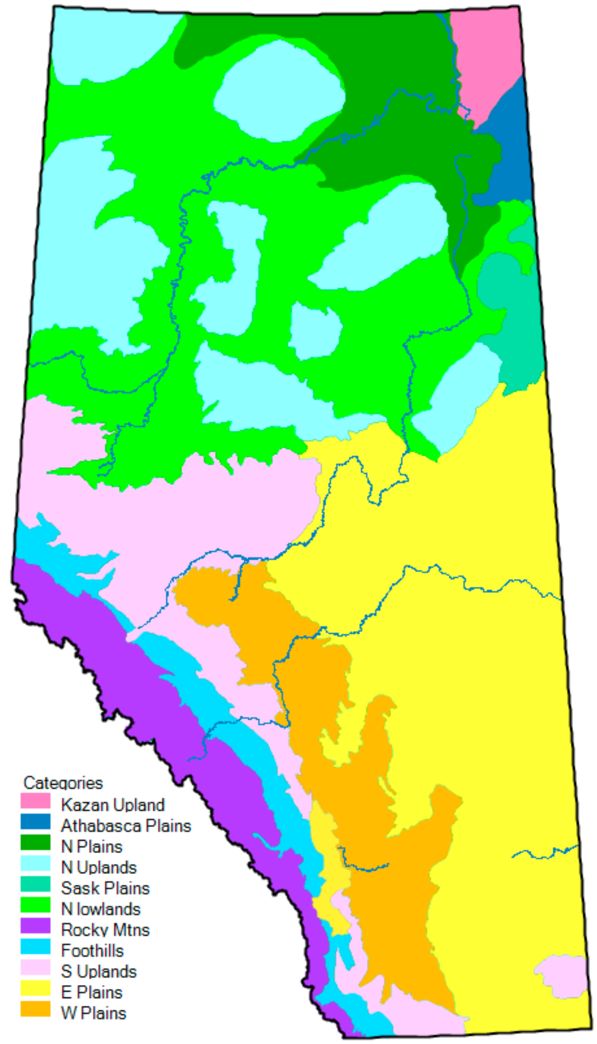

Fig. 1b. The physiographic regions of Alberta.

It should be reasonable to use the Natural Subregion classification as a first approximation in areas where the boundaries are based on distinct landforms (e.g., Boreal Highlands) or unique soils (e.g., Athabasca Plains). However, Subregion boundaries that are based on changes in vegetation (e.g., Lower to Upper Foothills) will require additional analysis. It is not that it is inappropriate to subdivide large landscapes on the basis of eco-climatic gradients; it is just a question of where best to draw the line. Robust criteria should be devised for these subdivisions. That said, selection decisions made using the existing Subregion boundaries will not be too far off, particularly if new protected areas are oriented in the direction of the dominant climatic gradient (e.g., upslope in the Foothills).

4.1.2 Fine-filter application

The physical landscape approach should serve the needs of most species. It also represents a robust strategy, in that its validity and utility are not dependent on a long string of assumptions concerning the trajectory of the future climate and potential ecological responses (Beier and Brost, 2010). However, as with any coarse-filter strategy, it will not meet the needs of all species.

Additional fine-filter measures will be required to protect uncommon habitat types and to meet the unique needs of species that are at risk of extirpation. Meeting these needs in the face of climate change will be challenging, in that sites selected for a specific species or purpose may lose their utility once ecosystems begin to shift. Failures of this type would represent a poor investment of conservation resources, given that the overall amount of land available for protection is limited. Where larger areas are involved (e.g., caribou habitat) it would be advisable to incorporate the specific needs of individual species into a broader suite of protection objectives. For example, Wood Buffalo National Park, established for the conservation of wood bison, also serves as the cornerstone of boreal forest representation and protects the Peace-Athabasca Delta.

If the amount of fine-filter habitat requiring protection is small, then a moveable reserve approach might be appropriate, despite the shortcomings of moveable reserves mentioned earlier. The maintenance of old-growth mixedwood forest provides a case in point. To avoid a critical bottleneck in the supply of old-growth habitat, particularly in the boreal forest, it will likely be necessary to protect it from harvesting and other anthropogenic disturbances in coming decades. Conventional protected areas are not well suited for this purpose, given the wide distribution and dynamic nature of old-growth stands. Instead, a floating reserve system based on dynamic planning and operational measures is the most appropriate approach.

4.1.3 Climate refugia

The coarse-filter approach can be augmented by identifying and protecting climatic refugia. Climatic refugia are habitats that components of biodiversity retreat to or persist in under changing environmental conditions (Keppel et al., 2012). This concept can be applied at different scales and for different purposes.

In one type of application, the objective is to maximize the overall stability of the protected area system by selecting sites that are least likely to change as the climate warms. This can be achieved by comparing the current locations of ecosystems with their projected locations in the future and assigning priority to regions of overlap (Carvalho et al., 2011; Stralberg and Bayne, 2013). This approach should be applied in conjunction with a physical landscape representation approach, to avoid gaps in representation (Tingley et al., 2013). Regional-scale physical landscapes would be delineated as a first step, and then the refugia approach would be used to select the most stable sites within each landscape.

Climatic refugia can also be used at finer scales (i.e., micro-refugia). Within a given landscape, areas of maximal stability under climate change can be identified on the basis of local topography, aspect, rate of natural disturbance, and other factors (Dobrowski, 2011; Ashcroft et al., 2012). For example, moisture stress is a greater concern for south-facing slopes than north facing slopes, and wildfire risk is lower in riparian areas than in upland forest. As ecosystems begin to shift, these sites of stability may become refugia for local biota.

Protecting microrefugia from human disturbance will allow local species to persist as long as possible in their original habitat. This will provide extra time for adapting to change, particularly when new habitat is slow to establish elsewhere. Alberta's parks legislation does not have a category appropriate for the protection of micro-refugia, which are typically small, numerous, and widely dispersed. Managing human activities in these areas will likely have to occur through forest management plans, sub-regional land-use plans, conservation easements, and other land management tools. Another option is to consider adding a new category to the *Parks Act*.

Application of the climate refugia concept is challenging under high levels of warming. The stability approach described earlier fails under these conditions, because ecosystems are likely to shift completely from their current locations, leaving no points of overlap between old and new. In anticipation of high levels of warming, the concept of refugia might still be applied in what amounts to a form of fine-filter protection. In this case, the target of protection would be habitat types that are expected to become rare in the future. The area protected would be the projected future location of these ecosystems, not (necessarily) their current location. For example, given the precipitous decline of Central Mixedwood projected under many climate scenarios, consideration could be given to protecting high-elevation boreal hills as the prospective final refuge of Central Mixedwood in Alberta. Although this approach has merit, it is totally dependent on long-range projections that are subject to considerable uncertainty. Therefore, it should probably not have a primary role in site selection, but could be usefully employed when weighing options within a coarse-filter approach (Tingley et al., 2013).

4.1.4 Connectivity

Connectivity among protected areas has always been an important design consideration, and it will become even more critical with climate change (Hunter et al., 2010). One approach to achieving connectivity is through the establishment of travel corridors that link individual protected areas. There is support for this approach in the literature (Doerr et al., 2011); however, the topic is somewhat controversial because corridors can be difficult to implement in practice and could potentially foster the movement of "weedy" species (Hodgson et al., 2009; Schneider et al., 2011).

Corridors can work well over short distances (e.g., the wildlife corridors over the TransCanada highway in Banff) or where the path of movement is well defined (e.g., valleys in a mountainous landscape). But Alberta is a large province and our protected areas are widely distributed, often separated from each other by over 100 km. It is difficult to envisage how linear travel corridors could be effective and practical across such large distances. Riparian corridors might be one solution, at least in some areas. Riparian zones are ecologically important linear features that traverse multiple ecosystem types, and can serve as movement corridors for a variety of species (Capon et al., 2013). Furthermore, the intactness of these corridors has been maintained in forested areas through forest management regulations. Elsewhere, general efforts to minimize barriers to movement within the managed landscape may be the best approach, emphasizing landscapes that separate individual protected areas from their nearest neighbours.

Another means of enhancing connectivity is to directly incorporate it into the selection and design of new protected areas (Dawson et al., 2011; Schneider et al., 2011). One approach is to emphasize large protected areas over small ones and to orient the sites along major climate gradients. In this way, much of the movement that will be required to accommodate climate change can take place within the protected area system itself. Another approach is to use smaller protected areas as stepping stones between other sites in the system (Hunter et al., 2010).

4.1.5 Park management

The implications of climate change for the management of existing parks depends on their stated mandates and how these mandates are interpreted. Where the objective is general conservation, ecological transitions resulting from climate change should be treated as natural phenomena. Rather than attempting to resist these types of changes, management efforts should instead continue to focus on protecting the site from human disturbances, and to support whatever species happen to reside in the reserve at any given time.

The situation is more complex if a park has a mandate for the preservation of a specific species or ecological feature, or where there is a desire to maintain existing recreation opportunities (Alberta Tourism Parks and Recreation, 2012). Maintaining the status quo may be possible if the amount of warming is not too great; however, increasing management inputs will be required. Under higher levels of warming, preservation of the original state may eventually become impossible and alternative approaches for maintaining the species or feature of interest may have to be developed. In the case of recreation, a transition to new types of activities may have to gradually take place.

4.2 Adaptation on the Managed Landscape

4.2.1 Maximizing the intrinsic adaptive capacity of species

In large part, adapting to climate change means tracking preferred climatic conditions and habitats as they move across the landscape. Simply put, species will have to shift their range. Changes in range are likely to occur slowly, over many years, through differential population growth. Populations will slowly expand along the leading edge of their range where climatic conditions are improving, and populations will slowly decline along the opposite fringe. This presents a problem for species that have experienced a reduction in growth potential as a result of anthropogenic disturbances, and are contracting towards the core of their range. These species will have reduced potential for expanding into new areas along the periphery of their range, and hence less adaptive capacity. A decrease in genetic diversity and gene flow can also be a factor in limiting range adjustments and adaptation to climate change. Barriers to movement are another issue, and are considered in the next section.

Accommodation of climate change will also require the capacity to effectively recover from disturbances. That is to say, species will need to be resilient. It is predicted that the amount of climatic variability and the rate of natural disturbances will both increase in coming decades (Kharin et al., 2007; Mladjic et al., 2011). We can expect droughts, floods, and storms, as well as wildfire and pest outbreaks, to become more frequent and more severe than in the past (Balshi et al., 2009; Woods et al., 2010). There is a concern that species that are stressed by anthropogenic disturbances may have insufficient resilience remaining for effectively handling additional disturbances associated with climate change.

The general point is that human activities that compromise the vitality and resilience of wild species will reduce their ability to adapt to climate change (Staudt et al., 2013). Thus, conventional conservation efforts designed to reduce or eliminate the deleterious effects of human activities on biodiversity will have a central role in facilitating adaptation to climate change (Heller and Zavaleta, 2009; Hodgson et al., 2009; West et al., 2009). A comprehensive review of all these measures is beyond the scope of this study, but some of the most important elements are summarized below.

In the Green Zone, disturbances from the petroleum industry and the forest industry are of greatest concern. Some of the most pressing issues are: cumulative habitat loss and fragmentation; high rates of uncontrolled human access along seismic lines, utility corridors, and industrial access roads; transformation of natural forest patterns and structures; and the presence of non-native grass species along seismic lines and rights-of-way (Schneider et al., 2003; Sumners and Archibold, 2007). A variety of management strategies for addressing these issues have been developed over the past two decades, including cumulative effects management, the emulation of natural disturbances, integrated land management, restoration of past disturbances, and a range of best practices for mitigating the effects of specific activities (Alberta Energy and Utilities Board, 2000; Long, 2009; Government of Alberta, 2013).

The full implementation of these approaches is one of the most effective steps that can be taken to facilitate species adaptation to climate change. This was a prominent theme among the domain experts that I interviewed. It is also a highly robust approach, in that it represents conservation action that is effective regardless of the amount of climate change that is actually realized (Hodgson et al., 2009). One priority is to complete and implement the province's proposed biodiversity framework (Government of Alberta, 2013). Other conservation measures that are still needed include: 1) the establishment of additional conservation areas to fill gaps in representation, 2) the implementation of coarse-filter biodiversity indicators and targets that will be measured and managed for, and 3) the effective management of cumulative industrial impacts through integrated landscape management techniques and the implementation of regional land disturbance plans (Government of Alberta, 2012; Government of Alberta, 2013).

