

Introduction

The International Panel on Climate Change (IPCC 2007) estimates that 20-30% of animals and plants will be at risk of extinction if temperatures rise 1.5° to 2.5° C above current conditions (i.e., 1980 to 1999 baseline). While translating global estimates to the provincial scale is problematic, BC's average annual temperature could rise 1.5° C within the next 30 years, and seems likely to exceed this level by the 2050s.¹ With the impact of climate change expected to be concentrated at higher latitudes and altitudes (Root et al. 2003, Chen et al. 2011, Lurgi et al. 2012a), British Columbia wildlife populations will likely come under increasing amounts of stress. Projected rates of climate change have no analog in Earth's recent history (last 50 million years; Chapter 2a), creating high uncertainty about the capacity for species to adapt and presenting a major ecosystem and wildlife management challenge.

It is anticipated that British Columbia will have an increasing role to play in the conservation of wildlife at the continental and global level. A common pattern of range change is for species to shrink to the edge of their range (Channel and Lomolino 2000a, Parmesan et al. 1999). In North America, species' ranges typically collapse from the east to the west and from the south to the north. This pattern has been seen for ungulates and carnivores (Figure 1) and is increasingly being seen for other species (e.g. Figure 2). It is anticipated that this trend will accelerate under climate change as species and ecosystems move north, are driven upward in elevation, or are able to persist only where they can move to cooler aspects. Because of our geographic position in North America, our mountainous terrain, and a series of north-south system of valleys and mountains, British Columbia likely holds the best chance for the long-term adaptation and survival of many wildlife species. This has been recognized as a driver in the setting of British Columbia's conservation goals (e.g. Conservation Framework; Bunnell et al. 2009a), however additional effort is needed to ensure goals are implemented (Auditor General of BC. 2013).

British Columbia already has more species of conservation concern than any other province or territory in Canada. Climate change is anticipated to provide both opportunity and pressure for species in BC. Opportunity will come with increased potential habitats for species that are currently restricted to small ecosystems but that may have the potential to expand under new climates. For example, grass, sage, antelope-bush and Garry oak dominated communities are rich in species at risk and are systems that, with careful management, may expand under climate change. Attention to landscape planning (e.g., creating corridors, reducing fragmentation from urban and agricultural use, minimizing the spread of alien species) will be necessary to take advantage of this opportunity.

¹ Plan2Adapt <http://www.plan2adapt.ca/tools/planners?pr=0&ts=8&toy=16>, accessed July 17, 2013

Risk assessments for wildlife are already taking into account the increased frequency and intensity of disturbance events that are forecast under most climate change scenarios (winter storm intensity, fires, insect and disease outbreaks; Ayres and Lombardero 2000, Hawkes et al. 2005, Carroll et al. 2006). Potential climate change effects are not restricted to species of concern, however. An increasing number of widespread and formerly common species are declining at a rate that will result in further “at risk” designations (Thomas et al. 2004). With the role of climate change in species declines becoming clearer (e.g., key ecosystem processes becoming uncoupled; Rosenzweig et al. 2008), we can expect the number of species at risk to increase, posing a significant ethical challenge and economic cost to the Province. Because landscape diversity in British Columbia will likely mean that there are more options for these species in the face of climate change than in many other jurisdictions, British Columbia can expect an increased international scrutiny of, and higher expectations for, species management. Maintaining our social licence to capture economic benefits from forest and range ecosystems may depend upon our ability to demonstrate internationally that the Province is making management of terrestrial wildlife a high priority.

