Scientific support for assessing the vulnerability of Alberta's biodiversity to climate change

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Rationale: Biodiversity is a complex concept that has been defined in many ways by many different people. The challenge of describing and understanding the variety and variability of living organisms that make up Alberta's biodiversity is a fundamental part of the Alberta Biodiversity Monitoring Institute's mandate. To conserve biodiversity for the benefit of Albertan's requires a deep understanding of how species and ecosystem processes are being altered by human land-use action and climate change. The goal of the CCEMC biodiversity mapping project is to use the best available information to model, map, forecast, and understand how biodiversity will change over time. Specifically, we are working to develop the science require to document vulnerabilities of Alberta biodiversity to climate change and make recommendations for adaptations that could be used to minimize climate change impacts.

Report approach: The project is being developed in a series of phases, with each phase having key steps that must be completed for a species before progress can be made on the next step. Each phase is happening in parallel with the others with the goal being a synergistic coordination at the end via a coordinated vulnerability assessment database that documents the risks to various species and ecosystem processes caused by climate change. Recommendations will be made for each species as to what actions are required to mitigate risk. The system will be delivered as an online tool.

Phase I: General vulnerability assessment

As outlined in our **Framework for assessing the vulnerability of Alberta's biodiversity to climate change: First Quarterly Report** the first step in our assessment of climate change vulnerability for Alberta's biodiversity is the development of the CCVI (Climate Change Vulnerability Index). The CCVI is a decision support tool that relies on literature review to parameterize a series of questions. These questions were created by NatureServe and are converted to a vulnerability ranking based on expert opinion about the weight of each question and its potential to influence a species ability to deal with changing climate.

Since our last report we have made considerable progress in parameterizing species as part of the review process. This includes compilation of range maps and literature review for hundreds of species, as well as the development of a new online database tool that is being used by team members. The database is designed to integrate with our project website. A working version will soon be available for review.

CCVI is only a first step. For many of the questions posed by CCVI the answer is "Insufficient Evidence". More work is needed to address these knowledge gaps. In addition, it is not clear whether all of the right questions about risks to biodiversity from climate change are actually being considered.

A major goal of the **Biodiversity Mapping & Climate Change Project** is to develop "better data" to parameterize the CCVI for Alberta specifically. This will be done through development of more refined maps, habitat requirements, and developing mechanistic links between habitat and climate change. These types of models emphasize how long-term changes in average conditions may alter habitat suitability for Alberta's biodiversity. At the same time, increasing variability in weather conditions can be expected with climate change. Thus, we will also be putting effort into understanding how extremes in weather/ climate influence key ecological processes and species.

The steps associated with each of these phases should be viewed as improving the spatial and temporal resolution of predictions by increasing ecological realism. Model validation will be key, however, as increasing resolution will result in increasing model uncertainty. This needs to be explored and described to help better understand Alberta's biodiversity climate change threats and how best to adapt to climate change.

Phase II: Mapping biodiversity based on average changes in climate

Step 1: **Bioclimatic envelope modeling**

Species distribution modelling (SDM) is a rapidly developing field that relies on remotely sensed variables to predict where and when you might expect species to occur and/or be more abundant. A key first step in understanding how species will react to climate change is knowing how species are distributed relative to climatic variables. Such models are known as bioclimatic envelope models and describe the climate space that species currently occupy.

Assuming that a species is in equilibrium with its current climate space, having such information allows you to predict how that species might change in abundance or distribution as those conditions change. A key challenge of bioclimatic models is the domain over which the model is created. To understand what species might "leave" or "enter" Alberta under climate change projections requires an understanding of future climate conditions. Using Global Circulation Models (GCM) described in our last report, we are working on developing the range of climates and where they will exist in Alberta based on various emissions scenarios.

Understanding how species will react to such changes requires that we have data from places that currently have those climatic conditions. In some cases, such as the boreal forest of Alberta, the climate we have today may be replaced with the climate currently in Alberta's prairie. Alberta's prairie system, on the other hand, may see climatic conditions more representative of ecosystem further south in the United States like Montana. Thus, bioclimatic envelope modelling requires an understanding of where species are across a broader spatial scale (not just in Alberta).