In the White Zone, opportunities for improving the health and viability of native species depend on the type of land use. On range lands, cattle grazing is the dominant use and much of the native prairie remains intact. Risks to biodiversity include the spread of non-native pasture grasses, a reduction in the amount of wildfire, and the detrimental effects that grazing can have on prairie ecosystems, particularly when the stocking rate is too high or when an area is subject to drought conditions (Sutter and Brigham, 1998; Alberta Sustainable Resource Development, 2008b). Addressing these issues through rangeland management will improve the ability of native species to adapt to climate change (though suppression of wildfires will undoubtedly continue because of the risk fire poses to human infrastructure).

On cultivated lands, the overriding issue for biodiversity is loss of habitat from agricultural conversion. The scope for conservation is limited here, but the development and adoption of farming "best practices" can help maintain the function of some ecological features, particularly wetlands (Government of Alberta, 2013). Restoration of habitat is another option. In dry grassland areas, where grazing may be a more appropriate land use than crop production, programs are in place to encourage the conversion of cultivated lands back to native ecosystems (McNeil, 2013). Restoration is also a possibility on lands that are removed from production through land purchases and conservation easements. However, high land values and the need for food production limit the amount of land that can be protected and restored to a natural state in this way.

The coarse-filter conservation efforts described above will improve the vitality of most species, helping them cope with climate change. But regional conservation efforts will not address all threats facing all species. Species-specific risks will have to be addressed through dedicated management or recovery plans, to the extent that management capacity exists. The incorporation of climate change into these plans is discussed in Section 4.3.

4.2.2 Removing barriers to movement

The ability of species to adapt to climate change can also be compromised by barriers to movement. Barriers can include physical blockages, such as the town of Canmore in the Bow Valley Corridor or the oilsands mines adjacent to the Athabasca River. But regionally, barriers usually involve areas where habitat quality has been degraded, slowing the rate at which populations can expand into new regions once the climate becomes suitable. Although these are not complete barriers, they will be of great importance in determining whether species can keep pace with the rate of climate change, or not, especially under higher levels of warming (Loarie et al., 2009).

Although it will not be feasible to remove all barriers from the landscape, steps can be taken to minimize them. For example, additional effort can be made to generally reduce the amount and intensity of ongoing landscape disturbances and to restore the existing anthropogenic footprint where feasible (e.g., old seismic lines and well pads). An emphasis should be placed on identifying strategic opportunities for facilitating the northward and upslope movement of native species. In the prairies there may be an opportunity to use utility corridors and rights-of-way to facilitate the northward movement of native grass species (and the biota they support) through regions that are highly cultivated. Another example is the protection of riparian zones.

4.2.3 Slowing the rate of ecosystem transitions

Under moderate to high scenarios of warming, some species may be unable to effectively track environmental changes, even if steps are taken to remove barriers. This may occur with species that have reduced vitality or a low intrinsic rate of migration. In other cases, the problem may relate to habitat asynchrony, where the supply of preferred habitat in new regions lags behind the loss of preferred habitat within the existing range.

In these cases, it would be helpful to slow the rate of ecosystem transition, preventing serious habitat bottlenecks from arising and buying time for slower-moving species (Galatowitsch et al., 2009). More generally, the aim would be to avoid abrupt transitions in favour of a slower process characterized by a gradual blending of old and new (Millar et al., 2007). To be clear, the intention is not to maintain the status quo, but to moderate the pace of change such that adaptation can effectively occur. Although this concept is broadly applicable, it has greatest relevance in forested systems. This is because forest ecosystems may transition to parkland or even to grassland ecosystems, with major ecological ramifications. In contrast, grasslands may experience changes in species composition, but the essential character of the grassland ecosystem should remain intact.

Several management approaches are available for slowing the rate of transition in forested systems. The critical point for intervention is reducing mortality from disturbances. This is because, for most trees, climate sensitivity is greatest in the seedling phase. Mature trees can persist in climates that are well outside of the optimal range, as evidenced by farmyard shelterbelts across the prairies (Hogg and Schwarz, 1997). Given that trees are naturally long-lived, delaying the mortality of mature trees by reducing disturbances will slow the overall rate of forest transition (Schneider et al., 2009).

Many of the management tools for reducing forest disturbances are already in place and used to protect the timber landbase from fire and insect damage. This is another example of repurposing existing management approaches to achieve new climate-related objectives. Some of the activities currently undertaken to prevent or control disturbances include:

- Programs to reduce human-caused wildfires;
- Development of FireSmart landscapes, designed to reduce the occurrence of large high-intensity fires[3];
- Active suppression of wildfires once they occur;
- Monitoring of forest pests to permit timely control efforts; and
- Active control efforts to reduce the spread and damage caused by selected pests (e.g., the Mountain Pine Beetle Management Program)[4].

Arguably, it is not only natural disturbances that should be reduced, but anthropogenic disturbances as well. However, the situation here is complex. In the case of forest harvesting, disturbed areas are actively reforested, so the net effect can be positive in terms of adaptation. This is because survival through the vulnerable seedling stage is assured (through replanting if necessary)

---

[3] http://esrd.alberta.ca/wildfire/fire-smart-landscapes/default.aspx

[4] http://mpb.alberta.ca/AlbertasStrategy/documents/MPB_man_strategy.pdf

and because it provides an opportunity for assisted migration, which can improve the alignment of forest species and genotypes with the future climate (Gray et al., 2011). But not all anthropogenic disturbances are reforested (e.g., seismic lines), and the viability of species can compromised by many different aspects of industrial development. Therefore, careful planning will be required to ensure that the combined effects of anthropogenic disturbance and climate change do not result in the loss of vulnerable species and habitat types.

Field research and modeling results suggest that the projected reduction in the coniferous component of the Central Mixedwood may serve as a negative feedback with respect to further transition of the forest, because the rate of fire in deciduous forest is lower than in coniferous forest (Cumming, 2001; Krawchuk and Cumming, 2011; Girardin et al., 2013; Terrier et al., 2013). It is an open question whether an increase in deciduous forest is something that should be hastened through forest management, as some authors have suggested (Girardin et al., 2013; Terrier et al., 2013). On the one hand, this approach may prove useful in maintaining a closed boreal forest, by slowing the expansion of grassy openings resulting from repeated intense fires. On the other hand, the loss of the spruce and mixedwood component of Alberta's boreal forest would negatively affect many boreal species. Further research of this topic is warranted.

4.2.4 Actively assisting migration

In some cases, active intervention may be warranted to facilitate the movement of species. Trees are a prime example. Because of their longevity and immobility, tree species can easily become out of sync with their preferred environment when the regional climate changes. Reciprocal transplant experiments have shown that there is already a substantial mismatch between local tree populations and the environments in which they occur, leading to sub-optimal growth (Gray and Hamann, 2011). Gray and Hamann (2013) determined that tree populations currently lag behind their optimal climate niche by approximately 130 km in latitude, or 60 m in elevation, and they expect that by the 2020s the average lag will be approximately 310 km in latitude, or 140 m in elevation. Understandably, assisted migration is most advanced in the context of forest management.

The assisted migration of tree species is almost entirely focused on commercial species. The main goal is to maintain the productivity of the forest landbase in the face of climate change (Gray et al., 2011). This limitation in scope reflects the high cost of assisted migration. Active intervention on behalf of commercial species does benefit the broader ecosystem though, in that it improves forest stability over the long term. Under cooler climate scenarios, there is a reasonable chance that most of the forest can remain intact indefinitely with assisted migration. Under warmer scenarios, the eventual transition of most of Alberta's low-elevation forest to parkland or even grassland cannot be prevented. In this case, the benefit of assisted migration of commercial tree species is to prolong the transition as long as possible, buying time for other forest species to successfully shift their range (see Section 4.2.3).

The implementation of assisted migration of tree species has already begun in Alberta, though it is at an early stage. Current efforts include research and preliminary changes in the use of seed zones that permit small-scale movement of seed in a northward or upslope direction on a case by case basis. Future efforts may involve steps to increase forest diversity, including long-distance movement of genotypes and species (Thorpe et al., 2006; West et al., 2009).

Though the use of assisted tree migration is likely to increase in coming years, it will be subject to various limitations:

- Application will continue to be limited to commercial species for the foreseeable future because of the high cost of seed collection and planting;
- Research, including provenance trials, is needed to determine the suitability and optimal use of alternative genetic populations and species under future climates;
- Physiological constraints imposed by the current climate together with uncertainty regarding the future climate will limit the assisted migration planning horizon to about 20 years into the future (Gray et al., 2011);
- The amount of forest land that can be planted per year is low relative to the overall area of forest (< 1%), which means that assisted migration may not be able to keep up with the rate of climate change under warmer climate scenarios (Zielke et al., 2012);
- Current reforestation policy, and general institutional inertia, may limit the implementation of more aggressive approaches that involve the use of non-native and hybrid stock.

Another potential application of assisted migration is to support noncommercial native species that are unable to keep pace with the rate of climate change. In contrast to the application involving trees, the objective here is to maintain species viability, not productivity. Because of the high cost involved, the emphasis is likely to be on species at risk of extirpation.

There are several scenarios where assisted migration might be utilized. One involves species, like caribou, that have a disjunct range. If parts of the range become unsuitable because of climate change, it may be advisable to move the remaining local population to a more viable area than to simply let it die out. Another example involves species that are stressed and are contracting to the core of their range. In this case, assisted migration may be necessary for the species to track changes in their preferred climate, or to make use of expanded range that becomes available. Similarly, intervention may be required for species with low intrinsic migration capacity and an inability to keep pace with moderate to fast rates of climate change (e.g., frogs, toads, and snakes). Finally, assisted migration may be required for species that are unable to shift their range effectively because of a barrier. One example is Arctic grayling, which could make use of high-altitude lakes, but cannot reach them because of physical barriers. Another example is the native vegetation of the Northern Fescue Subregion, which is blocked from northward movement by agricultural lands in the Central Parkland Subregion. Assisted migration could be used to help these species hop over the barrier and establish themselves in northern areas, once climatic conditions are suitable.

In Alberta, assisted migration for the purpose of maintaining species viability under climate change is still in the research phase. Pilot studies are currently underway to assess the feasibility of moving species and to better understand the risks and benefits and practical realities of this approach (Nielsen, 2013; Fisher and Bayne, 2014). Much additional research will be required before widespread implementation could be considered. In part, this is because there are many practical matters to be worked out, and in part to ensure that unintended outcomes do not occur. The burden of proof is particularly high in this case because the past history of biological manipulation is, on the whole, not a good one (Hagerman et al., 2010b). The entire concept remains controversial and public support is tepid in comparison to conventional adaptation approaches.

Another factor that will slow implementation is that, for animal species, it is not only the climate that must change in the target region, but the entire ecosystem. Herbivores require their preferred vegetation, and carnivores their preferred prey, and this will not be occur until well after the climate has changed. This suggests that assisted migration will initially involve plant species, and that application to animal species may be many decades away.

Finally, as noted earlier, cost will be an overriding factor in determining the extent to which assisted migration can actually be applied. Strategic opportunities may arise where costs can be shared, particularly for the movement of native plants. One example is the reclamation of industrial features, both in forested areas and on the prairies. Because reclamation is an existing requirement, the cost of planting is already accounted for. It is just a matter of deciding which species and genotypes to plant in which locations, to optimize the northward movement of native species. Other opportunities may arise for the restoration of native prairie on lands purchased for conservation or on marginal farmland if climate change makes intensive agriculture uneconomical.

4.2.5 Controlling invasive species

Invasive non-native species pose a serious threat to biodiversity, threatening native species and disrupting community structure, composition and ecosystem processes (McClay et al., 2004). In some cases, invasive species act as a disturbance agent, causing the direct mortality of individuals (e.g., mountain pine beetle). In other cases, invasive species crowd out native species through competitive exclusion (Mooney and Cleland, 2001). These processes can reduce the ability of affected native species to adapt to climate change, by reducing their vitality and by hampering their expansion into new range. Therefore, government programs to control invasive species will be important in helping species adapt to climate change.

