

# Adapting monitoring to more effectively assess the impacts of climate change on Alberta's biodiversity

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**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 authors and should not be construed as conclusions or opinions of the ABMI.

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## **EXECUTIVE SUMMARY:**

Biodiversity monitoring is essential to support climate change adaptation. High-quality, long-term monitoring data can provide a warning system for detecting the effects of climate change on species and ecosystems. Monitoring data can also be used for the construction and validation of future projections of species and ecosystem distributions, the development and measurement of ecological indicators, and evaluation of adaptive management actions related to climate change.

The Alberta Biodiversity Monitoring Institute monitors over 2500 species in terrestrial and wetland habitats in Alberta through field data collection and remote sensing along a systematic grid of sites spaced 20km apart. As the only province-wide, long-term (since 2003) biodiversity monitoring program, the ABMI has an essential role to play in providing data to support climate change adaptation. This report discusses how the relative abundance data from the ABMI's monitoring program can be used to detect changes in species distributions, even if their range edges do not occur in Alberta. We also discuss how recent implementations of new technology and remote sensing are improving monitoring of the timing of biological events like migration or spring green-up. Use of ABMI samples for understanding genetic variation and changes in genetic structure is identified as a key area where ABMI data can also be used to understand how biodiversity is adapting to climate change.

Finally, we discuss gaps in the ABMI's monitoring data that, if addressed, would improve our ability to both predict and detect the impacts of climate change on Alberta's biodiversity. This would include surveying at a finer spatial resolution along ecotones, like the boundary between the Parkland and Boreal Natural Regions and along elevation gradients in provincial hill systems. Expansion of the monitoring program to include collection of weather data like temperature and moisture is also recommended.

## INTRODUCTION

Greenhouse gas emissions from human activities are altering Alberta's climate. Climate change and resulting shifts in weather patterns have already been associated with changes in wildlife species in Alberta. Over the next century, climatic shifts in the province are going to further alter the environmental conditions to which Alberta species are currently adapted. The question is not whether this is going to occur (Beaubien and Hamann 2011, Dawe et al. 2014, Fisher et al. 2015), but how significant the changes will be. What unexpected environmental consequences will arise because of changes to biodiversity? What can Albertans do to minimize the deleterious effects of climate-induced biodiversity change on biodiversity and the ecosystems we rely on?

Over the past several years, researchers with the Biodiversity Management and Climate Change Adaptation<sup>1</sup> (hereafter BMCCA) project have worked to identify species in Alberta that will be positively and negatively affected by climate change. Starting with a literature review, we documented a risk matrix based on life history traits (Shank and Nixon 2014). While providing a baseline for assessing risk, this approach is limited by the research that has been conducted on specific species and how they might respond to climate change. Therefore, we also used future scenario modelling and climate envelope models to assess how the range of many species might shift, under the assumption that climate-related limits on current species distribution will tell us something about future distribution and abundance (e.g., Nixon et al. 2015, Schneider and Bayne 2015, Stolar and Nielsen in review, Stralberg et al. 2015a). While insightful, these models assume an equilibrium state whereby the non-climatic conditions that make up a species' habitat track changes in climate closely. The validity of this assumption is of concern because of the length of time it will take species to shift and the fact that non-climatic habitat attributes on species' distributions may alter the outcomes that have been predicted.

A true understanding of how individual species will react to climate change and the options available to mitigate risk to specific species requires long-term data that links a species' ecology directly to weather and climate. Work is also needed to understand the interactions between these phenomena, the species' habitat, and the other species that exist within the broader community. The BMCCA project took this approach, using a 20+ year dataset on Burrowing Owls (*Athene cunicularia*), to demonstrate that changes in the intensity and frequency of extreme weather events related to climate change have already negatively impacted population growth in this endangered species by altering their ability to obtain prey in a modified landscape (Fisher et al. 2015). Importantly, this decadal pattern is different than what is expected based on the long-term projected change in average climate in Alberta. Over the next 100 years, climate change models suggest that the drier and warmer prairie ecosystems that Burrowing Owls rely on will expand, making climate change theoretically beneficial for Burrowing Owls. This study and others within the BMCCA program demonstrate the importance of long-term data collected over large spatial extents for understanding the effect that climate change has at the population level, especially for species in decline that face multiple anthropogenic threats. Historical

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data collation to allow meta-analyses of the type used by BMCCA should be strongly encouraged to document changes in species that can be related to climate change observed to date.

However, to be most effective and proactive in responding to the effects of climate change on Alberta's biodiversity, a long-term monitoring program that covers a broad spatial extent and documents changes in multiple species and their habitats is required. Data collected haphazardly is far less effective than well-designed monitoring programs that collect data systematically with respect to climatic gradients and anthropogenic modifications. Fortunately, Alberta has such a system through the Alberta Biodiversity Monitoring Institute (hereafter ABMI). The objective of this report is (1) to highlight how the ABMI's monitoring system can track the effects of climate change on biodiversity; (2) demonstrate how the work done by the BMCCA project can be used to make ABMI more effective, and (3) to identify opportunities to improve biodiversity monitoring in the face of a changing climate.

### WHAT CAN BROAD-SCALE SURVEILLANCE MONITORING TELL US ABOUT CLIMATE CHANGE?

At its core, the ABMI is a form of surveillance monitoring as the program collects survey data to understand broad-scale changes in biodiversity over time and space caused by many factors, including land-use and climate change. In brief, the ABMI uses a 5-year return interval to monitor biodiversity at locations systematically spaced 20 km apart across Alberta (Figure 1). Standardized protocols and a centralized data repository facilitate the collection of a random and representative sample of the state of Alberta's biodiversity on an annual basis. Few programs monitor such a wide range of taxa, and ABMI's robust broad-scale statistical design is unparalleled (Nielsen et al. 2009).

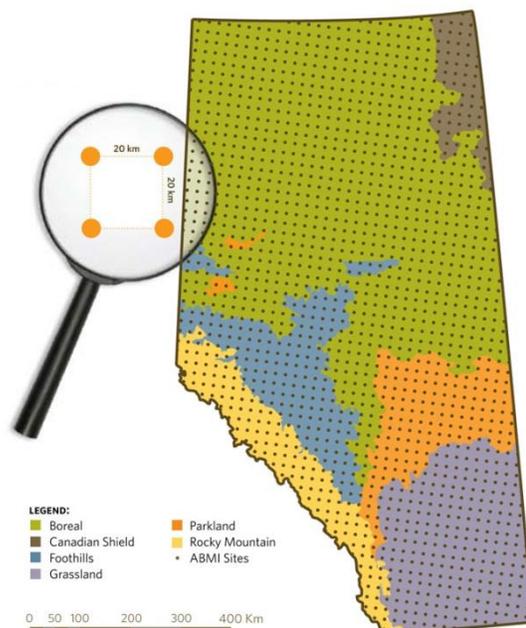


Figure 1. The Alberta Biodiversity Monitoring Institute sampling grid consists of 1656 sites evenly spaced at 20 km intervals through Alberta (courtesy of ABMI).

Surveillance monitoring like that done by ABMI has been criticized however, because of its lack of efficiency in addressing *a priori* hypotheses about important conservation issues (Lindenmayer and Likens 2009, but see Haughland et al. 2010). It has been argued that answering crucial conservation questions like “What is the impact of human activity *X* on species *Y*” can be done far more cost-effectively using a hypothesis-driven Before-After Control-Impact approach (Lindenmayer and Likens 2010). While partially true, the challenge with solely using a targeted approach to monitoring is that we are always left wondering, have we asked the “crucial” question, did we study the right species, are there interactive effects of the phenomena we studied with other processes that we ignored (Haughland et al. 2010)? Ultimately, a combination of targeted and surveillance monitoring is needed to be most effective in biodiversity conservation. Being able to identify unexpected and novel patterns requires long-term and broad-scale data. Testing the mechanisms causing such patterns often requires detailed studies that typically come after a pattern is observed in monitoring data.