To that end, we have been developing and coordinating datasets from various sources to model species distribution within and outside of Alberta's borders based on the climate space that we are likely to have in 2050 and 2080.

Below is a screen shot of a project from the Boreal Avian Modelling Project (www.borealbirds.ca) created by Dr. Erin Bayne and colleagues. Over the last several years this project has combined all known bird point count data into one data set for all of Canada and much of the Northern United States. In the last few months with the support of CCEMC we have predicted the distribution of several bird species birds across Canada and the northern United States as a function of climate. By December 2012, we will add additional species. These maps provide the core information to determine the relative suitability of climate for birds across the boreal and provide definitive range edge maps. Range edge maps used in the CCVI process in Phase I, are collated from a series of sources with highly variable accuracy. The maps on the BAM website are far more defendable as they rely on actual bird sightings and locations to derive range boundaries which are a fundamental part of the CCVI vulnerability ratings. These maps are now being used to reassess CCVI status for distribution.

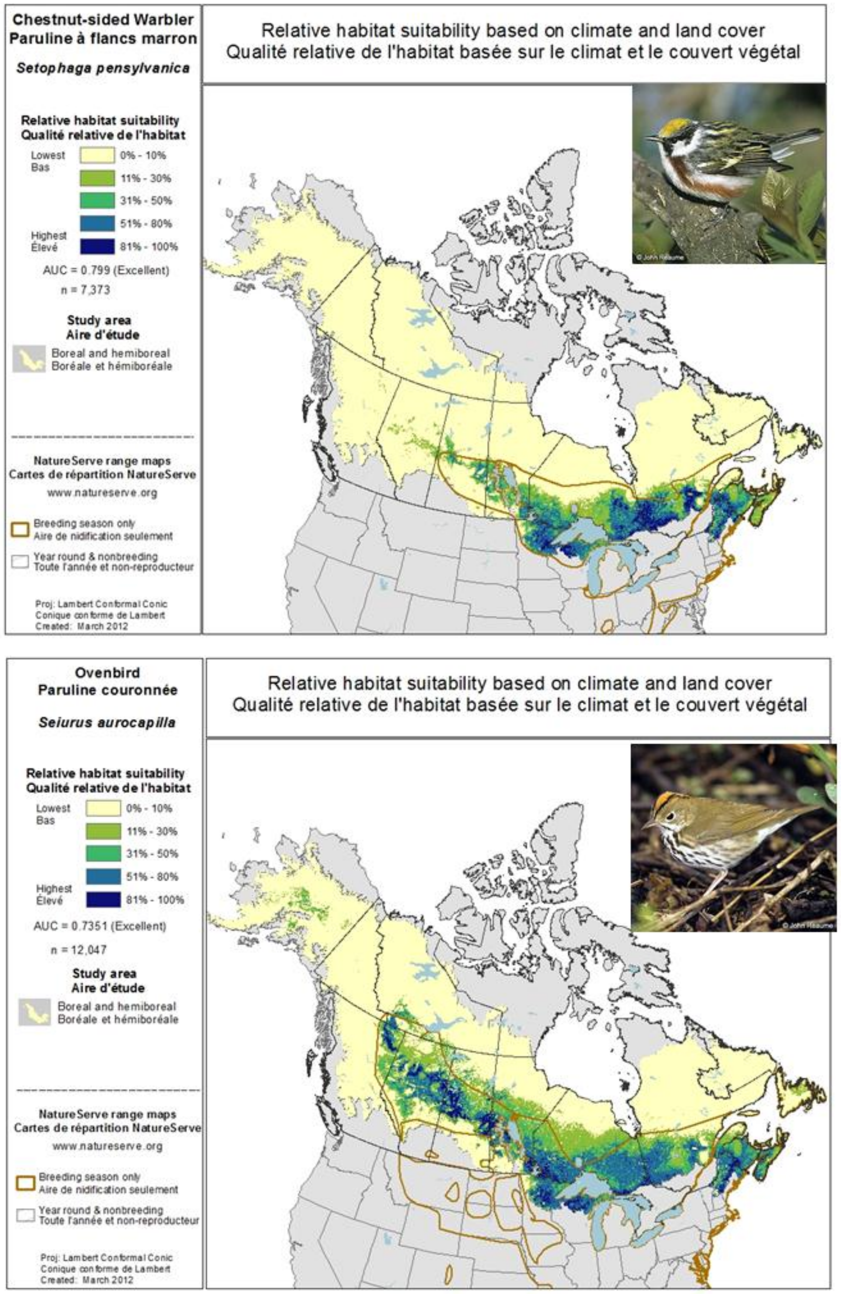

Figure 1. This map shows the predicted distribution of the (TOP) Chestnut-sided Warbler and (BOTTOM) OVENBIRD within Canada. Ranked categories of habitat suitability are presented. The maps were generated with Maxent models using data from the BAM avian dataset as well as BBS routes located in ecoregions that intersect the southern extent of the hemiboreal region. Chestnut-sided Warbler is an example of species whose range may increase into Alberta with climate change while Ovenbird is a species whose range may be forced into the far north. Bird photos by John Reaume, reproduced with permission through agreement with Boreal Avian Modelling project (www.borealbirds.ca).