Because eradication effort rises exponentially with infestation size, the elimination of non-native species is most likely to be successful in infestations smaller than 50 ha (Carlson et al., 2008). Thus, monitoring for new infestations is very important for controlling invasive species. Monitoring efforts may need to expand under climate change, because a warmer climate will improve the suitability of Alberta for a variety of potentially invasive species (Volney and Fleming, 2000; Woods et al., 2010; Smith et al., 2012; Chai et al., 2014). Some of these potential threats have already been identified and incorporated into monitoring programs. Additional research will be required to identify new threats and characterize their significance (Chai et al., 2014).

Another issue that needs to be considered is the effect of warming on non-native species that are already present in the province. Of particular concern are the non-native grasses that have been planted along roadways, pipeline corridors, and seismic lines throughout the forested regions of Alberta. In southern Alberta, many of these grasses, such as smooth brome, timothy, and crested wheatgrass, have invaded native prairies and now threaten the integrity of these ecosystems (McClay et al., 2004). In forested regions these grasses have remained largely contained, lacking the ability to invade intact forest (Sumners and Archibold, 2007). But they are likely to expand rapidly in the future, if and when forest regeneration begins to fail as a result of insufficient ground moisture and/or an excessive rate of fire (Galatowitsch et al., 2009). The presence of these agronomic grasses may hamper the immigration of native grasses and associated biota from the south, through competitive exclusion.

Two steps can be taken in forested areas to reduce the threat of widespread expansion of agronomic species. The first, which is now being implemented, is to only use native species for reclamation and erosion control. Second, a concerted effort should be made to reduce the amount of non-native grass that currently exists within forested areas. Cost will be a limiting factor, but strategic opportunities may exist. For example, the reforestation of old seismic lines, abandoned well pads, and other old disturbances has already been identified as a management priority, for restoring forest integrity and improving habitat quality for many species. Reforesting these disturbed areas would be an effective way of eliminating the grass that currently dominates most of these features.

Control programs exist for most of other types of invasive species that have become established in Alberta. However, because of constraints related to cost and feasibility, it is not possible to eradicate or even contain all of these species. In practice, invasive species are prioritized based on factors such as economic threat and effectiveness of available control measures, and resources are allocated accordingly (Carlson et al., 2008; McClay, 2010). These assessments will need to be re-examined in light of climate change, as invasive species are likely to respond to warming in different ways. Overall, it can be expected that the control of invasive species is likely to become more challenging in the future.

One final issue involves species native to neighbouring jurisdictions that migrate into Alberta through simple range expansion. In most cases, aggressive invasive behaviour is unlikely to be a problem, because these species are native to habitats similar to ours (but see below). As a general rule, their entry into Alberta should be considered a natural and necessary part of ecological adaption to climate change. Consider the migration of buffalo grass, native to northern United States, into southern Alberta. Under warmer and drier conditions this species will fill ecological niches in the Dry Mixedgrass Subregion that existing species are not well equipped for, thereby helping to maintain ecosystem stability and function.

Management intervention may be warranted in special cases, where a species seriously disrupts the natural process of adaptation. The mountain pine beetle is an example. This species is native to western North America, and so its influx into Alberta is arguably a natural consequence of a warming climate. However, control efforts may still be justified for the purpose of slowing the pace of ecosystem transitions (as described in Section 4.2.3) and because of its economic impacts.

4.3 Planning

Adaption to climate change also involves changes to decision making and planning. Under climate change, the decision space is more complex and it is harder to forecast management outcomes. These issues are of primary relevance to long-term planning, where the emphasis is on prevention and long-term success, rather than response to immediate threats. The planning of conservation activities that are very short-term or reactive in nature should not be greatly affected by climate change, except that the relevant reference states will need to become dynamic (see Section 3.3).

4.3.1 The decision space

Conservation objectives, represented by ERSs, will inevitably need to change over time, as ecosystems respond to the warming climate (Section 3.3). This presents a significant challenge for long-term planning. Not only is the decision space larger and more complex when the objectives keep changing, but conflicts are likely to arise among conservation objectives from different time periods, necessitating trade-off decisions. For example, when planting trees, do we select genotypes and species that have the greatest viability under today's climate, or the climate 50 years from now?

There are several factors that should be considered when weighing objectives from different time periods. Long-term objectives are arguably the most important, because the ultimate aim of conservation is the maintenance of biodiversity in perpetuity. However, under global warming the conservation objectives (ERSs) for future periods exist only as model projections and are subject to considerable uncertainty. Moreover, the level of uncertainty increases with time (see below). This uncertainty has the effect of reducing the weighting of long-term objectives. In addition, ecological patterns projected for future periods only become meaningful targets for management once the climate has actually changed. For example, warm-climate species cannot be established in northern areas until overwintering mortality is no longer a factor.

In practice, it can be expected that objectives from all relevant time periods will have a role in biodiversity management, though the temporal emphasis will vary among management applications. For decisions with very long time horizons, such as the establishment of climate refugia, it would be logical to place more emphasis on the future state of the landscape. Field-based conservation efforts, such as assisted migration, may focus on a shorter time horizon because of constraints related to the existing climate and habitat conditions. The challenge for managers is to strike the right balance in terms of temporal scope in each application.

4.3.2 Climatic uncertainty and climate scenarios

Arguably the greatest challenge in incorporating climate change into the planning process is the large degree of uncertainty associated with projections of the future climate and its effects on ecosystem structure and function (Mbogga et al., 2010; Stralberg and Bayne, 2013). Under the least-change scenario for Alberta we can expect approximately 2 °C of warming by the 2080s, but under the maximum-change scenario the temperature could rise in excess of 6 °C (Schneider, 2013). In ecological terms, this represents the difference between northern Alberta remaining forested or converting to a grassland ecosystem. The large difference between these two extremes is mainly a function of alternative assumptions concerning how much additional greenhouse gas will be emitted globally in coming decades. It also reflects the fact that climate modeling is inherently complex, and different modeling teams using the same input scenarios continue to generate different projections (Stralberg et al., 2013).

In principle, one could weigh the available climate projections on the basis of scientific merit. Few comparative reports are available, however, and these only involve a subset of the available models and focus on specific issues such as the simulation of clouds (Jiang et al., 2012). In any case, there is really no gold standard against which these models can be tested. Nor is there any reliable way of knowing how much carbon will ultimately be released by human society. Therefore, the formal differentiation of projections on the basis of model reliability is not a practical option. Instead, climate change will have to be incorporated into the planning process through scenario modeling.

Scenario modeling involves planning management activities around a limited set of plausible future conditions (Lawler, 2009; West et al., 2009). These models help organize our thinking, explore different management approaches, and gain qualitative insight on the range of magnitudes and direction of possible future changes without committing to them as forecasts (Millar et al., 2007).

To avoid overloading the planning process, the number of climate scenarios must be kept to a minimum. Temperature is the main driver of change (Schneider, 2013), so emphasis should be placed on exploring this parameter. A reasonable approach would be to define four scenarios: two that bound the range of outcomes that have a high likelihood of occurring by the end of the century, and two that represent plausible extremes.

To cite a reasonable example, the two "high likelihood" scenarios (low and high) might assume a rise in mean annual temperature of approximately 2 °C and approximately 4 °C, respectively (Fig. 2). Both scenarios would assume an increase in precipitation of approximately 8%, which reflects the median increase among all models. The ecological succession trajectories and spatial patterns of change for these two examples have been described in Schneider (2013), using HADCM3-B2 and ECHAM5-A2 as representative models (labelled as the Cool and Median models, respectively).

The extreme low-end scenario might be defined as minimal change in ecological status from the current condition over the next 100 years. This corresponds to the stable climate assumption used in most planning exercises to date. Ecological stability could occur if the expected rise in temperature is offset by a large increase in precipitation, forestalling ecological transitions associated with reduced ground moisture (e.g., the northward movement of grassland and parkland). Based on a comparison of model projections, the chances of this happening are remote, but cannot be entirely discounted. Furthermore, some changes, such as the melting of permafrost and the upslope movement of species, would not be prevented by increased precipitation. Even though this scenario is unlikely, it would be useful for making comparisons to the base case associated with conventional planning.

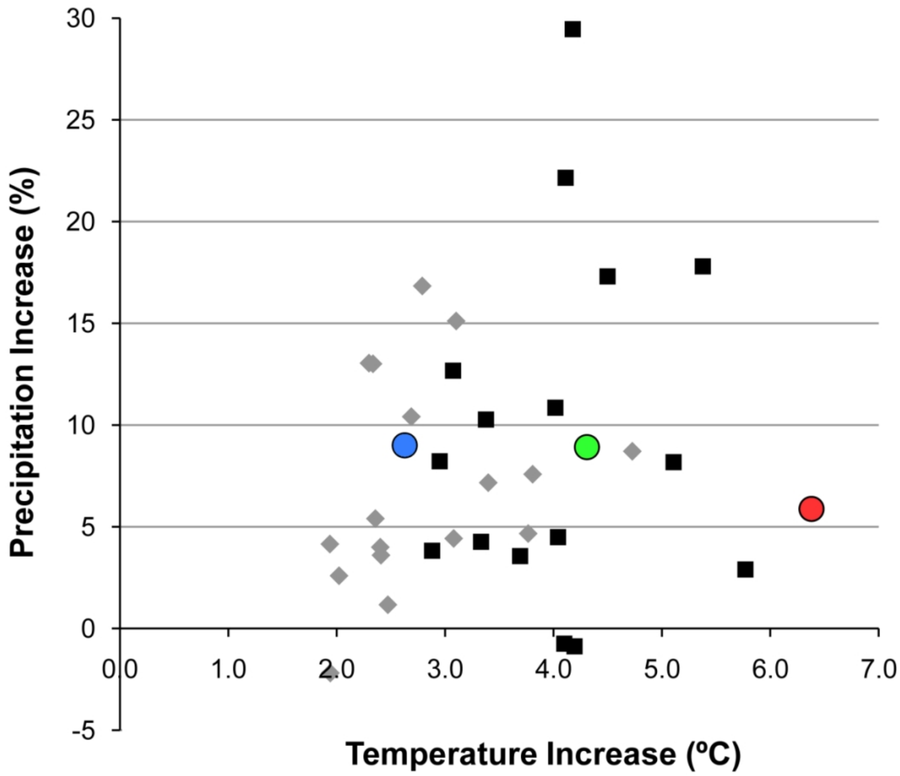

Fig. 2. Rise in mean annual temperature and increase in mean annual precipitation in Alberta in the 2080s, for the climate models examined in Schneider (2013). The three coloured circles represent three models referenced in the text: blue = "Cool", green = "Median, and red = "Hot".

The fourth scenario would describe the maximum-change outcome, associated with maximal warming (Fig. 2). This scenario is well illustrated by the HADGEM1-A2 model (the Hot Model in Schneider 2013). This projection appears to be an outlier, compared with other projections, but again, it cannot be entirely discounted. There is limited empirical guidance available for predicting successional changes under such extreme conditions, particularly toward the end of the century. Therefore, this scenario can only describe future ecological conditions in coarse terms.

The scenarios described above are most applicable to long-range planning (i.e., > 30 years). For shorter time periods the range of ecological outcomes is much narrower, partly because there is less variability among climate models in the initial period, and partly because ecological responses to climate change take time to manifest (Schneider, 2013). This suggests that, for short-term planning, it may be sufficient to focus on one main scenario, illustrated by either the median or ensemble mean projection. This could be augmented with a worst-case scenario, if desired. However, to truly understand the trajectory of change under high levels of warming it would be best to examine the projected outcomes for the end of the century, when changes are most discernable.

4.3.3 Bioclimatic modeling

The ability to forecast outcomes under alternative management scenarios provides the foundation for long-term planning. Several approaches are available for incorporating climate change into these forecasts, depending on the type of system involved and the level of detail required. For some simple systems it may be sufficient to include just the direct effects climate has on outcomes of interest (e.g., the effect of rising water temperature on fish viability). But in most cases, broader indirect effects, such as the influence of climate on habitat supply, will also need to be incorporated.