In no circumstance is this more relevant than for the question of biodiversity and climate change. Unexpected shifts in species at large spatial extents and over extended time horizons are likely with climate change. Detecting these patterns of change is crucial for understanding risks of climate change. However, climate change is occurring in the context of other environmental changes, including changes in land use and land cover, and, while climate change will have many direct consequences for biodiversity, it will also interact with these other agents of ecological change (Staudt et al. 2013). Determining the underlying mechanisms causing observed changes in biodiversity across the province will be complex and difficult to fully evaluate from correlative analyses alone. Thus, having both types of monitoring is important.

For example, the BMCCA project used a combination of information from surveillance and targeted monitoring to better understand the past, present, and potential future effects of climate change on Alberta’s Ferruginous Hawks. We used historical surveillance monitoring data on hawk density and reproductive success to look for patterns in these variables related to changes in extreme weather. While these data were not collected for this purpose originally, they were extremely useful in documenting patterns of change correlated with extreme weather. Knowing that such patterns existed, the BMCCA project then used targeted monitoring to gather further data to test the hypotheses that extreme weather was causing reduced reproductive success through changes in food availability, nest site destruction, and/or exposure of nestlings to the weather. We used the best of both monitoring approaches to identify that increasing frequency of extreme weather is a causal part of the decline of Ferruginous Hawks and identify mitigation strategies that could be employed to stem their declines (Shank and Bayne 2015; Laux et al. in review).

As most of the effects of climate change on biodiversity are still to come, there is a critical need to develop future projections to determine risk so that we can prioritize conservation efforts for particular species. A future projection is a hypothesis in that predictions are made based on the best available data available about what the future might hold based on a set of assumptions. The validity of that prediction depends on the underlying assumptions. Much of the climate change forecasting work done by the BMCCA project used data from surveillance monitoring or data collected to test hypotheses about phenomena unrelated to climate change. Specifically, we used distributional data from ABMI and

other sources to understand how the abundance and distribution of hundreds of species relate to current climate (e.g., Nixon et al. 2015; Stolar and Nielsen in review; Stralberg et al. 2015a; Zhang et al. in review). Based on various assumptions about how climate change will unfold and how species will react to the changes in their habitats caused by climate change, we have made predictions that now need to be validated. Such validation can only be done by monitoring species in time and space to determine if predictions about changes in population size, shifts in range, or alterations in timing of life-history events unfold as predicted. For this, there is absolutely no better system for monitoring the effects of climate change and testing the hypotheses developed by the BMCCA project than the systematic sampling grid of ABMI. The large-scale replicated temporal and spatial design of ABMI is by far the best approach for understanding large scale spatial shifts in species in relation to climate change. However, there are several ways that ABMI's data could be used more effectively or supplemented to generate stronger inferences about the effects of climate change relative to other agents of biodiversity change (i.e. land use).

Based on various types of modelling and experimentation, the literature on climate change suggests that for terrestrial species there are five main ways we might expect them to respond to climate change (Staudinger et al. 2012):

1. Phenotypic plasticity: Some species may be sufficiently plastic in their habitat use and behaviours that populations will remain stable in the face of climate change in the areas where the species currently exist.
2. Genetic adaptation: Natural selection for traits better adapted to altered climates may result in *in-situ* adaptations that allow species to persist in the same location but with different genotypes in the population.
3. Distributional shifts: Species may shift their distribution to track changing climates. This may occur along latitudinal or elevational gradients. The ability and speed of a species to track changes in climate along such gradients will depend on the specificity of other habitat elements they require and whether or not these elements move in concert with climate shifts.
4. Temporal shifts: Species will persist in the same spatial locations but the timing of important life-history events will change. Documenting such shifts is pivotal for understanding species population trends when the means of documenting status and abundance are influenced by the timing of monitoring.
5. Local extirpation: Some species will not be able to adapt *in situ* because their habitat requirements are not met in a changing climate in their current location and dispersal limitations prevent them from moving to more suitable climates. Populations at southern edges of their range might decline first as the climate conditions move outside the range of acceptable conditions earlier in time than at northern range edges, making monitoring of range edges very important.

In the literature, there is evidence for all of these responses occurring in response to the climate change the planet has undergone in the last century (Parmesan 2006). This includes numerous Alberta species (Beaubien and Hamman 2011; Dawe et al. 2014, Fisher et al. 2015). As climate change continues, more species will begin to show such patterns. The goal of this report is to highlight what some of these

patterns might be and how Albertans can adapt ecological monitoring to be better able to document and respond to the observed changes.

This is not simply an academic exercise. The ability to separate the effects of climate change from other sources of biodiversity change (i.e. land use) is crucial for Alberta's economy. Twenty-plus years of targeted monitoring have clearly demonstrated that woodland caribou are declining because of changes in predator-prey interactions. However, the mechanism causing the change in predator-prey dynamics remains controversial, with both climate and land-use change as potential contributing factors. Our inability to separate the relative importance of decreases in winter severity, changes in vegetation structure and composition caused by industrial development, and the combined effects these have on caribou, moose, deer and their predators creates uncertainty in land-use planning. While the management response to conserve caribou may be the same (reducing predation), the specific actions taken to achieve that objective may differ, depending on a more complete understanding of the relative importance of climate change versus land-use as drivers of such community shifts. Having a long-term and consistent surveillance monitoring program across Alberta starting in the 1960's as deer and moose numbers began changing would have allowed much stronger inference on the relative importance of these two mutually exclusive hypotheses as factors driving caribou. To avoid future controversies, a biodiversity monitoring system is needed that not only enables the detection of climate change impacts on biodiversity, but also allows better separation of the relative importance of land use versus climate change as factors influencing biodiversity. The ABMI's systematic grid provides a strong foundation for doing this.

### **SPATIAL RANGE SHIFTS**

Shifts in terrestrial species distributions observed to date, have primarily been detected by examining the edges of species ranges. However, species abundance is generally lower near range edges (Gaston 2003), making detection of range shifts difficult. A few chance absences inside the former range edge, or occurrences outside of it, along with observer biases that highlight rare observations, can create apparent range shifts when very little has actually changed (Shoo *et al.* 2006). Intensive and focused sampling across range edges has been identified as one way of tracking changes in range edge.

Work by the BMCCA indicates that the climate space for many Alberta species will shift enough in the next 50 to 100 years to be detectable. Ranges of many boreal birds and plants are predicted to have their southern ranges contract in the province as the climate space used by those species moves northward (e.g., Stolar and Nielsen in review, Stralberg et al. 2015a). Conversely, the northern range edge for many species that now live in the prairie ecosystem is predicted to move into the aspen parkland and boreal forest (e.g. Nixon et al. 2015). Thus, the aspen parkland ecotone from the southern edge of the boreal forest to the northern edge of the prairie will be an area where some of the most dynamic spatial change will occur. Many species currently have range edges in this area. One option for improving ABMI's ability to track climate change would be to increased spatial and temporal frequency of sampling in the region between the boreal forest and prairie ecosystems in Alberta.

There are several challenges with such an approach. Currently ABMI samples in this region in proportion to available land uses and habitats. Much of the aspen parkland region has already been converted to agriculture. With climate change, it is unlikely that we will abandon agricultural production although a shift towards crops better able to deal with warmer and drier conditions may occur. Thus, range shifts that might occur may be difficult to detect because the vegetation type (i.e. crop) that is predominately sampled may not change all that much. More effective detection of species' range shifts in this region may require stratification to increase sampling of remaining native vegetation which presumably will change more quickly. Including stratified samples within the ABMI's trend estimation in space and time is something that is being evaluated but requires new approaches to analysis that are not yet fully developed.

Focusing sampling on range edges alone runs the risk of not having sufficient number of species with concordant range edges to have a cost-effective monitoring program. To draw strong inference about whether climate is affecting spatial distribution of species, the patterns observed must occur across multiple species. Furthermore, they should be consistent with future scenario models based on climate envelope modelling. Thus, an alternative to sampling only where the effects of climate change are expected to be most pronounced, is to develop methods to detect shifts in abundance anywhere in a species' range. Huggard and Schieck (2010) have developed such a method for use with ABMI's monitoring data.