Birds are probably the dataset that is most developed in this regard. We are working to create similar databases that include data within and outside of Alberta for vascular plants and where possible other taxa. The ABMI core dataset is an excellent resource for understanding how changes in climate will affect species transitioning from the Alberta prairie to boreal forest, but more information is needed from areas further south to understand prairie dynamics. We are still collating and looking for such information for the other groups.

The bird data that is available is from point counts, which means we also have abundance data (number of birds per unit area). However, for many other species modelling at this scale may rely on presence only data (points where species have been found only). In addition, getting a dataset of this scale and magnitude is a long-term investment and process. Thus, we are doing several projects to understand the predictive accuracy of bioclimatic envelope models for Alberta's birds and other taxa created using lower quality data of lesser spatial extent:
Specifically, we are assessing spatial scale (extent & resolution) for 'accurate' model creation by:

- Using ecoregions and small spatial planning units as "species" in climate envelope modelling to see where they will shift to

- Comparing the quality and accuracy of input data by comparing models created using presence-only vs. presence/absence vs. abundance models to see how much this influences predictions

- Evaluating which climate variables matter at varying spatial scales to determine how accurately climate models based on data solely derived from Alberta data can predict distribution and abundance

- Comparing results from different algorithms / techniques to understand how this influences our conclusions and deriving methods for determining which model(s) are most likely

For example, we are currently working on a manuscript that shows differences in modelled distribution of birds are as function of whether you use density or presence/ absence data. How to incorporate this uncertainty is a cutting edge aspect of species distribution modelling that we are working to advance.