The most commonly used approach for predicting the ecological effects of climate change is bioclimatic envelope modeling (Pearson and Dawson, 2003; Schneider, 2013). These models assume a causal relationship between regional climate and broad ecological patterns, including the distribution of species and ecosystems. They quantify this relationship statistically, on the basis of current eco-climatic associations. Bioclimatic envelope models are best applied at the regional scale (e.g., Natural Subregions or larger) because fine-scale differences in ecosystem composition are more attributable to local factors, such as soil type and disturbance history, than to broad climatic patterns (Pearson and Dawson, 2003).

Once constructed, bioclimatic envelope models can be used in conjunction with climate projections to predict how species and ecosystem distributions may change as a result of global warming, assuming eco-climatic relationships remain stable over time. These types of predictions have a variety of management applications. For example, regional ecosystem projections can be used for quickly screening a broad range of species or populations to determine which are most vulnerable to climate change (Schneider et al., 2012). Detailed species-level habitat projections can be used to more completely characterize the climate-associated risks for selected species of special interest (Stralberg and Bayne, 2013). Bioclimatic envelope projections can also support land-use decision making, particularly when long-term outcomes are paramount (e.g., the selection of protected areas). In addition, they can be used to provide a coarse assessment of the sensitivity of existing and proposed management plans to climate change when fully integrated climate modeling (see below) is not feasible.

A problem with bioclimatic envelope projections is that they do not take ecological lags into account (Woodward and Beerling, 1997). It takes time for ecosystems to respond to climatic change, and in many cases transitions do not occur until some form of disturbance such as wildfire or drought disrupts the existing system (Schneider et al., 2009). Human activities, such as planting nursery-raised trees, suppression of fires, and assisted migration can also affect the rate of change, and to a lesser extent, the trajectory of change. All of these elements need to be integrated to achieve meaningful forecasts over the entire planning period. Integrated modeling approaches are not easy to implement, but they are necessary for bringing climate change into the core of the planning process, which involves making decisions concerning the management of human activities and not just the assessment of long-term risks.

A variety of modeling platforms now exist for the simulation of landscapes and associated ecological indicators subject to multiple agents of change (e.g., ALCES, LANDIS, SELES)[5]. There are no technical barriers to the incorporation of climate change; however, considerable effort is required for model parameterization. In these models, the initial state of the system is defined by the user and thereafter the system is updated, at regular time steps, on the basis of user-defined rules concerning successional change, the occurrence of natural disturbances, human activities, and so on. Climate change can be incorporated by using bioclimatic envelope projections to define successional pathways that are activated upon disturbance. These default trajectories can be overridden by simulated management actions, such as tree planting. Climate change can also be incorporated by modifying default rates of disturbance and through the direct effects that climate has on specific parameters (e.g., changes in winter survival rate). Detailed recommendations for parameterizing the ALCES™ cumulative effects simulator, for the integrated assessment of climate change effects in Alberta, are available in Schneider and Farr (2008).

4.3.4 Identifying the best management strategy

Identifying the best management strategy for a given application becomes more complicated under climate change, and new approaches for decision making will be required. Four approaches that utilize different forms of optimization are discussed below.

Deterministic approach

Most current planning initiatives utilize a deterministic approach. The aim is to identify a suite of management actions that best achieves one or more stated management objectives. The underlying assumption is that forecasts of future conditions under alternative management scenarios are sufficiently reliable to be used as the basis for planning. To backstop this assumption, efforts are made to identify points of uncertainty in the forecasting models and to address these uncertainties through additional research. In addition, the state of the system is monitored over time, and variances between the plan and actual outcomes are addressed through periodic replanning.

The management of timber harvest provides a good example. The future state of the forest is forecast on the basis of current inventory and statistical models describing tree growth and yield. Computer algorithms are then used to select forest stands for harvest, with the objective of maximizing harvest volume and minimizing haul costs while maintaining long-term timber supply and various other objectives. Fire is not included in the models, so timber losses due to large fires can seriously disrupt harvest plans. These variances are addressed through periodic replanning, or in the case of very large fires, through immediate replanning.

The handling of fire in timber management plans is controversial and provides a good illustration of the types of issues that are likely to arise with climate change. One perspective is that, over long periods, the rate of fire is predictable and should be formally included into forecasts of timber supply. Failure to do so might lead to overharvesting. The other perspective emphasizes the high

[5] A review of available models can be found on the Ecosystem-Based Management Tools Network website: http://ebmtoolsdatabase.org/tools

spatial and temporal variability exhibited by fire. If the risk of experiencing a large fire is low for individual companies, they may prefer to take that risk over the certainty of up-front harvest losses associated with fire contingency planning. The basic issue is how to manage risk — whether it is more efficient, in terms of costs and benefits, to address it proactively or reactively.

The incorporation of climate change into deterministic planning has many parallels to the incorporation of fire into timber management plans. The same questions and concerns regarding proactive versus reactive management apply. The difference is that the risks associated with climate change have not yet been well defined, nor is it clear how these risks will evolve over time. The necessary research has barely begun, and much additional effort will be required before effective decisions concerning risk management can be made.

Robust approach

In planning models, factors such as fire and climate change are handled as externalities — factors that influence the forecast outcome but are not under management control. If an external factor has limited influence on projected outcomes it can be treated as noise in the system and basically disregarded. Factors that do have a significant influence on the outcome can be incorporated as formal constraints on the system, and taken into account when management options are developed and evaluated. The proviso is that the long-term mean effect should be stable and reasonably well quantified.

Problems arise when an external factor has a potentially significant effect on projected outcomes but is subject to high uncertainty. This applies to climate change once projections begin to diverge after about 2050. The result is ambiguity over which future is to be the target of management optimization. Management solutions that work well for one future may not work well for another. Deterministic planning is no longer viable under these conditions.

Robust planning, also known as the "no regrets" approach, is an alternative to deterministic planning, intended for planning situations where uncertainty concerning future states is high (Ohlson et al., 2005; Millar et al., 2007; West et al., 2009). The essence of this approach is that planners seek management strategies that are most robust in terms of their utility across a range of potential futures, instead of just one (Johnston et al., 2010).

There are different ways that robust planning can be implemented, which reflect differences in the way that robustness is defined and calculated. The maximin regret approach involves ranking strategies by their worst-case outcomes (Kunreuther et al., 2013). The optimal strategy is the one that has the best worst-case outcome.

The alternative minimax regret approach is more demanding, in that it requires the comparison of differences between outcomes. However, information is gained in the process (Kunreuther et al., 2013). This approach seeks to identify the management strategy with the least overall regret across all potential futures. In the context of climate change, the suite of potential futures is defined by the set of climate scenarios being explored, with some consideration given to whether or not extreme scenarios should be weighted lower than other scenarios. For each climate scenario, regret is the difference in the utility of a given management strategy compared with the strategy that is actually best for that climate. The management strategy with the lowest overall regret score, adding over all climate futures, is selected as being most robust.

Less formal approaches to assessing robustness can also be used. For example, a strategy may be identified as the preferred choice, even though it is not optimal for any of the climate scenarios, because it has much less variance in its outcomes than other strategies (Krcmar et al., 2012). Another aspect of robustness is the ability of plans to be flexible and adapt over time. This might favour actions that are reversible.

Bet-hedging approach

Instead of trying to identify a management strategy that is in some sense optimal across all potential futures, the bet-hedging approach addresses uncertainty by applying multiple strategies simultaneously, in different parts of the landscape (Ohlson et al., 2005; Millar et al., 2007; Ando and Mallory, 2012). This is basically a risk-spreading strategy, which is useful for avoiding widespread management failure when the outcome of potential strategies cannot be predicted in advance.

The bet-hedging approach can also serve as an effective method of increasing knowledge, particularly for new approaches that may be useful in a changing climate but which have not yet been adequately field tested. There is much overlap here with the concept of adaptive management, in its broadest sense (Walters and Hilborn, 1978). The intent is to learn from experience, trying different approaches in different places, and iteratively incorporating lessons into future plans (Millar et al., 2007). To maximize learning, alternative strategies should be set up as pilot studies, with explicitly stated scientific hypotheses and with effective monitoring programs in place (West et al., 2009).

A variant of bet-hedging is the optimal portfolio approach (Crowe and Parker, 2008; Ando and Mallory, 2012). In this case, instead of applying different actions in different places, a single multi-pronged strategy is applied throughout the planning region. For example, in the context of reforestation, diverse seed stock might be utilized to maximize genetic and species diversity across the landscape, in the hope that some genotypes and species will thrive regardless of how the climate changes (Johnston et al., 2010; Gray et al., 2011).

Triage

In conventional conservation planning, the objective of optimization is to achieve stated objectives at the least cost (among other criteria). With conservation triage (also known as optimal resource allocation) the optimization process is inverted and the objective is to maximize conservation gains given fixed or limited conservation capacity (Bottrill et al., 2008). This approach is most useful in cases where conservation capacity is clearly inadequate and hard choices have to be made about how best to allocate the limited resources that are available (Lawler, 2009). It has also been used by funding agencies with fixed budgets in the context of maximizing conservation return on their investment (Murdoch et al., 2007).

Despite the change in optimization strategy, triage is still fundamentally a deterministic form of planning, reliant on forecasts of the future. As noted earlier, this makes it difficult to incorporate climate change, because long-term outcomes are inherently uncertain. A solution is to use qualitative ranking of climate risk as the basis for optimization, instead of forecast outcomes, because relative risk can be more reliably determined than specific endpoints.

The conservation of woodland caribou in Alberta provides an example. The application of triage involves the differential allocation of conservation resources, including habitat protection, among individual herds on the basis of their probability of long-term survival (Schneider et al., 2010). The objective is to maximize the viability of caribou at the provincial scale by directing conservation resources where they will do the most good, given the context of limited conservation capacity. Climate change should be incorporated as a herd-level risk factor because core habitat will be lost from many ranges if the boreal forest decreases in extent as expected (Schneider, 2013). A quantitative assessment of this risk is not possible, because the future climate cannot be predicted with any degree of certainty. But a reliable ranking of herds can be made on the basis of how each range is expected to be affected by moderate to high levels of climate change (Schneider et al., 2012). This relative ranking, in combination with other risk factors, can be used to direct conservation capacity to herds that are mostly likely to remain viable over the long term.

Although triage is fundamentally about making the best use of available conservation capacity, its practical application is contentious, particularly when applied at the species level (Bottrill et al., 2008; Lawler, 2009). The concern is that the triage concept could change the overall structure of the conservation framework, from a focus on saving all species to one focused on strategically accepting some losses but not others (Hagerman et al., 2010c). This represents a slippery slope that could lead to a gradual decline in biodiversity (Hagerman et al., 2010b).

The appropriate way to think about triage, in the context of climate change, is in relation to the concept of dynamic conservation objectives, described earlier. As the climate warms, species will shift from their historical range, and we must accept this rather than attempt to prevent it. But acceptance of change does not imply abandonment. Rather, the focus of conservation shifts to facilitating the transition and supporting the species in new areas. Triage, as illustrated by the caribou example, is simply a way of accomplishing this task in a management setting, with an emphasis on making optimal use of limited conservation capacity. We are not "giving up" on caribou, we are acknowledging that their range is changing and that conservation efforts will need to be redirected accordingly. The main caveat is that climate change introduces considerable uncertainty into the decision making process, so caution must be exercised before committing to irreversible decisions that may be premature or potentially unwarranted.

4.3.5 Species at risk

Alberta's policies and plans concerning the conservation of biodiversity are most clearly articulated for species that are, or may be, at risk of extirpation. Enabling legislation is provided in the *Wildlife Act* (Government of Alberta, 2000a) and specific goals and strategies are provided in *Alberta's Strategy for the Management of Species at Risk* (Alberta Sustainable Resource Development, 2008a). Planning efforts have included a general assessment of the status of Alberta's wild species and detailed assessments of 73 species of special concern.[6] Recovery plans have been developed for 31 species.

Climate change is not mentioned in the *Wildlife Act* or the associated strategy document, but it is referenced in some of the species assessments and recovery plans (Pembina Institute, 2012). The references to climate that do exist are fairly rudimentary at present, based mostly on hypotheses rather than quantitative analysis. It appears that there is recognition of the potential threat posed by climate change, but that the background research needed to quantify the level of risk is lacking (Pembina Institute, 2012). None of the recovery plans include adaptation to climate change as part of their recovery strategies or action plans.