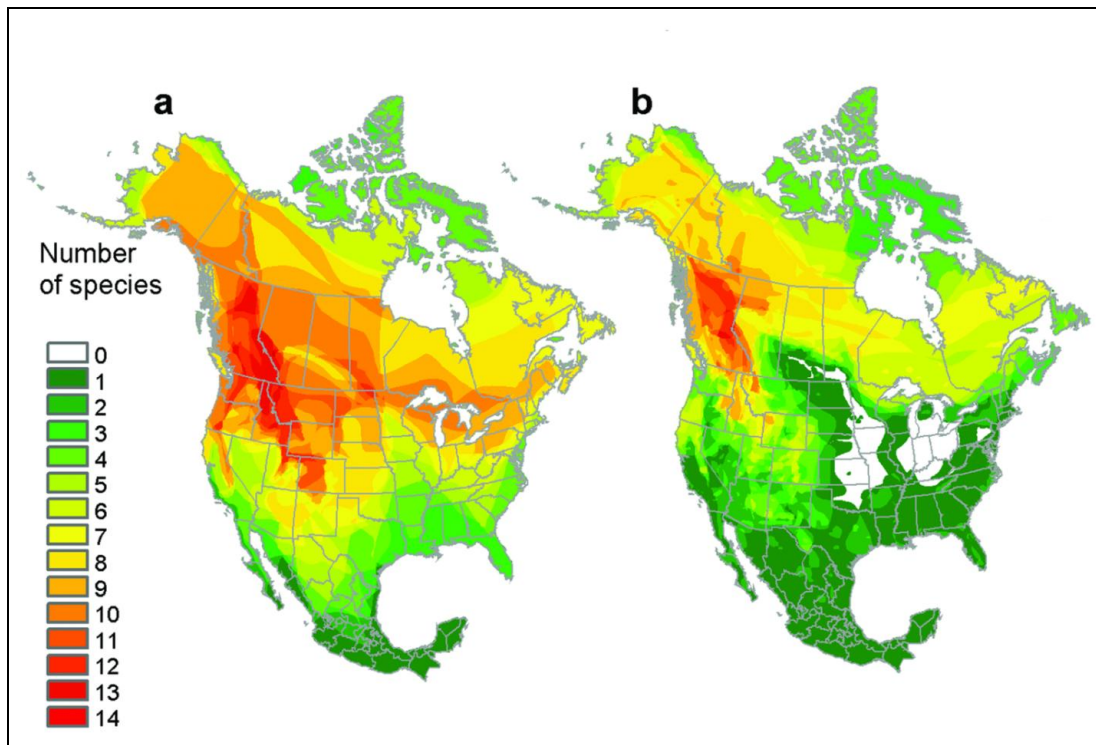
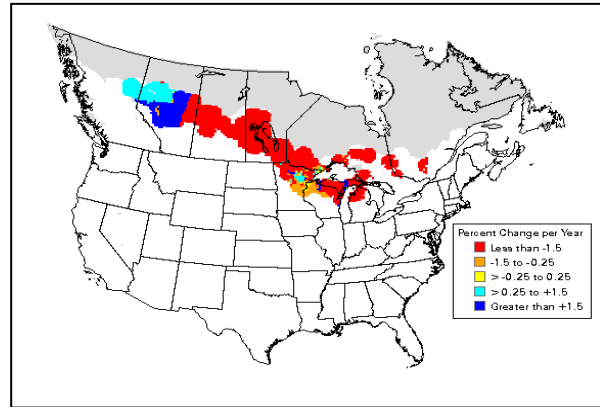


Figure 1. Species richness of ungulates and carnivores at the time of human contact (left) and currently (right) (Laliberte and Ripple 2004).

Fig.2. Trend pattern for Canada Warbler. If current trends continue, the center of abundance for Canada Warbler will be in northern Alberta and northern British Columbia. The species has also expanded into the southern Yukon in the last few decades. COSEWIC listed Canada Warbler as a threatened species in 2007. Map generated by the USGS Breeding Bird Survey, 2006.



Climate Change and Terrestrial Wildlife

The impact of climate change on British Columbia wildlife varies depending on species, their range, plasticity, adaptability and ability to disperse. Today's species evolved to tolerate past climates, including weather extremes and the range of climate-driven natural disturbance. They evolved without substantial human influence. For example, woodland caribou (*Rangifer tarandus caribou*) evolved in environments subject to extensive natural disturbances (Johnson and Rowe 1975). In the past when habitat was affected by landscape-scale disturbance, caribou would find alternative habitat. In the current environment, however, human activities limit the availability of alternative habitat for caribou (NCTAC 2004), hence reducing their flexibility to respond to widespread habitat alteration.