The Huggard and Schieck (2010) method statistically models how spatial variation in abundance changes over time. The method assumes one of the following patterns will occur in Alberta as climate change progresses: 1) prairie (southern) species will increase in abundance over time at all points with a steady decrease in abundance the farther north (or otherwise at the cold end of a temperature gradient) one samples (Fig. 2a); 2) boreal (northern) species will decrease in abundance at all locations with a steady increase in abundance the farther north one samples (Fig. 2b); or 3) mixed changes will occur depending on the local direction of the abundance gradient for a species with local maxima or minima in a region (Fig. 2c).

The process to test the validity of range shift hypotheses are to: 1) use existing surveillance monitoring data to model spatial distributions of species as a function of climate based on ABMI's existing data and other datasets; 2) use spatially explicit predictions from statistical models that predict species abundance as a function of climate variables and project future species distributions for several time periods estimated by global circulation models (Stralberg et al. 2015a, Nixon et al. 2015, Stolar and Nielsen in review); 3) test these predictions by collecting a second round of monitoring data for multiple species, at spatially defined systematic points across a region (i.e., ABMI grid); 4) fit spatial surface models to the abundances of species in all time steps; 5) calculate the "slope" and "aspect" of the fitted spatial surface (the rate and compass direction in which abundance is changing) at a regular grid of points (i.e., across the ABMI grid); 6) extract the poleward component of the abundance gradient at each point on the grid; 7) plot abundance versus the poleward component of the abundance gradient at each point; 8) repeat sampling at the same points; 9) fit a spatial surface to the new abundance data; 10) regress the change in abundance at each grid point against the original poleward component of the abundance gradient at each point. The regression slope is the estimate of the average distance

poleward the species has moved in the region; and 11) statistically compare the regression slope estimated by actual data to that forecast by climate envelope models to determine consistency with climate change predictions.

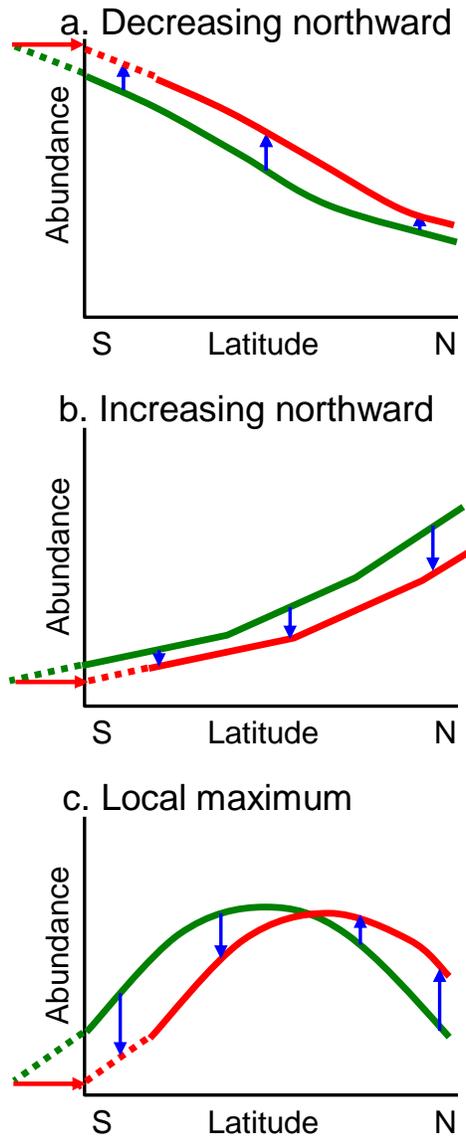


Figure 2 – FROM Huggard and Schieck (2010). Hypothetical species' abundances along a south-north transect in a region currently (green), and after a northward shift in distribution (red). With the shift northward, abundance increases at points along the transect where a species' current abundance shows a decrease to the north (a, right side of c); abundance decreases where the species' current abundance shows an increase to the north (b, left side of c; blue arrows). The magnitude of change is proportional to the slope of current abundance at each point.

By plotting predicted abundance of a species against the poleward component of the abundance gradient at each grid point (step 6), a user can interpret whether changes in the abundance of the species within a region are poleward in nature, or are random with respect to a poleward estimate. A clear poleward range shift by species would produce the largest declines in species abundance at grid points with the lowest (i.e., negative) poleward slope, little change where poleward slope is zero, and greatest increases in species abundance at grid points with the highest poleward slope (Fig. 3). By regressing change in abundance at each grid point against the original poleward component of slope (step 7), one obtains a direct measure of the amount of poleward shift in species abundance. With a regular grid of points, the regression slope has units of distance ( $=\Delta\text{Abundance} / (\Delta\text{Abundance}/\text{Distance})$ ). The intercept of the regression is then the overall change in abundance across the region, and the scatter around the regression line is local change in abundance that is unrelated to the poleward gradient. By including land-use covariates as part of the regression model to fit spatial patterns, confounded effects of development over time can be separated by climate change. This is where ABMI's detailed land-use mapping at its sampling points (ABMI 2013) is critical.

To date, ABMI and the BMCCA have been able to complete steps 1 and 2 of this process. There has not been enough repeated sampling in a systematic fashion to test the remaining steps to this modelling approach. As ABMI returns to the same sites over time, this approach will gain increasing statistical power to help Albertans understand the relative importance of land-use and climate change as drivers of species range shifts in the province. ***Fundamental to this being successful however, is ensuring that the ABMI's systematic grid sampling becomes fully operational and is not biased by funding allocations that force sampling to occur in particular spatial locations.*** Placing monitoring emphasis on land-use issues in a particular location in the province creates a biased sample that makes the approach outlined above statistically less powerful and thus less able to separate the effects of climate change from land-use.

## **ELEVATION SHIFTS**

As Alberta's climate changes, many areas of the province that are currently forested will shift to a climate space that is not conducive to supporting trees. At a macro-scale this will result in the shift of entire ecosystems with conditions that currently support prairie and aspen parkland biomes moving north (Schneider 2013). This shift will have large-scale consequences for biodiversity in the province. Some projections suggest that in flat low-lying areas boreal forest climates will no longer occur by the end of the century (Schneider 2013). However, climate envelope models done by the BMCCA project indicate that, for many species that rely on trees, hill systems, and to a lesser extent river valleys, may be the only place that their habitat will persist as refugia in an altered future climate (Stralberg et al. 2015b). In particular, north facing slopes with lower mean annual temperature may become particularly important areas for conservation. (e.g., Ashcroft et al. 2012) .