Adaptation to climate change can be incorporated into the management of species at risk through the normal updating cycle for assessments and recovery plans. The next general status assessment is due in 2015 and this iteration could, and should, include a screening for risks associated with climate change. This screening should include an assessment of vulnerability based on potential net loss of habitat, which can be derived from basic bioclimatic envelope projections. It should also include an assessment of vulnerability based on intrinsic adaptive capacity, taking into account factors such as dispersal ability, degree of habitat specialization, and current population size (Dawson et al., 2011; Pearson et al., 2014). Much of this information is now becoming available in the scientific literature (e.g., Schneider, 2013; Stralberg and Banye, 2013; Shank and Nixon, 2014).

In cases where screening results indicate that the risk profile of a species increases significantly because of climate change, additional analysis should be undertaken to fully characterize that risk. For example, it would be important to know how the risk evolves over time, its interaction with other risk factors, potential adaptation measures, and key points of uncertainty. This type of analysis would require dedicated population modeling and could be undertaken either as part of a government-led detailed assessment or as academic research (Brook et al., 2009; Fordham et al., 2013; Franklin et al., 2013). Because of limited research capacity it would be advisable to first prioritize species on the basis of perceived climate risk, from initial screening results, and then direct research efforts to the species facing the most risk.

The incorporation of climate change into species recovery plans is challenging because the planning horizon is very short. The short-term focus is understandable, given that the species selected for recovery planning are the most imperilled — long-term threats are of little consequence if a species is unable to survive the immediate threats it is faced with. Nevertheless, for at least some of these species, climate change will be a key factor in determining long-term outcomes, and this somehow needs to be taken into account. At a minimum, a section on climate change should be included in the recovery plan's discussion of species biology, including short-term effects (e.g., from increased climatic variability) as well as potential long-term changes under various bioclimatic envelope scenarios.

[6] Available at: http://esrd.alberta.ca/fish-wildlife/species-at-risk/default.aspx

Consideration should also be given to incorporating climate change into recovery strategies when there is a potential to improve long-term survival through adaptation actions taken today. The application of triage to woodland caribou is one example. In other cases, recovery strategies might include pilot studies related to assisted migration.

Attention will eventually also have to be given to the way that recovery goals are specified. The issue is that many recovery plans include a spatial dimension in their statement of the recovery goal, using wording such as "maintain a viable population within its remaining historical range" (Alberta Sustainable Resource Development, 2013). Fixed spatial targets will eventually have to be made dynamic, while remaining consistent with the fundamental goals of recovery.

The process by which species are listed as "at risk" may also require revision in the face of climate change. One issue is that, with warmer temperatures, species may enter Alberta from other jurisdictions and might require support while their initial population levels are low. Should this support be provided? Conversely, some species in Alberta may eventually face extirpation, as their existing range within Alberta is lost because of climate change. Should we attempt to recover these species, or do we view the loss as a shift in range? These issues merit exploration and discussion, but they are not a practical concern at this time. This is because, under the *Species at Risk Act* (Government of Canada, 2003), species that have extended their range into Canada do not qualify for protection until they have been here for at least 50 years. Second, as previously noted, it is unlikely that any species in Alberta will decline to the point of extirpation as a direct result of climate change over the next 50 years. This suggests that changing the listing process to accommodate climate change may eventually be necessary, but it is not a near-term priority.

4.3.6 Coarse-filter conservation

In contrast to the management of species at risk, coarse-filter conservation efforts lack a firm legislative foundation in Alberta. The word biodiversity does not appear in either the *Environmental Protection and Enhancement Act* (Government of Alberta, 2000b) or the *Alberta Land Stewardship Act* (Government of Alberta, 2009), though these Acts do make reference to protection of the environment and the principle of sustainable development in their statements of purpose. The main policy statements concerning the conservation of biodiversity were developed in the late in 1990s and include *Sustaining Alberta's Biodiversity* and *The Alberta Forest Legacy* (Alberta Environmental Protection, 1998a; Alberta Environmental Protection, 1998b). Additional policy guidance concerning the management of biodiversity is included in the *Land-use Framework* and associated documents (Government of Alberta, 2008). Climate change is not referenced in any of these documents, except in the context of mitigation strategies for minimizing the emissions of greenhouse gases.

A new biodiversity management framework is currently under development and could provide an entry point for incorporating climate change at the policy level. At this early stage, the most urgent need is for policy that identifies the need for adapting to climate change and enables and promotes preparation across all levels of biodiversity management. Managers should have a clear mandate to begin incorporating climate change into management plans, undertake pilot studies and other relevant research, begin systematically monitoring the ecological effects of climate change, and undertake any other actions needed to ensure that we are ready to handle changes in climate as they manifest in coming decades. Preparation should also include the initiation of a public dialog concerning how and when biodiversity objectives should change as a consequence of climate change.

In contrast to the management of species at risk, the relationship between policy documents and management action is much more complex with coarse-filter conservation. Coarse-filter objectives are achieved in two main ways: the establishment of protected areas and, on unprotected lands, through the incorporation of biodiversity objectives into land-use plans and regulations. Protected areas were discussed in Section 4.1 and will not be revisited here. On unprotected lands, there are major differences in management approaches between the Green Zone, which is comprised mostly of forested public lands, and the White Zone, which is largely devoted to agriculture and has a high proportion of private ownership.

In the Green Zone, biodiversity is managed through a wide variety of land-use plans and regulations, with forest management plans and regional land-use plans under the *Land-Use Framework* among the most notable. Because land-use planning involves making trade-offs among multiple competing objectives, it is the entire plan that must be made climate-ready; there is no way of working on the conservation component in isolation (Johnston et al., 2010). There are two distinct points of entry for integrating climate change into the planning process. First, land-use and forest management plans should be expanded to include the conservation adaptation measures described in Section 4.2. Second, the planning process itself must adapt, incorporating the new planning concepts described earlier.

Incorporating climate change into land-use planning will be challenging, and trying to do too much too soon may lead to missteps and resistance from affected parties. An evolutionary, rather than a revolutionary, approach to change is advisable. Initially, the objective should be to augment the existing approach to plan development, not to replace it. This could involve adding climate parameters to the system models used to support planning, for the purpose of sensitivity testing. The models used to support the regional planning process under the *Land-Use Framework* are an obvious place to start — adding climate change to these models could and should begin forthwith (Schneider and Farr, 2008). Questions might include: how will climate change affect specific outcomes of interest and how robust is the overall management plan to alternative climatic futures? Amendment of the original plan could be considered if serious concerns are identified.

In time, climate change will need to be fully integrated into the planning process. This might involve a two-stage hybrid approach to planning where the scope of deterministic planning is reduced to 20 or 30 years, and non-deterministic approaches are utilized for longer planning horizons. This represents an acknowledgement that reliable forecasts of future outcomes cannot be made past 2050, and that beyond this point we really only have scenarios to work with. Short-term forecasts should continue to be reliable because the amount of expected warming is relatively small (< 1 °C), there is high agreement among climate models, and ecological inertia will limit the pace of ecological change. The value of longer-term scenario-based modeling is in the insights it provides into long-term trends under alternative future climates. It also establishes a connection between current management activities and long-term outcomes, providing the possibility of minimizing the risk of undesirable future states through proactive action.

The management of old-growth forest provides an illustrative example. Existing harvest plans, which do not include climate change, suggest that adequate amounts of old-growth habitat will be retained on the landscape indefinitely. Even if climate change was included in the planning process, little cause for concern would be identified if the planning horizon was limited to the next 30 years. It is only through long-term scenario-based modeling that a potential bottleneck in habitat supply could be identified, allowing proactive steps to be taken (beginning now) to avoid this outcome.

In the White Zone, the scope for long-term coarse-filter planning is much reduced because three-quarters of the land base is privately owned (Government of Alberta, 2008). Conservation efforts to date have focused on the protection of habitat through land purchases and easements, wetland restoration and protection, minimizing disturbances from industrial development (i.e., oil and gas), and programs to promote land stewardship among farmers and ranchers (Prairie Conservation Forum, 2011). Although these efforts have been guided by strategic plans, such as the *Alberta Prairie Conservation Action Plan*, planning efforts have generally not included quantitative forecasts of future conditions (Prairie Conservation Forum, 2011). This may now change with the advent of regional planning under the *Land-use Framework*. Although climate change projections were not included in the development of the *South Saskatchewan Regional Plan*, the opportunity for doing so exists in future iterations of the plan and in any subregional plans or management frameworks that are developed to support it. Formally including climate change could lead to changes in the way that conservation efforts are allocated, including greater emphasis on facilitating species movements and on protecting wetlands in more northerly areas.

4.4 Supportive measures

4.4.1 Institutional support

Adaptation and investment in adaptive capacity can be enhanced or constrained by institutional structures and norms (Williamson et al., 2012). At the highest level are the legal and policy frameworks that support the conservation of biodiversity. There is an immediate need to incorporate climate change into these frameworks, with the initial aim of enabling and promoting preparation across all levels of biodiversity management. Another priority is to complete and implement the province's proposed biodiversity framework (Government of Alberta, 2013). Additional government-led conservation measures that still need to be fully implemented were described in Section 4.2.1.

In time, we will need to transition from deterministic planning linked to well-defined objectives to a more flexible system of planning, associated with objectives that change over time (Johnston et al., 2010). The main challenge is to develop a system that embraces flexibility while safeguarding against activities that are inconsistent with the aims of conservation and actors seeking to avoid environmental regulation (Craig, 2010). The whole concept of accountability also needs to be reconsidered. We must be prepared to take risks in the context of adaptive management, and to accept that failures will sometimes occur, while somehow continuing to hold companies and government agencies accountable for the decisions they make and the actions they take (Hagerman et al., 2010c). It may be best to begin with pilot projects that can serve as laboratories for identifying and solving the many practical issues that must be dealt with. These pilot projects should involve management systems that are not overly complex and which will be strongly affected by climate change at an early stage. The management of Arctic grayling and the Cypress Hills are two potential examples.

Another form of institutional support needed for climate adaptation is high-level coordination and facilitation of adaptation efforts (Heller and Zavaleta, 2009; West et al., 2009). The pursuit of synergistic opportunities among different management sectors is of particular importance for conservation management, given that funding constraints severely limit the types of adaptation measures available when conservation is the sole objective. For example, efforts to slow the rate of ecosystem change in Alberta's boreal forest through the facilitated migration of trees would not amount to much were it not that the forestry sector shares a similar objective. The regional planning system under the *Land-use Framework* is well positioned to facilitate this type of coordination.

Because climate change impacts are occurring at scales much larger than even largest planning regions, the successful adaptation to climate change also demands a strong collaboration among regions and jurisdictions. The Air and Climate Change Policy Branch of Alberta Environment and Sustainable Resource Development could play a lead role in fostering this type of collaboration. But to do so effectively, the Branch needs to be given a higher profile within government and additional resources to work with, particularly with respect to its adaptation mandate.

The allocation of human and financial capital is another important aspect of institutional support for climate adaptation. Without additional resources and staff for addressing the climate change aspects of policy development, planning, research, and monitoring, it will be difficult to make substantive progress in terms of adaptation.

4.4.2 Monitoring

Monitoring is a core component of the decision making cycle, providing the feedback needed to optimize progress towards management objectives through periodic adjustments of management plans (Ohlson et al., 2005). In the context of biodiversity management, the aim is to understand how well biodiversity is being maintained as a result of our management of human land uses. Climate change complicates this process because it introduces a second agent of long-term change. Efforts must be made to disentangle observed changes in biodiversity resulting from human disturbances from changes resulting from climate change.