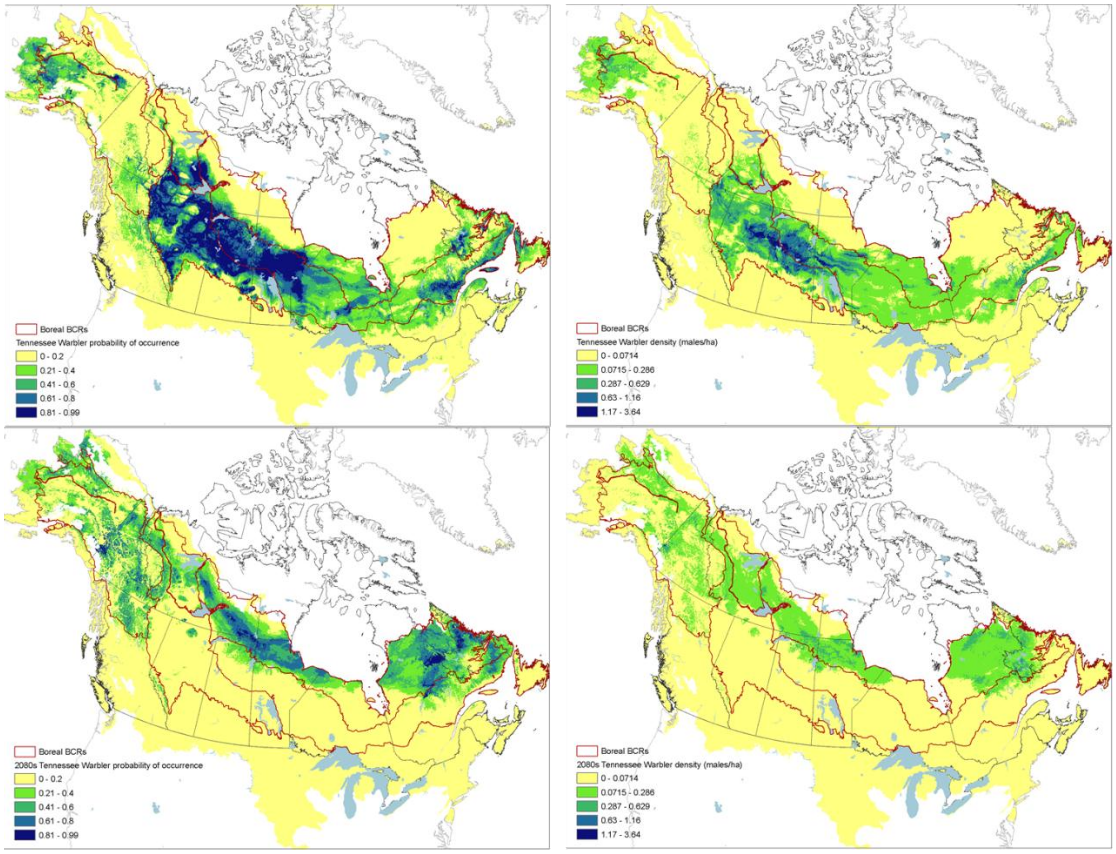

Figure 2. Distribution models (TOP) and future projections (BOTTOM) for Tennessee Warbler based on density (LEFT) and presence (RIGHT). Differences in where refugia can be identified are conditional on model selection and method.

***Step 2:* Understand & predict future climate using averages and extremes**

To forecast climate change you have to know what you expect to occur and range of possible conditions. As outlined in our previous report we have taken the approach of looking at multiple GCM models, excluding those that do not seem plausible. We then plan to take a consensus or weight of evidence of approach to document the most likely scenarios. To date most modelling of climate change has focused on understanding how different scenarios of human population growth/economics influence different GCMs in terms of average changes in temperature and precipitation. While more discussion is occurring with other CCEMC groups modelling climate change on specific scenarios, we have developed our base strategy as described the previous quarterly report.

What has not been addressed is how to model extreme weather events & their trends (past, present & future). Over the last several months we have worked to understand whether there have been trends in extreme weather in Alberta. We have coordinated a daily summertime storm map for all of prairie Canada showing where extreme events occurred each day. This will be used to examine how changes in extreme events result in changes in nest failure and bird mortality (see Step 4). Specifically, we have looked at whether there is any evidence of more extreme precipitation during the breeding season for Burrowing Owls. Thus far, there is no evidence that the size of storms is changing in the Alberta portion of the prairie provinces. We are currently analyzing whether the frequency or timing of storms is changing.