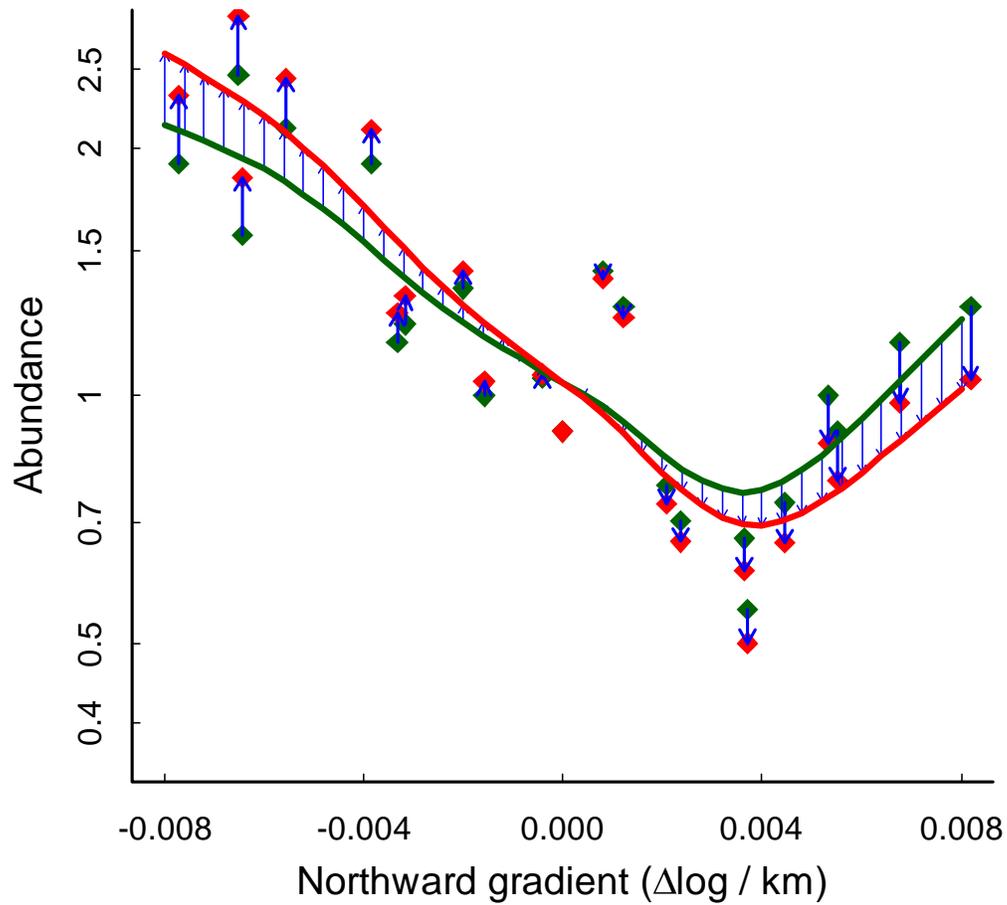


Figure 3 – FROM Huggard and Schieck (2010). Hypothetical example of abundances as a function of the northward component of slope in the abundance surface at a subset of points on a regular grid in initial surveys (green), and expected abundances after a 100 km northward shift (red). Lines show smoothed relationship initially (green) and after the range shift (red). Note that the magnitude of change in abundance at each point is proportional to the northward component of slope in the abundance surface.

Hill systems may serve as refugia in multiple ways. First, higher elevation forests will retain sufficient moisture longer in a warmer world, allowing existing populations of many species to persist and increase in what may currently be marginal habitat. Secondly, climate velocity, or the distance an organism must move to track climate (Loarie et al. 2009, Hamann et al. 2014) is much lower in topographically diverse areas (Ackerly et al. 2010), allowing for much more rapid distributional responses to climate change. Finally, complex terrain often results in fire skips that allow forests in areas of greater ruggedness to have older patches than flatter regions (Burton et al. 2008).

Alberta's hill and mountain systems provide unique opportunities to test for elevation shifts. ABMI's systematic grid is not currently suited for this type of analysis however and if climate change is a priority these areas may warrant denser sampling than the current ABMI grid allows. For example, hill systems in the boreal forest of Alberta are relatively rare and relatively few ABMI survey points hit such areas. In addition, the points that do lie in hill systems do not form an elevation gradient within a single hill system because of the 20-km spacing between survey points. Thus, a better design would be to study specific slopes from the bottom to the top of an elevation gradient and do so over time to establish a better baseline and get a better idea of the shift in species location up or down slopes. For example, the Grinnell resurvey project in California, where Joseph Grinnell's surveys were revisited 100 years later provides a model example of what is possible over long time periods (Moritz et al. 2008, Tingley et al. 2009, Tingley and Beissinger 2009, Dobrowski et al. 2011).

Similar inference may be obtained over shorter time periods with greater sampling effort and better statistical design. While an additional cost, such monitoring would aid in monitoring in Alberta's parks as many of the hill systems in boreal Alberta have some degree of protected status. The BMCCA began a monitoring program in Alberta hill systems in 2014. Specifically, we went to the extremes of latitude and elevation in forested hill systems in Alberta. Very strong patterns in species richness were observed for birds and plants along the elevation and latitudinal gradient sampled (Figure 4). Returning to these sites on the standard ABMI 5-year rotation is encouraged as it will allow a critical evaluation of how species are changing over time and if they are moving upslope as predicted by climate envelope models. Equally important is collecting more standardized data in Alberta's Rocky Mountains. Numerous biodiversity monitoring programs exist within Alberta's mountain parks, and there have been several studies evaluating biodiversity patterns along elevational gradients. Repeated sampling of these gradients using standardized protocols at a future point in time would be particularly useful (Pearson and Goater 2008, Gorzelak et al. 2012).

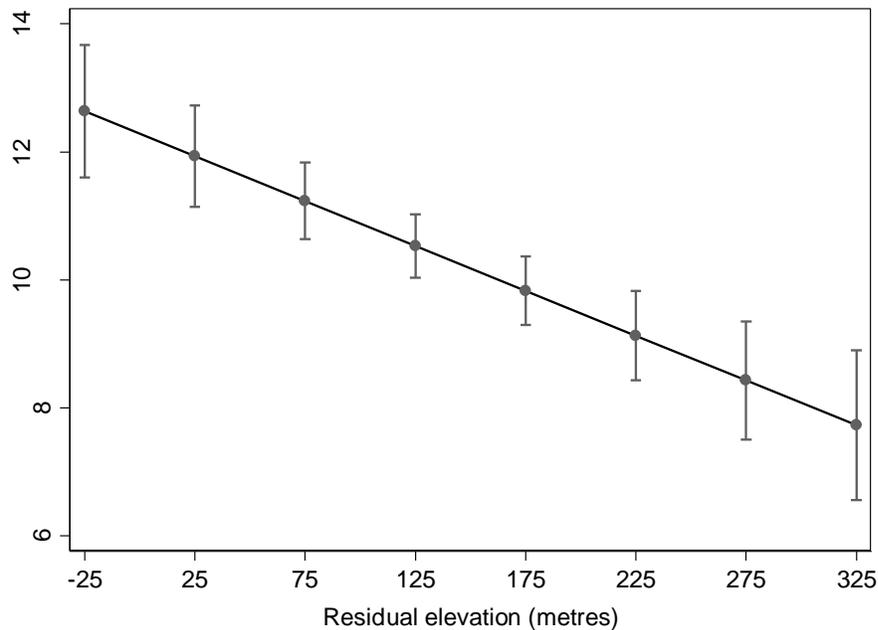


Figure 4 – FROM Bayne and Stralberg 2015. Number of bird species (alpha richness) detected per station as a function of residual elevation in hill systems in boreal elevation (metres).

The approach of Huggard and Schieck (2010) can be applied to track changes in distribution where species are located along elevation gradients. This can be done by fitting appropriate spatial surface climate terms relevant to the organism of interest (e.g., growing degree-days, minimum winter temperature, summer precipitation). The aspect at each point on the sample grid can then be calculated for the climatic variables that predict the species' abundance along the elevation gradient. Using climate variables strongly correlated with elevation gradients and testing for their changes over time provides a robust and relatively easy test of a common climate change prediction for a relatively small budget.

## PHENOLOGICAL SHIFTS

Albertans' ultimate concern for biodiversity conservation in the face of climate change is with respect to species abundance and distribution. However, phenological shifts (aka changes in the timing of major life history events) are likely to occur and should be of concern. From a conservation perspective, mismatches in timing between interacting species can have large impacts on population dynamics, especially for migratory species. For example, many migratory animals time their arrival and breeding to coincide with pulses of food resources. If the food resource (e.g. insects) begin to emerge earlier over time but the animals continue to migrate at the same time due to hard-wired migration schedules then the optimal timing for important life history events may become out of sync. Depending on plasticity of

migration behaviors, this may over time result in species declining because they are not finding sufficient resources at the right time of the year.

Phenological shifts can also create numerous monitoring challenges. Any measure of change in animal abundance or distribution can be confounded by phenological changes in what is being monitored. For example, if birds sing earlier in the year but sampling dates are fixed, early-singing southerly birds may be missed increasingly and appear to decline while late-singing northerly birds may appear to increase, regardless of actual changes in distribution. Designs incorporating analytical corrections for detectability changes partially mitigate this effect but do require that sampling take place at such a time that the species can be detected (Mackenzie 2006). This creates a significant challenge for ABMI due to constraints caused by training schedules and the fact that many staff are summer students who are typically not available to work until May.

One way of reducing this problem is to rely on monitoring approaches that do not require people to be present. ABMI has recently shifted to using two new technologies that will provide valuable insights into phenology: automated recording units and remote cameras. Automated recording units (ARUs) are audio recorders that can be programmed to turn on and off at any time schedule and can record for months. ABMI has chosen to place ARUs in late February until late July providing a very long seasonal record of when animals start and stop making sounds. Calling behaviour is correlated with numerous life history events (i.e. breeding, territory establishment) so provides us with a clear understanding of when those processes are occurring.