Monitoring has several additional roles, many of which are new or expanded because of climate change:

- Increase awareness and understanding among politicians and the general public of the effects that climate change is having in Alberta — an essential step for adaptation.
- Model validation and refinement. The available forecasts of future ecological conditions are constructed using a combination of models and basic ecological principles. Empirical data collected in coming years on climatic and ecological change (including ecological lag effects) will help refine these projections and increase confidence in their use.
- Dynamic ERSs. Monitoring the ecological state of protected areas provides the basis for characterizing dynamic ERSs, to be used to support conservation planning in the face of climate change (Section 3.3).
- Adaptive management. Because climate change increases uncertainty regarding management outcomes there will be an increased reliance on "learning by doing", and trying alternative approaches in different parts of the landscape. Careful monitoring will be needed to assess the outcomes of these management experiments (West et al., 2009).
- Surveillance. With climate change there is an increased risk that new invasive plant species, insect pests, and diseases will enter Alberta. Because control efforts are most effective when populations are small and not yet well established, increased surveillance efforts are warranted (Galatowitsch et al., 2009).

The monitoring program run by the Alberta Biodiversity Monitoring Institute (ABMI) provides the main vehicle for monitoring the state of biodiversity in the province. The program uses a systematic design that permits great flexibility of use, and can readily be applied to monitoring the ecological effects of climate change. With appropriate analysis it should be possible to detect directional shifts in species abundance along climatic gradients as they occur (D. Huggard, unpublished data). However, it will be necessary to separate out the influence of human disturbances from the influence of climate change. Statistical methods are available to do this, but their effectiveness depends on having a wide range of disturbance intensities represented among the sites available for analysis. Protected areas can serve as useful "control" sites and should be a priority for monitoring (Wiersma, 2005).

Another factor to consider when selecting sites for monitoring is that ecological responses to climate change will first occur along ecotones and in island ecosystems such as the Cypress Hills (Johnston et al., 2010). These areas should be given a high priority for monitoring, in order to obtain early empirical insights into the ecological effects of climate change.

In forested areas, ABMI monitoring data can be augmented by the provincial permanent sample plot system (Alberta Environment and Sustainable Resource Development, 2013). These plots are widely distributed and provide long-term data on tree and stand development. They could provide a valuable baseline for assessing changes in forest growth and structure as the climate warms (Peng 2011). Efforts are now underway, through the Provincial Growth and Yield Initiative, to coordinate and standardize sample plot design and measurement among government and industry participants and to fill gaps in representation (Alberta Environment and Sustainable Resource Development, 2013). An ongoing challenge is that plots continue to be disturbed by industrial activities (especially related to oil and gas development) despite the protective notations that are in place. Given the increasing importance of these sites for monitoring, additional steps should be taken to ensure that they are protected from disturbance.

Additional sources of monitoring data that will be helpful for assessing the effects of climate change include: the Agroclimatic Information Service, which provides real-time and historical climate data from 350 weather stations across Alberta; government programs for monitoring selected species at risk, as well as invasive species; and a variety of specialty programs such as the Climate Impacts on Productivity and Health of Aspen, run by the Canadian Forest Service. What is still lacking is a system to integrate all of this information, to provide an ongoing assessment of the ecological effects of climate change in Alberta. The ABMI's application centre is well positioned to undertake this work.

Finally, as ecosystems shift as a consequence of climate change, planning systems will need to replace static ERSs with dynamic ERSs, as described in Section 3.3. To prepare for this transition, it would be useful to increase monitoring of protected areas, so that a reliable baseline is in place.

4.4.3 Research and knowledge transfer

The research needed to support climate adaptation efforts falls into three main categories: 1) climate projections, 2) ecological responses, and 3) management actions. The primary need with respect to climate projections is to reduce the uncertainty regarding long-term outcomes. Considerable resources are being directed towards this objective at the climate modeling centres around the globe. Locally, there is a need for continued refinement of bioclimatic envelope modeling and the inclusion of climatic variability into model projections.

With respect to ecological responses, there is a need to validate and refine the spatial patterns of ecosystem change that have been predicted on the basis of bioclimatic envelope models and existing knowledge of ecological patterns and distributions. There is also a need to better understand the processes by which transitions will occur, and for better estimates of the rate of ecological change. Empirical research, in combination with additional modeling, will be required for substantive progress to be made on these topics. Research programs should include the study of sites and systems subject to early change, such as island ecosystems and ecotones, as well as long-term datasets derived from monitoring programs.

The list of potential topics for ecological study is long, but application to the boreal forest should be considered a priority because of the high potential for dramatic ecological change. For example, there is a pressing need to understand how, exactly, boreal mixedwood forest will convert to a parkland ecosystem, both at the stand scale and at the landscape scale. The empirical identification of climatic breakpoints governing forest stability (versus transition) in the face of disturbance would be of great value in projecting the overall rate of change. We also need to know how grasslands might expand, and in particular, the potential for the spread of non-native roadside pasture grasses at the expense of native grasses. Transition dynamics in peatlands and in boreal permafrost zones are also of interest. Will these sites eventually support boreal mixedwood forest, and if so, how long will it take?

At the species scale, case studies are needed to determine how species of special interest are likely to respond to climatic and ecological changes. Integrated assessments and population models that incorporate species-specific bioclimatic envelope projections, realistic estimates of future climatic variability, detailed information concerning adaptive capacity, and the effects of human disturbances, will be most useful. Additional provenance trials are a high priority for commercial tree species.

In terms of management, research will be needed to determine the viability of potential adaptation actions, taking economic and social costs into account. There are also many practical questions that need to be addressed. For example, with new approaches such as the assisted migration of animal species, experience needs to be gained in small pilot programs before large-scale application can be considered. In other cases, such as the restoration of native grasses, research is needed into ways of bringing costs down.

Research is also needed in the context of planning. For protected areas, site selection is the main issue. Efforts are needed to redefine representation objectives on the basis of physical landscapes and to incorporate the concept of climate refugia (both macro and micro). On the managed landscape, integrated cumulative effects models including both climate change and human activities need to be developed and parameterized. There is also a need for a detailed analysis of the policy implications of some of the new planning concepts described in this report, including dynamic conservation objectives, bet hedging, and triage.

To be useful, research results need to be accessible, understandable, and relevant to managers and other interested parties. The Internet is the obvious tool for disseminating information to users, from raw data though to research reports. A web portal on climate adaptation in Alberta would be useful, augmenting the nationally-focused Climate Change Adaptation Community of Practice[7] by providing information of specific relevance to Albertans. There is also a pressing need to find clear ways to explain and communicate new climate concepts to the general public. Without an awareness of the impending changes in ecological systems and risks to existing land-use objectives, public and political support for new management approaches may not be forthcoming and there may also be an underinvestment in adaptive capacity (Williamson et al., 2012).

5. Literature Cited

Alberta Energy and Utilities Board. 2000. Cumulative Effects Assessment in Environmental Impact Assessment Reports Required under the Alberta Environmental Protection and Enhancement Act. Alberta Energy and Utilities Board, Edmonton, AB.

Alberta Environment and Sustainable Resource Development. 2013. Minimum Standards and Suggested Protocol and Priorities for Establishing and Measuring Permanent Sample Plots in Alberta. Alberta Environment and Sustainable Resource Development, Edmonton, AB.

[7] https://www.ccadaptation.ca

Alberta Environmental Protection. 1998a. Sustaining Alberta's Biodiversity. Alberta Environmental Protection, Edmonton, AB.

Alberta Environmental Protection. 1998b. The Alberta Forest Legacy - Implementation Framework for Sustainable Forest Management. Alberta Environmental Protection, Edmonton, AB.

Alberta Sustainable Resource Development. 2006. Alberta Forest Management Planning Standard. Alberta Sustainable Resource Development, Edmonton, AB.

Alberta Sustainable Resource Development. 2008a. Alberta's Strategy for the Management of Species at Risk (2009-2014). Alberta Sustainable Resource Development, Edmonton, AB.

Alberta Sustainable Resource Development. 2008b. Grazing Management Adjustments for Healthy Rangelands. Alberta Sustainable Resource Development, Edmonton, AB.

Alberta Sustainable Resource Development. 2013. Alberta Greater Sage-grouse Recovery Plan 2013-2018. Alberta Sustainable Resource Development, Edmonton, AB.

Alberta Tourism Parks and Recreation. 2012. Climate Change Risk Assessment and Adaptation Report: Ministry of Tourism, Parks, and Recreation. Alberta Tourism Parks and Recreation, Edmonton, AB.

Anderson, M. and C. Ferree. 2010. Conserving the stage: climate change and the geophysical underpinnings of species diversity. PLoS One 5:e11554.

Ando, A. and M. Mallory. 2012. Optimal portfolio design to reduce climate-related conservation uncertainty in the Prairie Pothole Region. Proceedings of the National Academy of Sciences 109:6484-6489.

Archer, D. and V. Brovkin. 2008. The millennial atmospheric lifetime of anthropogenic CO_2. Climatic Change 90:283-297.

Ashcroft, M., J. Gollan, D. Warton, and D. Ramp. 2012. A novel approach to quantify and locate potential microrefugia using topoclimate, climate stability, and isolation from the matrix. Global Change Biology 18:1866-1879.

Balshi, M., A. McGuire, P. Duffy, M. Flannigan, and J. Walsh. 2009. Assessing the response of area burned to changing climate in western boreal North America using a Multivariate Adaptive Regression Splines (MARS) approach. Global Change Biology 15:578-600.

Beier, P. and B. Brost. 2010. Use of land facets to plan for climate change: conserving the arenas, not the actors. Conservation Biology 24:701-710.

Bennett, A., A. Haslem, D. Cheal, M. Clarke, and R. Jones. 2009. Ecological processes: a key element in strategies for nature conservation. Ecological Management and Restoration 10:192-199.

Bottrill, M., L. Joseph, J. Carwardine, M. Bode, and C., Cook. 2008. Is conservation triage just smart decision making? Trends in Ecology and Evolution 23:649-654.

Brook, B., H. Akcakaya, D. Keith, G. Mace, and R. Pearson. 2009. Integrating bioclimate with population models to improve forecasts of species extinctions under climate change. Biology Letters 5:723-725.

Camacho, A., H. Doremus, J. McLachlan, and B. Minteer. 2010. Reassessing Conservation Goals in a Changing Climate. UC Irvine School of Law Research Paper No. 2012-4.

Capon, S., L. Chambers, R. Mac Nally, R. Naiman, and P. Davies. 2013. Riparian ecosystems in the 21st Century: hotspots for climate change adaptation? Ecosystems 16:359-381.

Carlson, M., I. Lapina, M. Shephard, J. Conn, R. Densmore, and P., Spencer. 2008. Invasiveness Ranking System for Non-Native Plants of Alaska. US Department of Agriculture.
Carr, A., P. Weedon, and E. Cloutis. 2004. Climate Change Implications in Saskatchewan's Boreal Forest Fringe and Surrounding Agricultural Areas. Saskatchewan Forest Centre, Prince Albert, SK.
Carvalho, S., J. Brito, E. Crespo, M. Watts, and H. Possingham. 2011. Conservation planning under climate change: Toward accounting for uncertainty in predicted species distributions to increase confidence in conservation investments in space and time. Biological Conservation 144:2020-2030.
Chai, S., A. Nixon, J. Zhang, and S., Nielsen. 2014. Predicting Invasive Plant Response to Climate Change: Prioritization and Mapping of New Potential Threats to Alberta's Biodiversity. Alberta Biodiversity Monitoring Institute, Edmonton, AB.
Choi, Y. 2007. Restoration ecology to the future: a call for new paradigm. Restoration Ecology 15:351-353.
Craig, R. 2010. Stationarity is Dead - Long Live Transformation: Five Principles for Climate Change Adaptation Law. Harvard Environmental Law Review 34:9-75.
Crowe, K. and W. Parker. 2008. Using portfolio theory to guide reforestation and restoration under climate change scenarios. Climatic Change 89:355-370.
Cumming, S. 2001. Forest type and wildfire in the Alberta boreal mixedwood: what do fires burn? Ecological Applications 11:97-110.
Davis, M. and R. Shaw. 2001. Range shifts and adaptive responses to Quaternary climate change. Science 292:673-679.
Dawson, T., S. Jackson, J. House, I. Prentice, and G. Mace. 2011. Beyond predictions: biodiversity conservation in a changing climate. Science 332:53-58.
Dobrowski, S. 2011. A climatic basis for microrefugia: the influence of terrain on climate. Global Change Biology 17:1022-1035.
Doerr, V., T. Barrett, and E. Doerr. 2011. Connectivity, dispersal behaviour and conservation under climate change: a. Journal of Applied Ecology 48:143-147.
Downey, B. 2006. Status of the Ferruginous Hawk (Buteo regalis) in Alberta: Update 2006. Alberta Sustainable Resource Development, Edmonton, AB.
Dunlop, M., H. Parris, P. Ryan, and F. Kroon. 2013. Climate-Ready Conservation Objectives: A Scoping Study. National Climate Change Adaptation Research Facility, Gold Coast, Queensland.
Environment Canada. 1995. Canadian Biodiversity Strategy: Canada's Response to the Convention on Biological Diversity. Environment Canada, Hull, QC.
Environment Canada. 2013. Bird Conservation Strategy for Bird Conservation Region 10 Pacific and Yukon Region: Northern Rockies. Environment Canada, Ottawa, ON.
Fisher, R. and E., Bayne. 2014. Burrowing Owl Climate Change Adaptation Plan for Alberta. Alberta Biodiversity Monitoring Institute, Edmonton, AB.
Fordham, D., H. Akcakaya, B. Brook, A. Rodriguez, and P. Alves. 2013. Adapted conservation measures are required to save the Iberian lynx in a changing climate. Nature Climate Change 3:899-903.