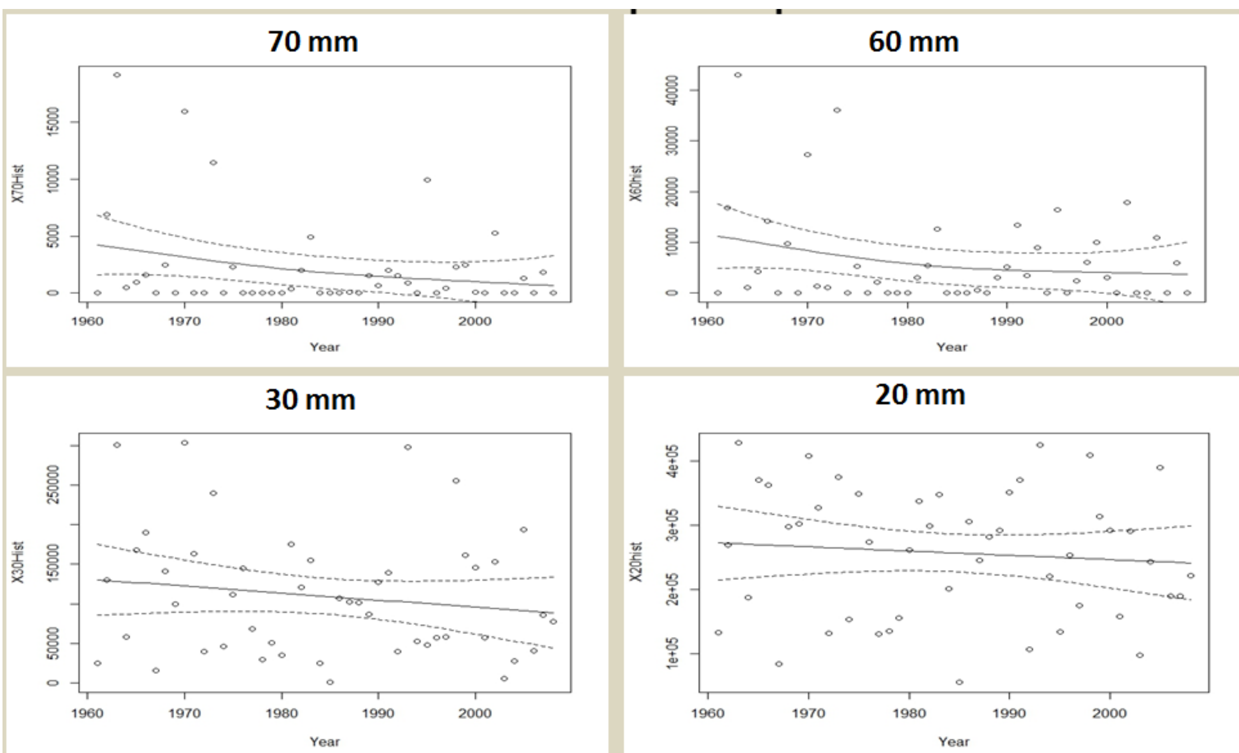

Figure 3. Area over which storms with 24 hour precipitation greater than the reported threshold (20, 30, 60, and 70mm) occurred since 1960. We are currently waiting to get data from past 2010.

Step 3: **Future predicted distribution of biota**

Using the models created in step 1 and the projections developed in step 2, the next step will be to forecast where species are likely to be as climate shifts spatially across North America. This approach is common in the literature and assumes:

- Niche associated with climate is in equilibrium
- There are no dispersal limitations for the species
- The habitat elements required by the species move with the shift in climate space
- Relationships with other species are not altered
- Key ecosystem processes are static (e.g., fire and other major processes do not change)

To date we have forecasted changes in a few bird species across Canada's boreal forest based on shifts in climate alone. These models are being finalized and will be used to aid CCVI estimates of vulnerability.