Understanding how phenology is changing and the influence this has on ABMI's monitoring accuracy will require several advances in processing audio recordings. In the past, ABMI relied on a single 10-minute recording at each point. With the shift to ARUs, ABMI now has hundreds of hours of recordings to process at each point. Clearly, human processing of all recordings will not be possible. The Bioacoustic Unit of the ABMI-University of Alberta is currently working on automated species recognition tools that will allow the entire season of recordings to be processed to determine when a species is first heard and when it stops calling. This type of data will be invaluable in understand our ability to track changes in abundance by better understanding the factors influencing detectability of species in time. Figure 5 shows an example of seasonal soundscape and how it changes over the length of the year and day. Soundscapes will shift in time and space with climate change. Using a soundscape that describes the state of whole communities will be valuable in rapidly tracking the effects of climate change.

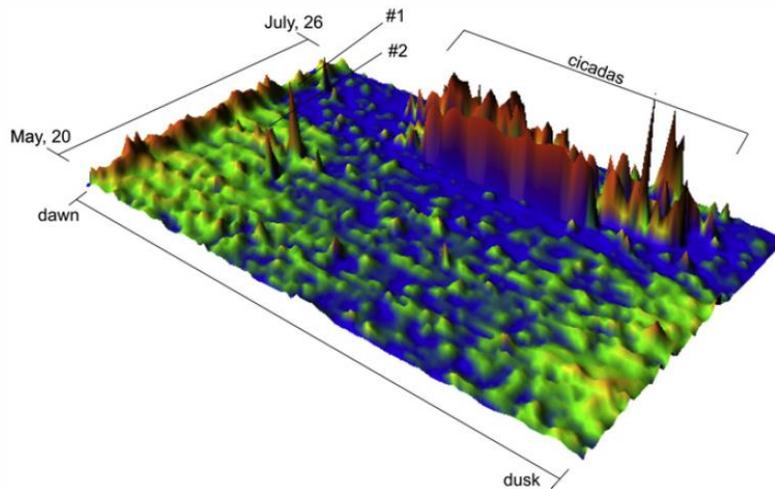


Figure 5 – FROM Farina et al. 2011. 3-D representation of the soundscape over the course of the season (56 days) (y axis) and daily sessions (90) (x axis). From the image it is possible to note the dawn and dusk chorus of birds, reduced song activity in the middle of the day, and the presence of anomalies: 1: This peak is the result of a low altitude helicopter flight. 2: The introduction of cicadas' song in July when bird activity is much reduced or absent. This picture and resulting statistics provide a quick index for monitoring to assess how change is occurring because of readability and the ability to verify anomalies.

Remote cameras are being used by ABMI to track mammals in the province. Cameras will be particularly useful for tracking changes in species behavior by documenting when certain species become active. For example, bears are one of the most commonly photographed species. Cameras provide a new tool for tracking when bears awake from hibernation, which has been shown to be strongly influenced by local weather conditions (Schooley et al. 1994). Similarly, cameras can be used to track the background vegetation in images. Ground-level green-up and snow melt patterns will be possible to detect with ABMI's camera program as long as a decision is made to have the cameras take a daily photo. Combined with more traditional remote sensing, these tools will provide powerful information to track changes in seasonality in key ecological processes associated with climate change.

Two fundamental challenges for ABMI are monitoring the phenology of plants and insects. ARUs have the potential to track some vocalizing insects very well (i.e. cicadas) but also could be used to monitor emergence times of mosquitoes and other insects that fly near the microphone. Work is needed to calibrate these technologies with our more standardized approaches. The Bioacoustic Unit is currently exploring whether there are species-specific wing beat frequencies in bees that could be monitored via sound or whether cameras can be used to take photographs of sufficient quality to identify species. Simply providing a lure for specific insects (i.e. provide pollinators a colored disc like a flower) could be used to increase species breadth for species that ABMI currently does not monitor. Exploration of other passive sampling techniques for monitoring insect emergences in time and space will broaden ABMI's capacity and provide valuable information on timing mismatches caused by climate change.

## **CLIMATE-SENSITIVE SPECIES POORLY SAMPLED BY ABMI**

While ABMI monitors thousands of species, there are thousands of others that are not monitored. While all species are important and of concern, there simply are insufficient resources to monitor all species as effectively as we would like in a systematic system. As part of our BMCCA review, we undertook an evaluation of 173 species in Alberta and assessed their risk from climate change (Shank and Nixon 2014; Figure 6). In this assessment, 55 species of birds were assessed. In general, most of the species on this priority list can be monitored via the new ARU approach that ABMI began to use in 2015. To increase statistical power however, targeted sampling in specific habitats will be required. The Bioacoustic Unit is currently working to identify these habitats and the sampling effort that will be required to track changes in certain acoustic species. Some species are so rare and/or do not call sufficiently for this approach to be effective (Ferruginous Hawk, Whooping Crane, Burrowing Owl). In all of these cases, other monitoring programs exist for these species. Adding ARUs at open water wetland, along with a standardized visual scan for species while setting up these wetland ARUs would improve power for other species like waterfowl that are poorly sampled currently.

ABMI's mammal monitoring program has recently been undergoing considerable changes. In the past, winter tracking was used to count tracks of animals in the snow. This was generally effective, albeit quite variable, for those species that were active in the winter. This created several problems for monitoring the effects of climate change, however. As snowfall changes the amount of time available for sampling will change. In the extreme, monitoring would have to stop in years when no snow falls. Second, snow depth influences animal movement which can change the interpretation of such data (greater snow depth might mean animals move less rather than there being fewer animals). This has led to ABMI exploring the use of remote cameras for tracking mammals. For about 1/3 of the species of mammals listed on the BMCCA climate change vulnerability index, remote cameras on a systematic grid will likely be effective for tracking changes in abundance. Most of these are large and wide ranging species. Camera placement could be adjusted to provide additional information for smaller species like voles, pikas, and marmots. The first aspect of tracking such change would be non-stratified sampling whereby the specific habitats of these species are targeted for sampling. Additionally, changes in local camera placement could be considered and other lures used to draw smaller mammals to cameras (i.e. point camera down at small food bait). Bats are thought to be particularly sensitive to climate change. The ARU technology being used by ABMI can be adapted to record bat feeding calls and could be included in future plans. In general, there has been limited evaluation of how acoustic signals could be used to track mammals within the ABMI program and is an area that warrants further research as many mammals are quite vocal at certain times of the year (i.e. ungulate rut).

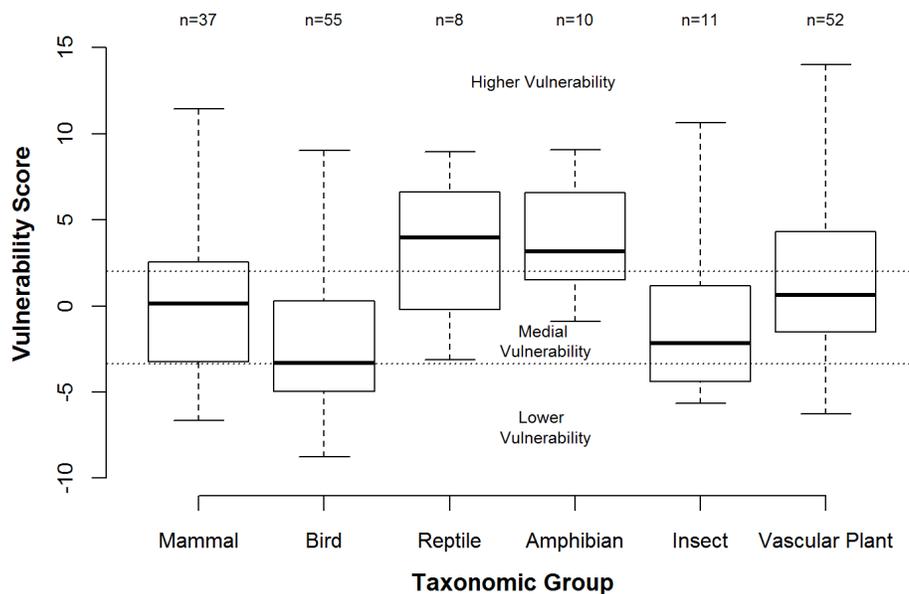


Figure 6 – From Shank and Nixon 2014. Vulnerability scores to climate change by taxonomic group in Alberta. Whiskers represent extreme values. Higher Vulnerability refers to the highest 25% of scores for all Alberta species assessed and Lower Vulnerability represents the bottom 25%. Medial Vulnerability refers the middle 50% of scores.