Franklin, J., H. Regan, and A. Syphard. 2013. Linking spatially explicit species distribution and population models to plan for the persistence of plant species under global change. Environmental Conservation 1-13.

Galatowitsch, S., L. Frelich, and L. Phillips-Mao. 2009. Regional climate change adaptation strategies for biodiversity conservation in a midcontinental region of North America. Biological Conservation 142:2012-2022.

Game, E.,. Lipsett-Moore, E. Saxon, N. Peterson, and S. Sheppard. 2011. Incorporating climate change adaptation into national conservation assessments. Global Change Biology 17:3150-3160.

Girardin, M., A. Ali, C. Carcaillet, O. Blarquez, and C., Hely. 2013. Vegetation limits the impact of a warm climate on boreal wildfires. New Phytologist 199:1001-1011.

Glick, P., H. Chmura, and B. Stein. 2011. Moving the Conservation Goalposts: A Review of Climate Change Adaptation Literature. National Wildlife Federation, Merrifield, Virginia.

Gomez-Baggethun, E. and M. Ruiz-Perez. 2011. Economic valuation and the commodification of ecosystem services. Progress in Physical Geography 35:613-628.

Government of Alberta. 2000a. Wildlife Act. Alberta Queen's Printer, Edmonton, AB.

Government of Alberta. 2000b. Environmental Protection and Enhancement Act. Alberta Queen's Printer, Edmonton, AB.

Government of Alberta. 2008. Land-Use Framework. Government of Alberta, Edmonton, AB.

Government of Alberta. 2009. Alberta Land Stewardship Act. Alberta Queen's Printer, Edmonton, AB.

Government of Alberta. 2012. The Lower Athabasca Regional Plan 2012-2022. Government of Alberta, Edmonton, AB.

Government of Alberta. 2013. Draft South Saskatchewan Regional Plan 2014-2024. Government of Alberta, Edmonton, AB.

Government of Canada. 2003. Species at Risk Act. Government of Canada, Ottawa, ON.

Gray, L., T. Gylander, M. Mbogga, P. Chen, and A. Hamann. 2011. Assisted migration to address climate change: recommendations for aspen reforestation in western Canada. Ecological Applications 21:1591-1603.

Gray, L. and A. Hamann. 2011. Strategies for reforestation under uncertain future climates: guidelines for Alberta, Canada. PloS One 6:e22977.

Groves, C., E. Game, M. Anderson, M. Cross, and C. Enquist. 2012. Incorporating climate change into systematic conservation planning. Biodiversity and Conservation 21:1651-1671.

Hagerman, S., T. Satterfield, and H., Dowlatabadi. 2010a. Climate change impacts, conservation and protected values: Understanding promotion, ambivalence and resistance to policy change at the world conservation congress. Conservation and Society 8:298.

Hagerman, S., H. Dowlatabadi, T. Satterfield, and T. McDaniels. 2010b. Expert views on biodiversity conservation in an era of climate change. Global Environmental Change 20:192-207.

Hagerman, S., H. Dowlatabadi, K. Chan, and T. Satterfield. 2010c. Integrative propositions for adapting conservation policy to the impacts of climate change. Global Environmental Change 20:351-362.

Hagerman, S. and T. Satterfield. 2013. Entangled judgments: Expert preferences for adapting biodiversity conservation to climate change. Journal of Environmental Management 129:555-563.
Hamann, A. and S. Aitken. 2013. Conservation planning under climate change: accounting for adaptive potential and migration capacity in species distribution models. Diversity and Distributions 19:268-280.
Hannah, L., G. Midgley, S. Andelman, M. Araujo, and G., Hughes. 2007. Protected area needs in a changing climate. Frontiers in Ecology and the Environment 5:131-138.
Harris, J., R. Hobbs, E. Higgs, and J. Aronson. 2006. Ecological restoration and global climate change. Restoration Ecology 14:170-176.
Heller, N. and E. Zavaleta. 2009. Biodiversity management in the face of climate change: a review of 22 years of recommendations. Biological Conservation 142:14-32.
Hobbs, R., E. Higgs, and J. Harris. 2009. Novel ecosystems: implications for conservation and restoration. Trends in Ecology and Evolution 24:599-605.
Hobson, K. and E. Bayne. 2000. Breeding bird communities in boreal forest of western Canada: consequences of "unmixing" the mixedwoods. The Condor 102:759-769.
Hodgson, J., C. Thomas, B. Wintle, and A. Moilanen. 2009. Climate change, connectivity and conservation decision making: back to basics. Journal of Applied Ecology 46:964-969.
Hof, C., I. Levinsky, M. Araujo, and C. Rahbek. 2011. Rethinking species' ability to cope with rapid climate change. Global Change Biology 17:2987-2990.
Hogg, E. 1994. Climate and the southern limit of the western Canadian boreal forest. Canadian Journal of Forest Research 24:1835-1845.
Hogg, E. and P. Hurdle. 1995. The aspen parkland in western Canada: a dry-climate analogue for the future boreal forest? Water, Air, Soil Pollution 82:391-400.
Hogg, E. and A. Schwarz. 1997. Regeneration of planted conifers across climatic moisture gradients on the Canadian prairies: implications for distribution and climate change. Journal of Biogeography 24:527-534.
Hunter, M., E. Dinerstein, J. Hoekstra, and D. Lindenmayer. 2010. A call to action for conserving biological diversity in the face of climate change. Conservation Biology 24:1169-1171.
Hunter, M., G. Jacobson, and T. Webb. 1988. Paleoecology and the coarse-filter approach to maintaining biological diversity. Conservation Biology 2:375-385.
Jiang, J., H. Su, C. Zhai, V. Perun, and A. Del Genio. 2012. Evaluation of cloud and water vapor simulations in CMIP5 climate models using NASA "A-Train" satellite observations. Journal of Geophysical Research: Atmospheres 117:1-24.
Johnston, M., T. Williamson, A. Munson, A. Ogden, and M. Moroni. 2010. Climate change and forest management in Canada: impacts, adaptive capacity and adaptation options. A state of knowledge report. Sustainable Forest Management Network, Edmonton, AB.
Keane, R., P. Hessburg, P. Landres, and F. Swanson. 2009. The use of historical range and variability (HRV) in landscape management. Forest Ecology and Management 258:1025-1037.
Keppel, G., K. Van Niel, G. Wardell-Johnson, C. Yates, and M., Byrne. 2012. Refugia: identifying and understanding safe havens for biodiversity under climate. Global Ecology and Biogeography 21:393-404.

Kharin, V., F. Zwiers, X. Zhang, and G. Hegrl. 2007. Changes in temperature and precipitation extremes in the IPCC ensemble of global coupled model simulations. American Meteorological Society 20:1419-1444.

Krawchuk, M. and S. Cumming. 2011. Effects of biotic feedback and harvest management on boreal forest fire activity under climate change. Ecological Applications 21:122-136.

Krcmar, E., S. Mah, G. Nigh, C. Fletcher, and C., van Kooten. 2012. Uncertainty in Adaptation to Climate Change in Forest Management. Future Forest Ecosystems Scientific Council, Victoria, BC.

Kunreuther, H., G. Heal, M. Allen, O. Edenhofer, and C. Field. 2013. Risk management and climate change. Nature Climate Change 3:447-450.

Landres, P., P. Morgan, and F. Swanson. 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecological Applications 9:1179-1188.

Lane, J., L. Kruuk, A. Charmantier, J. Murie, and F. Dobson. 2012. Delayed phenology and reduced fitness associated with climate change in a wild hibernator. Nature 489:554-557.

Lawler, J. 2009. Climate change adaptation strategies for resource management and conservation planning. Annals of the New York Academy of Sciences 1162:79-98.

Lemieux, C. and D. Scott. 2005. Climate change, biodiversity conservation and protected area planning in Canada. The Canadian Geographer 49:384-397.

Lemmen, D. and F. Warren. 2004. Climate Change Impacts and Adaptation: A Canadian Perspective. Government of Canada, Ottawa, ON.

Leroux, S., F. Schmiegelow, R. Lessard, and S. Cumming. 2007. Minimum dynamic reserves: a framework for determining reserve size in ecosystems structured by large disturbances. Biological Conservation 138:464-473.

Lindenmayer, D., W. Steffen, A. Burbidge, L. Hughes, and R. Kitching. 2010. Conservation strategies in response to rapid climate change: Australia as a case study. Biological Conservation 143:1587-1593.

Loarie, S., P. Duffy, H. Hamilton, G. Asner, and C. Field. 2009. The velocity of climate change. Nature 462:1052-1055.

Long, J. 2009. Emulating natural disturbance regimes as a basis for forest management: A North American view. Forest Ecology and Management 257:1868-1873.

Lyons, K., C. Brigham, B. Traut, and M. Schwartz. 2005. Rare species and ecosystem functioning. Conservation Biology 19:1019-1024.

Magness, D., A. Lovecraft, and J. Morton. 2012. Factors influencing individual management preferences for facilitating adaptation to climate change within the National Wildlife Refuge System. Wildlife Society Bulletin 36:457-468.

Malcolm, J., A. Markham, R. Neilson, and M. Garaci. 2002. Estimated migration rates under scenarios of global climate change. Journal of Biogeography 29:835-849.

Margules, C. and R. Pressey. 2000. Systematic conservation planning. Nature 405:243-253.

Mbogga, M., X. Wang, and A. Hamann. 2010. Bioclimate envelope model predictions for natural resource management: dealing with uncertainty. Journal of Applied Ecology 47:731-740.

McCauley, D. 2006. Selling out on nature. Nature 443:27.

McClay, A. 2010. Priorities and Strategies for Invasive Plant Management in the Green Area: A Review for Alberta Sustainable Resource Development. McClay Ecoscience, Edmonton, AB.

McClay, A., K. Fry, E. Korpela, R. Lange, and L. Roy. 2004. Costs and Threats of Invasive Species to Alberta's Natural Resources. Alberta Sustainable Resource Development, Edmonton, AB.

McGregor, A., B. Coffey, C. Deutsch, G. Wescott, and J. Robinson. 2011. What are the Policy Priorities for Sustaining Ecological Processes? A Case Study From Victoria, Australia. Ecological Management and Restoration 12:194-199.

McNeil, R. 2013. Conversion of Cultivated Lands to Native Perennials in the Dry Prairies (Framework #1). Prairie Conservation Forum, Lethbridge, AB.

Millar, C., N. Stephenson, and S. Stephens. 2007. Climate change and forests of the future: managing in the face of uncertainty. Ecological Applications 17:2145-2151.

Mladjic, B., L. Sushama, M. Khaliq, R. Laprise, and D. Caya. 2011. Canadian RCM projected changes to extreme precipitation characteristics over Canada. Journal of Climate 24:2565-2584.

Mooney, H. and E. Cleland. 2001. The evolutionary impact of invasive species. Proceedings of the National Academy of Sciences 98:5446-5451.

Moss, E. 1952. Grassland of the Peace River Region, Western Canada. Canadian Journal of Botany 30:98-124.