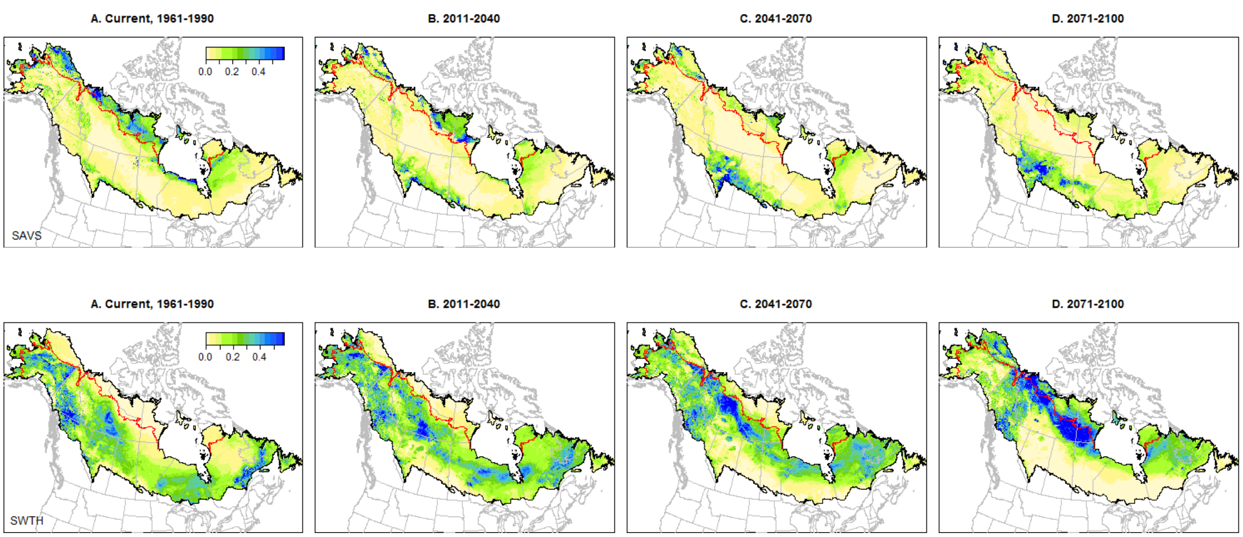

Figure 4. Spatial distribution of (TOP) Savannah Sparrow and (BOTTOM) Swainson's Thrush across Canada. Savannah Sparrow is a species that prefers grassland or tundra environments. In Alberta, expansion of climate conditions that result in grassland ecosystems are expected to increase and the species is predicted to expand its range into the boreal forest. Swainson's Thrush is a forest specialist. Over time the climate space currently occupied by this species will shift almost entirely out of the province of Alberta.

Step 4: **Linking species biology to inter-annual variation in weather extremes**

Long-term changes in average conditions will alter habitat suitability for many species but the changes will be "relatively gradual". For some species with small population sizes, a more significant concern will be the immediate impact to their persistence caused by catastrophic failure induced by weather extremes. Using existing and new datasets, we are looking at how extreme weather events affect several endangered species.

- We are finishing a research paper that evaluates the effects of extreme rainfall on Burrowing Owl demography. We found that storm events > 20 mm in a 24 hour period negatively influenced the nesting success of Burrowing Owls because: A) some nests get flooded killing the whole brood; and 2) nests that do not flood have higher nestling mortality because of starvation. Several solutions present themselves to mitigate these effects, although we recognize that these precipitation events have not increased in frequency in recent time suggesting that this is a natural phenomenon. Predictions made by several climate models do, however, suggest that extreme events will become more common in the future. Mitigation strategies may therefore be required to increase reproductive success of a species already at risk because of agricultural land conversion.

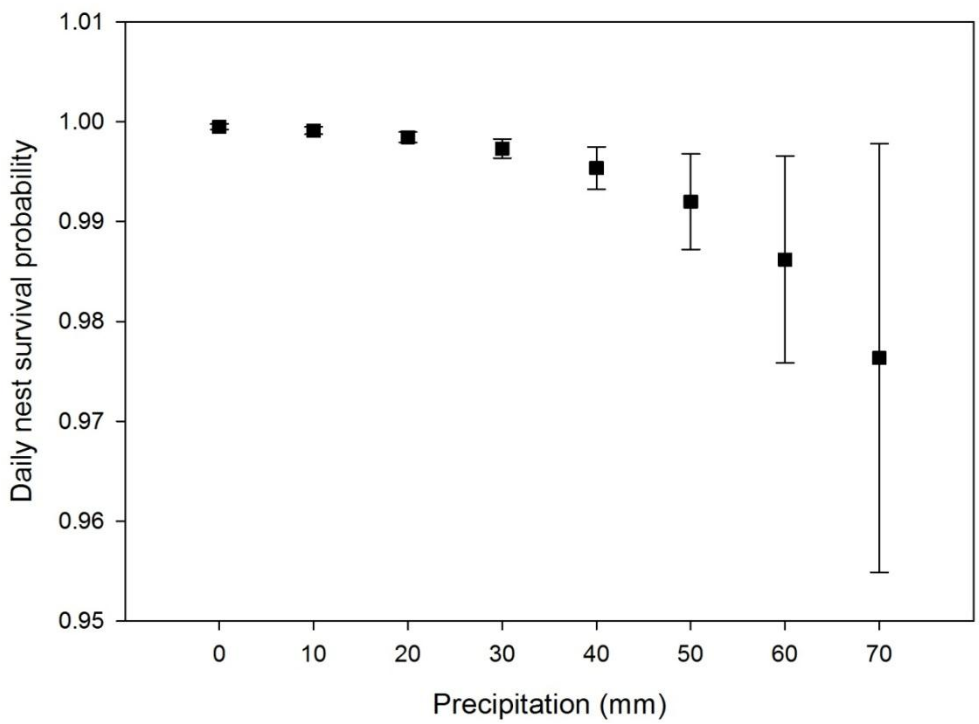

Figure 5. Daily nest survival probability of Burrowing Owls as a function of 24 hour precipitation.