Until the advent of the ARU technology, ABMI did not have an amphibian monitoring program. Given the perceived sensitivity of amphibians to climate change this was a gap. ARU technology and placement by wetlands will improve ABMI’s capacity in this regard. Recently, ABMI started discussions with Terrestrial Wetland Global Change Research Network about utilizing the amphibian ARU data as part of their North American wetland monitoring program. The goal of this network is to assess the interrelated physical, chemical, and biological nature of climate/global change over time. This is done by using standardized, multidisciplinary methods applied consistently and integrated across relevant spatiotemporal scales and this includes the ARUs now being used by ABMI. Several non-vocal amphibians will not be sampled at all (salamanders) with this approach and would require a timed visual survey when visiting sites or some form of trapping. A similar rationale applies to reptiles in the province, which may require timed visual surveys.

Butterflies and moths have been identified as potentially being sensitive to climate change. No protocols exist within ABMI currently to cost-effectively sample them. As discussed in the phenology section, the use of remote cameras holds promise in this vein and should be explored via protocol development research.

Plant species potentially sensitive to climate change are many. From a population perspective, ABMI’s systematic grid will sample species quite effectively. The only way to improve monitoring for these species is to target specific habitats and start using meandering surveys. This approach is being explored in ABMI’s rare plants program for its cost efficacy.

Recognizing that ABMI's systematic grid can't sample every species with sufficient intensity, alternative methods of data acquisition are needed. The ABMI has developed a research fund for students to develop new techniques for sampling and/or to sample for specific animals or habitats it does not currently sample well. What has been lacking, however, is a consistent way of collecting these data so that these same sites could be revisited in the future. Such systems are possible and very valuable. A good example is the Boreal Avian Modelling project<sup>2</sup>, which has collated most existing avian point count data across boreal North America into a single database. Knowing what species are where and when counts were done allows people the ability collect these data again in the future. For example, many of the original forestry-related studies done by the University of Alberta in the early 1990's have been integrated in this database. New students and staff are repeating these studies twenty years later to see how vegetation change in harvested areas over that time has altered the resulting patterns. Having a consistent database structure for students sponsored by ABMI program is a necessary step for effectively monitoring rare and elusive species that are of greater climate concern. Encouraging Albertans to conduct surveys for species of concern and having a repository with common standards for the data is one of many ways of better being able to monitor the effects of climate change cost-effectively.

## **CHANGES IN INDIVIDUALS**

In general, the ABMI focuses on collecting data that provides information on metrics related to species abundance. Detecting patterns of abundance and how they change in space and time are essential for documenting the effects of climate change. However, when changes in the abundance of a species in either space or time are detected, there has already been a significant shift in a population, which is not a desirable outcome if the goal is mitigation. Changes in the behaviour, survival or growth rate of individuals have been used to demonstrate responses to climate change. For example, the Ferruginous Hawk project conducted by the BMCCA project has been evaluating how reproductive success of individuals over multiple years is influenced by local weather and specifically how it alters feeding behaviour. Demonstrating shifts in feeding rates by species and individuals and the consequences this has for reproductive success with changes in weather associated with climate change provides a useful early warning sign of the effects climate change may have.

ABMI does not collect data on individuals explicitly. However, several of the protocols do allow for testing of attributes of individuals that would be useful for assessing impacts of climate change. Specifically, ABMI measures the size (diameter at breast height) of all trees within various sized quadrats (ABMI 2014). By repeatedly measuring these areas over time, rates of tree growth can be assessed and correlated with climatic conditions occurring in the region of interest (Figure 7). Furthermore, tree cores/ cookies collected at the same sites can be used to measure the width of growth rings over time providing the ability to track changes in tree growth rates more precisely. Currently ABMI cores 9 trees per site. These cores are taken from: 1) the largest (biggest DBH) live tree within the 1 ha area,

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<sup>2</sup> [www.borealbirds.ca](http://www.borealbirds.ca)

regardless of species; 2) the largest live tree from the leading species (species with the highest stem density of dominant and/or co-dominant canopy trees), within each 50 x 50 m quadrant (total of 4 trees per site); and 3) the largest secondary species (species with the 2nd highest stem density of dominant and/or co-dominant canopy trees), if it occurs, within a 50 x 50 m quadrant (potentially one tree from each quadrant), not including veteran or residual trees from a former stand. One concern with this approach is that growth rate – climate relationships may not be the same between the largest trees and smaller trees. Although Chhin et al. (2008) found that trees of all diameter classes generally responded to climate in the same way in lodgepole pine stands in Alberta, future research should validate this pattern for other species of trees to ensure that the ABMI’s approach to monitoring tree growth in response to climate change is robust.

Just as with other species, placing more permanent sampling plots for trees in areas where the greatest and least amount of change caused by climate are likely seems wise. Creating more permanent sampling plots along elevational gradients also seems warranted as the large changes in climate over a short spatial gradient will be easier to detect. ABMI will play a pivotal role in future studies evaluating spatial patterns in tree growth based on predictions made by climate envelope models.

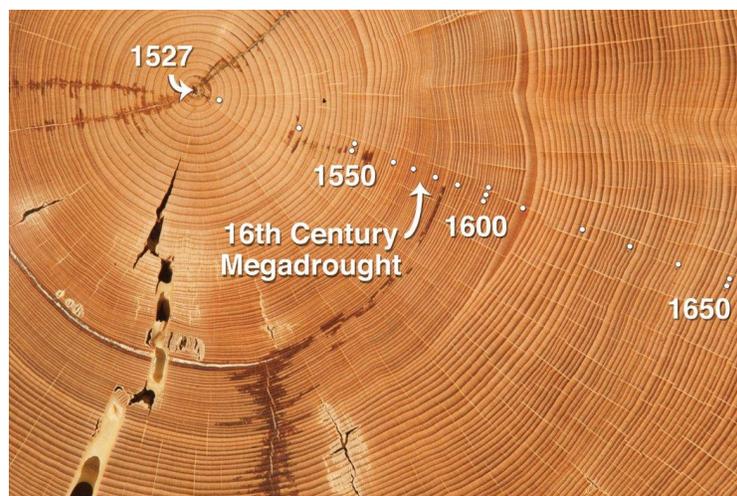


Figure 7. An example of how tree rings can be used to identify important climate events. From <http://www.zmescience.com/ecology/environmental-issues/california-drought-tree-ring-05122014/>

## CHANGES IN GENETICS

BMCCA has demonstrated clearly that the climate space used by species in Alberta is likely to move. If species can track these changes, large spatial shifts in range and abundance will occur. If they cannot there are two possible outcomes: 1) the species will go extinct; 2) the species will adapt in place through natural selection. Current climate envelope models do not typically account for differential adaptation of populations to recent local climates, genetic diversity levels and degree of local adaptation (Aitken et al. 2008). However, plants generally show strong population differentiation for traits relating to adaptation to local climate. Anecdotal evidence suggests that trees may be able to adapt rapidly to new environments. For example, steep genetic clines during post-glacial migration have been reported (Davis and Shaw 2001). Similarly, locally adapted land races of introduced tree species within one or two generations of introduction have been seen (Saxe et al. 2001). Experiments have shown high among-population levels of genetic variation for quantitative traits related to adaptation, geographic structuring of that variation along climatic gradients, and genotype-by-environment interactions, indicating local adaptation of populations to climate can and does occur (Howe et al. 2003; Savolainen et al. 2007). The big question is will moderate to high average levels of genetic diversity be sufficient to allow for rapid adaptation and what role will generation length play in natural selection for individuals better adapted to a changing climate?