Murdoch, W., S. Polasky, K. Wilson, H. Possingham, and P. Kareiva. 2007. Maximizing return on investment in conservation. Biological Conservation 139:375-388.

Nations, United. 1992. Convention On Biological Diversity. United Nations.

Natural Regions Committee. 2006. Natural Regions and Subregions of Alberta. Government of Alberta, Edmonton, AB.

Nelson, H., K. Zielke, B. Bancroft, C. Brown, and C. Stewart. 2011. Validating Impacts, Exploring Vulnerabilities, and Developing Robust Adaptive Strategies under the Kamloops Future Forest Strategy. Future Forest Ecosystems Scientific Council, Vancouver, BC.

Nielsen, S. 2013. Technologies for Conserving Climate-sensitive Species at Risk: Rare Plants. Alberta Biodiversity Monitoring Institute, Edmonton, AB.

Noss, R. 2001. Beyond Kyoto: forest management in a time of rapid climate change. Conservation Biology 15:578-590.

Ohlson, D., G. McKinnon, and K. Hirsch. 2005. A structured decision-making approach to climate change adaptation in the forest sector. The Forestry Chronicle 81:97-103.

Pearson, R., J. Stanton, K. Shoemaker, M. Aiello-Lammens, and P. Ersts. 2014. Life history and spatial traits predict extinction risk due to climate change. Nature Climate Change 4:217-221.

Pearson, R. and T. Dawson. 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? Global Ecology and Biogeography 12:361-371.

Pembina Institute. 2012. Climate Change Impacts to Biodiversity in the Prairie Provinces. Prairie Adaptation Research Collaborative, Regina, SK.

Poiani, K., R. Goldman, J. Hobson, J. Hoekstra, and K. Nelson. 2011. Redesigning biodiversity conservation projects for climate change: examples from the field. Biodiversity and Conservation 20:185-201.

Prairie Conservation Forum. 2011. Alberta Prairie Conservation Action Plan: 2011-2015. Prairie Conservation Forum, Lethbridge, AB.

Prober, S. and M. Dunlop. 2011. Climate change: a cause for new biodiversity conservation objectives but let's not throw the baby out with the bathwater. Ecological Management and Restoration 12:2.

Sauchyn, D., E. Barrow, X. Fang, N. Henderson, and M. Johnston. 2009. Saskatchewan's Natural Capital in a Changing Climate: An Assessment of Impacts and Adaptation. Prairie Adaptation Research Collaborative, Regina, SK.

Schneider, R. 2013. Alberta's Natural Subregions Under a Changing Climate: Past, Present, and Future. Alberta Biodiversity Monitoring Institute, Edmonton, AB.

Schneider, R., A. Hamann, D. Farr, X. Wang, and S. Boutin. 2009. Potential effects of climate change on ecosystem distribution in Alberta. Canadian Journal of Forest Research 39:1001-1010.

Schneider, R., G. Hauer, W. Adamowicz, and S. Boutin. 2010. Triage for conserving populations of threatened species: the case of woodland caribou in Alberta. Biological Conservation 143:1603-1611.

Schneider, R R. and D, Farr. 2008. A Modeling Framework for Assessing the Potential Impacts of Climate Change in Northeastern Alberta. University of Alberta.

Schneider, R R., G Hauer, K Dawe, W Adamowicz, and S, Boutin. 2012. Selection of reserves for woodland caribou Using an optimization approach. PLoS One 7:e31672.

Schneider, R., G. Hauer, D. Farr, W. Adamowicz, and S. Boutin. 2011. Achieving conservation when opportunity costs are high: optimizing reserve design in Alberta's oil sands region. PloS One 6:e23254.

Schneider, R., J. Stelfox, S. Boutin, and S., Wasel. 2003. Managing the cumulative impacts of land uses in the Western Canadian Sedimentary Basin: A modeling approach. Conservation Ecology 7:Article 8.

Schwartz, M., C. Brigham, J. Hoeksema, K. Lyons, and M. Mills. 2000. Linking biodiversity to ecosystem function: implications for conservation ecology. Oecologia 122:297-305.

Shank, C. and A., Nixon. 2014. Climate Change Vulnerability of Alberta's Terrestrial Biodiversity: A Preliminary Assessment. Alberta Biodiversity Monitoring Institute, Edmonton, AB.

Smith, A., N. Hewitt, N. Klenk, D. Bazely, and N. Yan. 2012. Effects of climate change on the distribution of invasive alien species in. Environmental Reviews 20:1-16.

Srivastava, D. and M. Vellend. 2005. Biodiversity-ecosystem function research: is it relevant to conservation? Annual Review of Ecology, Evolution, and Systematics 36:267-294.

Staudt, A., A. Leidner, J. Howard, K. Brauman, and J. Dukes. 2013. The added complications of climate change: understanding and managing biodiversity and ecosystems. Frontiers in Ecology and the Environment 11:494-501.

Staudt, A., A. Leidner, J. Howard, K. Brauman, and J. Dukes. 2013. The added complications of climate change: understanding and managing biodiversity and ecosystems. Frontiers in Ecology and the Environment 11:494-501.

Steenberg, J., P. Duinker, L. Van Damme, and K. Zielke. 1998. Criteria and indicators of forest soils used for slash-and-burn agriculture and alternative land uses in Indonesia. Journal of Sustainable Development 6:32-64.

Stein, B., A. Staudt, M. Cross, N. Dubois, and C. Enquist. 2013. Preparing for and managing change: climate adaptation for biodiversity and ecosystems. Frontiers in Ecology and the Environment 11:502-510.

Stralberg, D. and E. Bayne. 2013. Modeling Avifaunal Responses to Climate Change Across Alberta's Natural Regions. Alberta Biodiversity Monitoring Institute, Edmonton, AB.

Stralberg, D., S. Matsuoka, A. Hamann, E. Bayne, and P. Solymos. 2013. Projecting boreal bird responses to climate change: the signal exceeds the noise. Ecological Applications, accepted for publication.

Sullivan, M., a. Paul, C. Johnson, J. Tchir, and D. Park. 2013. Alberta Fisheries and Climate Change Adaptation: Discussion Paper. Alberta Fish and Wildlife, Edmonton, AB.

Sumners, W. and O. Archibold. 2007. Exotic plant species in the southern boreal forest of Saskatchewan. Forest Ecology and Management 251:156-163.

Sutter, G. and R. Brigham. 1998. Avifaunal and habitat changes resulting from conversion of native prairie to crested wheat grass: patterns at songbird community and species levels. Canadian Journal of Zoology 76:869-875.

Tam, J. and T. McDaniels. 2013. Understanding individual risk perceptions and preferences for climate change adaptations in biological conservation. Environmental Science and Policy 27:114-123.

ter Steege, H., N. Pitman, D. Sabatier, C. Baraloto, and R. Salomao. 2013. Hyperdominance in the Amazonian tree flora. Science 342:1243092.

Terrier,., M. Girardin, C. Perie, P. Legendre, and Y. Bergeron. 2013. Potential changes in forest composition could reduce impacts of climate change on boreal wildfires. Ecological Applications 23:21-35.

Thorpe, J., N. Henderson, and J. Vandall. 2006. Exotic Tree Species as an Adaptation Option to Climate Change in the Western Canadian Boreal Forest. Prairie Adaptation Research Collaborative, Regina, SK.

Tingley, M., L. Estes, and D. Wilcove. 2013. Ecosystems: Climate change must not blow conservation off course. Nature 500:271-272.

Todd, D. 2005. Status of the Burrowing Owl (Athene cunicularia) in Alberta: Update 2005. Alberta Sustainable Resource Development, Edmonton, AB.

Tree Improvement Alberta. 2012. Outline of Tree Improvement Alberta (TIA) and Climate Change and Emissions Management (CCEMC) Corporation Tree Adaptation Risk Management Project. Available at: http://tia.foothillsri.ca/.

Volney, W. and R. Fleming. 2000. Climate change and impacts of boreal forest insects. Agriculture, Ecosystems and Environment 82:283-294.

Walker, J. 2005. Status of the Arctic Grayling (Thymallus arcticus) in Alberta. Alberta Sustainable Resource Development, Edmonton, AB.

Walters, C. and R. Hilborn. 1978. Ecological optimization and adaptive management. Annual review of Ecology and Systematics 9:157-188.

Watson, J., H. Grantham, K. Wilson, and H. Possingham 2011. "Systematic conservation planning: past, present and future." Pp. 136-160 in *Conservation Biogeography*, edited by R. Ladle and R. Whittaker. Hoboken, NJ: Blackwell Publishing Ltd.

Wellicome, T., R. Fisher, R. Poulin, D. Todd, and E. Bayne. 2013. Return rate of adult Burrowing owls in Canada is influenced by weather during migration and on their wintering grounds. Submitted to Condor.

West, J., S. Julius, P. Kareiva, C. Enquist, and J. Lawler. 2009. US natural resources and climate change: concepts and approaches for management adaptation. Environmental Management 44:1001-1021.

Wiersma, Y. 2005. Environmental benchmarks vs. ecological benchmarks for assessment and monitoring. Environmental Monitoring and Assessment 100:1-9.

Williamson, T., H. Hesseln, and M. Johnston. 2012. Adaptive capacity deficits and adaptive capacity of economic systems in climate change vulnerability assessment. Forest Policy and Economics 15:160-166.

Williams, S., L. Shoo, J. Isaac, A. Hoffmann, and G. Langham. 2008. Towards an integrated framework for assessing the vulnerability of species to climate change. PLoS Biology 6:e325.

Woods, A., D. Heppner, H. Kope, J. Burleigh, and L. Maclauchlan. 2010. Forest health and climate change: a British Columbia perspective. The Forestry Chronicle 86:412-422.

Woodward, F. and D. Beerling. 1997. The dynamics of vegetation change: health warnings for equilibrium 'dodo' models. Global Ecology and Biogeography Letters 6:413-418.

World Commission on Environment and Development. 1987. Our Common Future. Oxford University Press, New York, NY.

Zielke, K., B. Bancroft, H. Nelson, B. Seely, and L. Kremsater. 2012. Guidance to Adapt Forest Management for Climate Change in the Kamloops TSA. Future Forest Ecosystems Scientific Council of BC, Victoria, BC.

Appendix 1: List of Domain Experts Interviewed

Name	Affiliation
Andreas Hamann	University of Alberta
Ann Hubbs	GOA: Fish and Wildlife
Barb Thomas	University of Alberta
Barry Adams	GOA: Range Resource Management
Bob Demulder	Nature Conservancy
Brian Kolman	GOA: Land-use Framework
Dan Kraus	Nature Conservancy
Dave Belyea	AB Environment (retired)
Dave Howerter	Ducks Unlimited
Deogratias Rweyongeza	GOA: Forest Management
Diana Stralberg	University of Alberta
Elston Dzus	Alpac
Erin Bayne	University of Alberta
Gordon Court	GOA: Fish and Wildlife
Grant Glessing	Tolko
Harry Archibald	AB Sustainable Resource Dev (retired)
Harry Stelfox	AB Sustainable Resource Dev (retired)
Hugh Norris	GOA: Fish and Wildlife
Jason Edwards	Canadian Forest Service
Jim Schiek	AB Innovates
John Stadt	GOA: Forest Management
Kendra Isaac	GOA: Climate Secretariat
Kim Rymer	Alpac
Laura Gray	University of Alberta
Leonard Barnhart	GOA: Forest Management
Marian Weber	AB Innovates
Mark Johnston	SK Research Council
Marty Luckert	University of Alberta
Mike Russell	GOA: Fish and Wildlife
Mike Sullivan	GOA: Fish and Wildlife
Pat Fargey	GOA: Fish and Wildlife
Ryan Fisher	Environment Canada
Samantha Song	Environment Canada
Scott Milligan	GOA: Land-use Framework
Scott Nielson	University of Alberta
Simon Dyer	Pembina Institute
Stan Boutin	University of Alberta
Steve Kennett	Consultant
Sue Cotterill	GOA: Fish and Wildlife

Appendix 1 (Continued)

Name	Affiliation
Ted Hogg	Canadian Forest Service
Terry Antoniuk	Consultant
Vic Lieffers	University of Alberta
Wayne Pettapiece	Ag Canada (retired)