- In the summer of 2012 we collected data from >400 Ferruginous Hawk nests (another threatened prairie raptor, Figure 6). We are still analyzing these data but have found that extreme wind events (threshold to be determined) resulted in loss of nests because of tree damage or due to nests blowing out of trees. We are currently evaluating wind trends and nest structure attributes to determine what options exist to minimize this effect. Specifically, we are looking at whether age of nest tree, health, and among others density of trees around a nest influence failure rates in order to determine which nest types are most stable in high winds.

Figure 6. Ferruginous Hawk nest in isolated tree in Canadian prairie. Numerous historical nest trees that have been present for decades were destroyed in 2011 – 2012 by wind. Picture by Janet Ng with permission

Phase III: Evaluating assumptions and limitations of bioclimatic envelope modelling

In Phase II – Step 3 we identified a number of assumptions behind the bioclimatic approach to understanding the future predicted distribution of biota. Many of these assumptions have not been tested and require considerably more research to understand the potential impacts of climate change on biodiversity. As we develop the CCVI and bioclimatic modelling approaches we will gain a better understanding of which species are most sensitive, but this will also require more explicit testing of the underlying assumptions behind these approaches. We are therefore trying to understand complexities in biodiversity responses including dispersal limitations, species interactions, time lags, and other key ecological processes. This phase will begin in 2013 and adapt over as we identify key uncertainties. Using field data we will:

- Identify general dispersal rates & limitations & develop a simulation approach to incorporate lags in dispersal rates using GIS simulations. This will be done by literature review and experimentation of modeling techniques in the field.

- If organisms migrate at the velocity of climate change can they successfully establish? As part of our experiments in phase V we plan to determine the ability of several plants to establish outside their current climate space. By studying competition and regeneration niches for some model species we will get a better idea of the frequency with which colonization occurs.

- While average conditions may change dramatically over time, there is the potential for local climate refugia that maintain conditions that allow the persistence of specific habitats. For example, north facing slopes in valleys may be crucial important microenvironments for the persistence of particular species of trees. Understanding the value of such areas for biodiversity and how their micro-climate differs from the dominant landforms is important. In the summer of 2012, we conducted point count surveys for birds and rare plant surveys in areas of steep terrain in the boreal forest with different moisture regimes than the surrounding area to evaluate the importance of these habitat conditions for biodiversity. In future years, we plan to study in detail microclimate conditions in such areas.

- Most climate change predictions assume that the only adaptation that will take place is likely to be via migration to new areas. However, *in situ* adaptation is possible for some species, particularly with assisted migration. We are currently examining possible experimental ways of testing for adaptation within plants.

- The information we have on birds allows us to predict distribution and abundance well. One thing that is missing from our current models is timing back from migration. In other systems, timing mismatches between birds arriving on the breeding grounds and various other ecological processes (peak insect emergence, timing of nesting to avoid predation, etc.) may be important. We are putting together data from banding stations and long-term population studies on swallows and bluebirds in Alberta to see if we can find any evidence for such patterns.

- All of the bioclimatic envelope models require that species track changes in climate perfectly. While birds can easily migrate in response to climate whether they will do so is unclear because they will only migrate if the vegetation they require is present. Models that track changes in birds that focus on how they react to changes in vegetation rather than climate per se will be created. Essentially this will use changes in vegetation age, structure, and composition as predictors of birds rather than a change in climate. By modelling tree dynamics as a function of climate rather than bird dynamics as a function of climate we will identify the importance of time lags for birds.