As part of population monitoring, ABMI collects many voucher specimens. To date, limited use of these permanent records has occurred, but there is considerable potential for tracking changes in the genetic composition of species at ABMI sites over time. For relatively short-lived plant species, current sampling designs with a 5 year rotation will allow analysis of the genetic variation within species and how it change with climate over time. In contrast, current sampling of material from trees that could be used to assess genetic variation will create a bias. For example, the xylem present in tree cores collected by ABMI can be ground up to extract DNA. However, sampling the largest trees in a stand for tree cores (which can be used for genetic analysis) will tend to provide a DNA record of the trees that grew decades before. Sampling for these trees will not allow an effective assessment of the younger individuals that just started growing and presumably are under stronger natural selection pressure. Having such a record over time will add to ongoing provenance trials being done by forestry researchers to identify the genotypes of trees most robust to climate change. What ABMI provides most effectively in its current design is the ability to have this type of information for a wider array of vascular and non-vascular plants. Other samples that could be explored in this vein include mites and numerous aquatic invertebrates. Linking current genetic variation in a species to current climate via climate envelope models could be used to determine how genetic variation within a species might change over time much as BMCCA has already done with individual species models (Figure 8).

To date, long term sample storage has not focused on collecting material and storing it in a way that maximizes its usefulness for genetic analysis. ABMI should investigate whether the preparatory approaches to storing specimens for long term storage is optimal for the retrieval of genetic information.

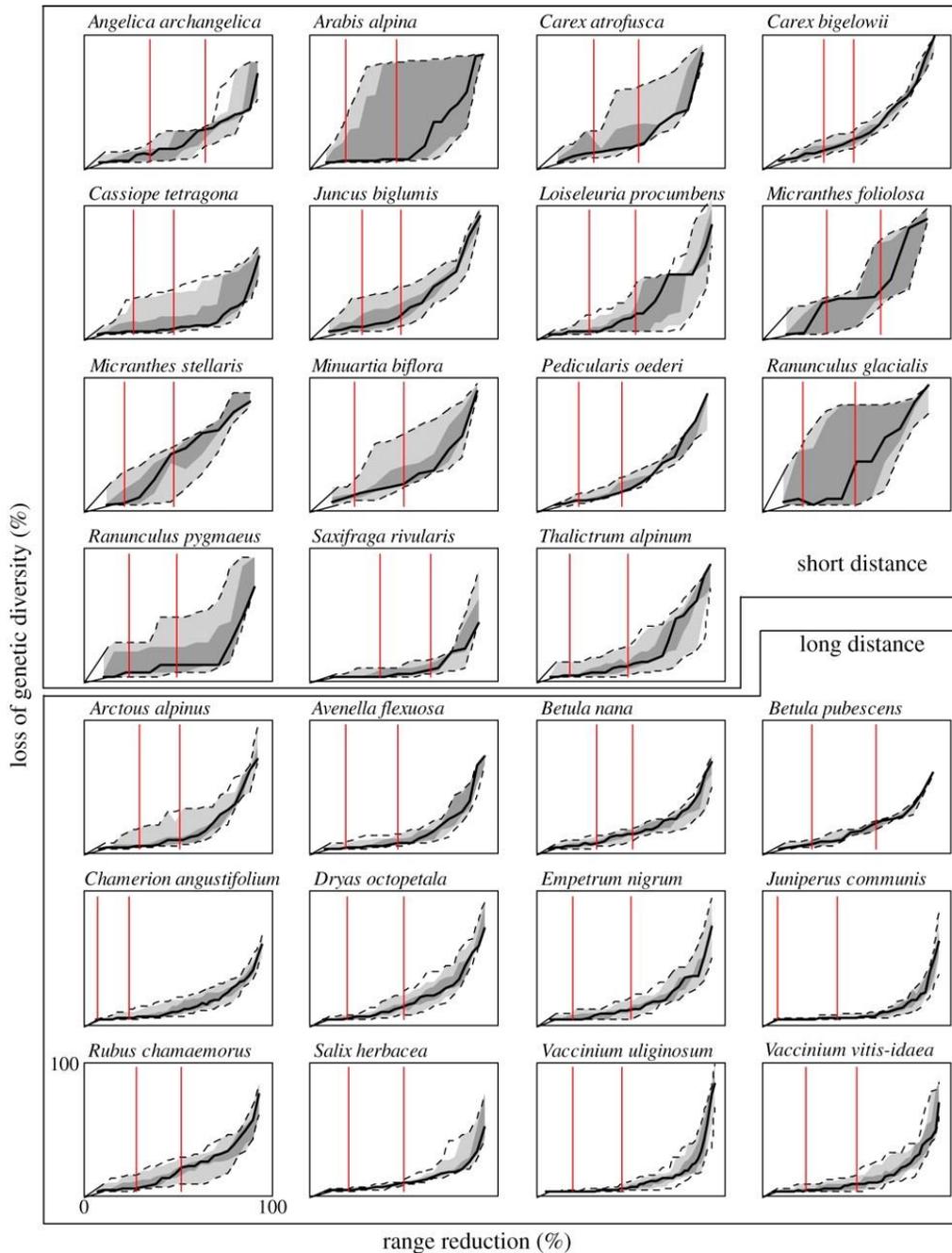


Figure 8 - FROM Alsos et al. 2012. Estimated loss of genetic diversity as a function of decreasing range for 27 northern plant species in northern hemisphere. The bold line refers to the median; the dark grey shaded area refers to 50% CI; the light grey shaded area refers to 90% CI; and the dashed lines refer to minimum and maximum loss of genetic diversity. Vertical red lines show minimum and maximum range reduction expected by the year 2080 by any of seven species distribution models, two emission scenarios and two global circulation models.

## REMOTE SENSING

ABMI is involved in detailed mapping of the environmental conditions of Alberta at a variety of spatial scales. Specifically, they have utilized existing sources of information to create standardized and corrected layers related to human footprint and vegetation at a coarse level across Alberta. At ABMI sites specifically, aerial photos are taken every 5 years and highly detailed aerial photo interpretation is done to track changes in vegetation conditions, human footprint, and wetlands. As such, ABMI has coarse-level resolution census that can be used to track changes in habitats for Alberta species and a detailed sample of more specific environmental conditions. Both of these products will be useful for documenting changes in Alberta's ecosystems over time. Linking observed differences in habitats over time to climate change will require the development of detailed analyses that evaluate if the observed shifts follow predicted patterns expected from climatic envelope models.

Recently, ABMI has started documenting the effects of climate change on Alberta's biodiversity based on phenology. ABMI has started making an annual NDVI (Normalized Difference Vegetation Index) layer. NDVI is particularly good at tracking patterns in greenness over time which indicates the timing of when plants start becoming photosynthetically active each year. Specifically, ABMI is creating provincial wide layers that include but are not limited to: start of the growing season; end of the growing season; length of the growing season; and peak of the growing season. How fast plants begin greening up and the rate of time it takes to reach maximal greenness have been used to track changes in the timing and intensity of spring conditions. Tracking the rate of NDVI change over time will be valuable in determining changes in the phenology of various Alberta ecosystems (i.e., Figure 9).

Higher temperatures will have a variety of effects on Alberta's hydrology. Understanding changes in the amount of surface water, moisture in soils, and moisture in vegetation can be tracked using Canada's Radarsat technology along with other microwave based sensors (Trudel et al. 2012). In Alberta, Radarsat images were collated for 2003 (<http://www.ags.gov.ab.ca/MapServer/RadarSat/>). Periodically repeating this effort in conjunction with predictive models on how climate change is influencing hydrology will be pivotal for understanding how biodiversity is responding to changes moisture and water levels. Such products can be useful for biodiversity distribution modelling. Other optical sensors, like Landat or MODIS should also be used to track snow cover and to maintain these data in common format. Snow cover and timing of snowfall and snowmelt will be pivotal in understanding seasonality which will have strong influences on biodiversity.