- Invasion by non-native species because of changes in climate has the potential to alter numerous ecological processes. Non-native earthworms have been expanding in Alberta, mainly because of changes in human land-use and to a lesser albeit poorly understood effects of climate. The implications of earthworm invasions on climate change mitigation in Alberta are however profound. Earthworms alter carbon storage and sequestration rates. In some areas, invasion of earthworms has switched forested systems from being carbon sinks to carbon sources. We are building from past investigations on spatial simulation models of earthworms (Figure 7) to determine what implications earthworm invasions of Alberta's boreal forests will have for carbon storage and how this will be changed by warming soil temperatures.

Figure 7. Current modelling distribution of invasive earthworms in ALPAC FMA of NE Alberta (LEFT) and predicted distribution based on rates of spread and introduction in 50 years (RIGHT). Spatial model will be adapted to show changes in carbon storage capabilities.

- Changes in fire regimes are one of the key ways that vegetation is likely to change in the face of climate change. Age, structure, and composition of forest are key attributes that are influenced by fire and thus, need to be included when simulating/projecting changes in biodiversity. We are developing partnerships with other researchers within the CCEMC program (forestry adaptation) as well as people working on fire dynamics at the Canadian Forestry Centre to incorporate these new dynamics in our predictions of risk to biodiversity caused by climate change.

Phase IV: Using what we learn to help Alberta's biodiversity adapt to climate change

Step 1: Explicit recommendations for adaptation actions (immediate vulnerabilities and future vulnerabilities)

- Prioritize species (what species are likely to be most affected)
  - For threatened and endangered species which actions could be taken in the next decade to ensure persistence
  - Ensure that actions taken in the short term are likely to have sufficient benefits that the species will have appropriate environment for persistence further into the future

- Prioritize places (including connectivity for future migrations)
  - Identify climate refugia at different scales to determine the efficacy of Alberta's park system and other land uses to protect biodiversity.

- Develop recommendations that identify those areas of the landscape required to ensure connectivity among these regions.

Step 2*:* Re-parameterize CCVI for AB context and species using explicit species-habitat predictions / models (rather than range maps)

The CCVI system is one approach to assessing risk that utilizes existing information. The main point of the additional science is to provide Alberta-specific information for CCVI that allows more specific recommendations to be made because of the Alberta context.

Step 3: How effective will current monitoring systems be for detecting change?

- Currently, the Alberta Biodiversity Monitoring Institute provides the most extensive information on tracking large-scale shifts in biodiversity caused by climate change. As models of rates of change are developed we will test how effective ABMI will track such changes based on known sampling variance. This type of analysis will allow us to make recommendations on addition sampling that could be added to ABMI to maximize its effectiveness in monitoring climate change impacts

- Specifically we will be evaluating how timing of biotic measures due to phenology/timing might need to be adapted in ABMI to fully track climate change

Step 4: How & when should policy adapt to changes/stressors?

In some cases, our results may clearly show that the range of a species is likely going to shift out of the province of Alberta or dramatically within Alberta. If this is the case, then we argue that a discussion is needed to determine whether many of our current legal instruments for dealing with endangered species will apply. Political boundaries may mean very in the face of extreme climate change and as such we may require a new discussion about what should be done. Areas we will examine will include discussions of:

- Static vs. dynamic protected areas & the importance of corridors.

- Legislative revisions for shifting species concepts whereby species may be persisting but not in Alberta (i.e. if they are doing well in NWT, what should Alberta do?).

- Policy of invasive species. What does invasive really mean when all species may be shifting their range to adapt to the new norms? How do we define invasive and is control / prevention an actual possibility?

- If Albertan's are serious about climate change adaptation, then discussion of new policy instruments will be required to allow ecologists to move species around. What would such a policy look like and how would it be permitted?

Phase V: Helping threatened species immediately

Step 1: All of the research above assesses risk. Numerous species of animals are currently at risk of extirpation in Alberta because of land-use changes and possibly recent climate change. We will use the information we obtain in the phases described above to design adaptive management experiments to test the feasibility of adaptation strategies that involve protecting individual species. Examples might include but are not limited to:

- Nest structure enhancements for Ferruginous Hawks to deal with extreme wind and precipitation.
- Facilitate burrowing owl recovery through food & nest supplementation.
- Assisted migration for dispersal-limited species like plants.