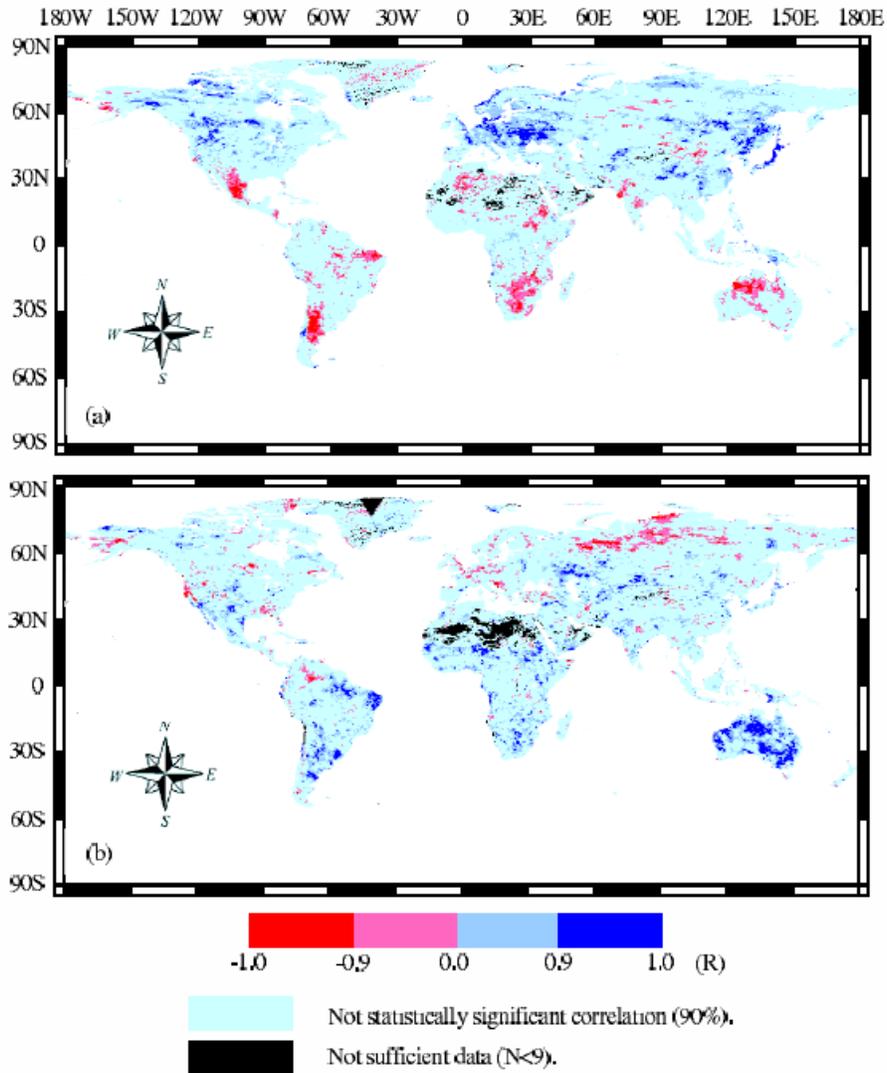


Figure 9 – FROM Ichii et al. 2010. Global maps of correlation coefficients between annual averages of (a) NDVI and temperature and (b) NDVI and precipitation, for 1982–1990. Coloured areas indicate statistically significant relationships (90% significance level). Grey areas are not statistically significant and black areas represent insufficient data ( $n < 9$ ).

## **WEATHER & EXTREME WEATHER MAPPING**

To make use of ABMI monitoring data for tracking large scale shifts in biodiversity and be effectively able to separate climate change from other factors (i.e. land-use), requires we understand how climate shifts as well. Weather data (temperature, precipitation, humidity, wind) are currently collected primarily at weather stations placed in centres of human development. Relatively few long-term monitoring stations exist in other areas. This is a fundamental weakness for tracking climate change in Alberta. Most of the models used to date to predict climate-change effects are based on interpolated climate surfaces from weather stations spaced irregularly and generally far apart. We know that elevation and terrain make baseline interpolations less accurate than they could be. Given this, more effort is warranted in tracking weather variables in a more systematic way across the province. Tracking extreme weather events more precisely is particularly important. Fisher et al. (2015) were able to demonstrate linkages between reproductive success of Burrowing Owls over time and the frequency of storms. However, there was considerable uncertainty in the exact extent of storms or storm intensity based on the network of weather stations available. More intense and systematic sampling would allow detailed maps showing the spatial extent of storms which can be used to effectively predict the consequences of extreme weather.

Recognizing the limitations of current weather stations for understanding the weather conditions within Alberta's hill systems (which essentially have not been sampled), the BMCCA project undertook a pilot program using inexpensive temperature monitoring technology in 2014. These systems have been operational for a year and the data will be accessed this fall to determine how effective the technique was and determine the logistical issues of using this approach. Assuming the tools used were effective, we strongly encourage ABMI to invest in more comprehensive versions of such technology (also including moisture sensors) whereby data will be collected for multiple years at each site by such systems without human intervention. In areas with more people, citizen science could be a very effective tool for gathering data on extreme weather (<http://www.cocorahs.org/Canada>).

## **BUILDING A CLIMATE & BIODIVERSITY MONITORING "BOX"**

Many of the advances made by ABMI in biodiversity monitoring recently have come through the novel use of technology. The next step in this evolution is the development of geosensor webs. A geosensor web is an internet-based information and communication system connected to one or many sensor networks in the field. On-line connectivity allows users to operate the network and query the physical world from anywhere and at any time. With on-going advances of in situ sensing and communication technologies, geosensor webs offer the potential to produce the data required to describe and understand environmental conditions at unprecedented quantity and quality. A geosensor web can offer continuous temporal observations (e.g., micro-climate and wildlife presence) that either cannot be directly measured by traditional remote-sensing technologies, or are too costly to obtain through conventional field surveys. An NSERC CRD at the Universities of Calgary, Alberta, and Saskatchewan with Dr's McDermid, Castila, Liang, Bayne, Nielsen, and Franklin is working to design, develop, test, and demonstrate a low-cost geosensor web prototype that will collect ground biophysical data (e.g. animal presence, vegetation structure, microclimate).

The basic idea is to use existing commercial off-the-shelf open-source hardware and software architectures in novel combinations. Specifically the monitoring “box” will be a multi-purpose terrestrial-sensing platform configured to support air-temperature and humidity sensors; soil-vibration, moisture, and temperature sensors; microphones; and time-lapse, low-resolution cameras to track vegetation development and animal presence. The proposed terrestrial-sensor nodes will provide continuous ground-truth data to complement coincident remote-sensing observations, and will enhance the information that can be derived from the latter. The sensor network will be assessed for sensibility, accuracy, and reliability relative to existing technologies like Acoustic Recording Units (ARUs), Camera Traps (CTs), temperature data loggers etc that the BMCCA project used to verify efficacy, quality, and accuracy. The sensor nodes being considered are intended to be less expensive, and provide higher sampling rate, and a denser spatial coverage (more nodes per area) than the approaches currently being used. The expected outcome is a new functional terrestrial monitoring “box” that integrates a variety of sensors into a single unit that can be deployed easily and more cost effectively.

The amount of data from such systems will require an open geospatial cloud computing prototype designed to manage, analyze, and share the data and information generated. The geospatial cloud platform will enable government, businesses, and citizens to share, collaborate, and access the information generated from the project via a coherent web-service API. The proposed geospatial cloud computing platform will have the following components: (i) a high-performance sensor data-management system based on open-cloud platforms, (ii) sensor feeders that connect field sensor networks to the platform, (iii) a data integration engine that fuses and transforms heterogeneous raw data from various sources into coherent and actionable information (e.g., from individual readings to spatio-temporal maps), (iv) a standards-based sensor metadata library that stores and manages sensor metadata, and (v) a web-service interface that publishes the data and information according to open standards. This prototype is currently being developed will be promoted as a possible standard for Alberta’s future biodiversity and climate change monitoring starting in the next couple of years.

## **CONCLUSIONS**

Climate change is going to alter Alberta’s biodiversity and ecosystems. The three primary questions are: 1) how large an effect will this be; 2) how fast will the effects occur; and 3) what will people do about it? To make decisions in an informed manner about which species need help, how they can be helped, and when they needed to be helped requires monitoring. This report highlights some of the strengths and weaknesses of the ABMI monitoring system for tracking the effects of climate change on biodiversity. Having a comprehensive monitoring program like ABMI is a key element of helping Albertan’s understand the consequences of climate change and will be pivotal in making informed decisions that will allow Albertans to effectively adapt to climate change.

## ACKNOWLEDGEMENTS

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