Although it is uncertain how species will respond to future climate, there is evidence of how wildlife has responded to the previous half-century of 0.6° C warming (McCarty 2001, Walther et al. 2002, Parmesan and Yohe 2003, Root et al. 2003, IPCC 2007). The observed and expected response of wildlife to climate change can be categorized as change in: 1) phenology, 2) species range and distribution, 3) habitat availability, and 4) population dynamics and wildlife community structure.

Phenology

In general, wildlife species are adapted to a wide range of climatic conditions and have persisted under historic variability driven by climate oscillations, such as the Pacific Decadal Oscillation (PDO) and El Niño/Southern Oscillation (ENSO) (Stenseth et al. 2002). Despite their adaptability, wildlife species suffer periodic weather-related mortality due to extreme events like cold winter temperatures, high snow accumulation or summer drought (Epps et al. 2004). Further, the reproductive success and population recruitment of wildlife are impacted by the weather driven production of food crops, as illustrated by the favourable grizzly bear (*Ursus arctos horribilis*) response to years with good huckleberry crops (McLellan and Hovey 1995).

Wildlife species employ a variety of timing mechanisms to compensate for seasonal variation in the availability of food and climatic conditions - termed phenology. For example, shifts in the arrival and departure times of some migratory birds have been observed in British Columbia (Bunnell et al. 2009b). Parmesan and Yohe (2003) concluded that recent shifts in phenology, including earlier frog breeding, bird nesting, and arrival of migrant birds and butterflies, match trends expected with climate change.

Although these shifts may not compromise the viability of some wildlife populations, there are cases where the timing of life history events becomes uncoupled, undermining reproductive success (Menzel et al. 2006). For example, by synchronizing migration with warming on breeding grounds, birds, such as wood warblers (Parulidae), are able to arrive when caterpillars, their preferred prey, are available (Strode 2003). Due to recent warming, caterpillar activity now occurs earlier and the warbler misses its optimal foraging opportunity because migration to its breeding ground is based on non-climatic photoperiod cues (Strode 2003). In addition, life history strategies can become compromised for species that hibernate or den to conserve energy over the winter and time their emergence with warmer spring air temperatures. For example, Inouye et al. (2000) found that yellow-bellied marmots (*Marmota flaviventris*) in the Rocky Mountains emerge 38 days earlier than in 1976, likely due to warmer air temperature, however with increased snow accumulation attributed to climate change, the ground is still covered, limiting forage opportunities and stressing the marmots.

To compensate for short- and long-term variation in climatic conditions, species may exhibit phenotypic plasticity by modifying their behaviour, such as breeding earlier to match food availability. As well, they may be able to genetically adapt, through microevolution selection, if the rate of climate change is slow enough to allow them to become better adapted to novel conditions. Studies of the North American red squirrel (*Tamiasciurus hudsonicus*) in the Yukon (Réale et al. 2003) have documented both phenotypical adaptation and microevolution genetic selection resulting from climate change. In response to warmer spring temperature the squirrels advanced their breeding by 18 days over 10 years, with most of this advancement due to a plastic response to increased food abundance. However, they also documented a microevolutionary response, with selection favouring earlier breeders (Réale et al. 2003).

The predicted increase in extreme weather events for British Columbia (Hamann and Wang 2006, Wang et al. 2012) will result in increased wildlife mortality (Thibault and Brown 2008). Root et al. (2003) concluded that with warming over the past 50 years there has already been significant changes in phenology and that future predicted temperature increases would impact wildlife by further disrupting the synchronicity between seasonal cues. The ability for species to adapt their seasonal timing in the future will be highly dependent on the rate of climate change and on the species' plasticity. Generalist species will be better suited to future change than specialists (Menendez et al. 2006, Lurgi et al. 2012b).

Range and Distribution

A wildlife species' range is the geographic area where it occurs and it is dependent on a suitable climate envelope (the range of temperature and precipitation that a species can physiologically tolerate), the availability of habitat, and historical occupancy. A poleward and altitudinal shift in a variety of taxa has been observed in the 20th century and these changes are consistent with the observed shifts in climate envelopes (Hughes 2000, McCarty 2001, Hickling et al. 2006). Species are expected to follow future climate envelope migrations depending upon their ability to disperse and resource availability (Walther et al. 2002, Duckworth 2008). In British Columbia, range shifts have been documented for some species of birds (Bunnell et al. 2009b). Globally, contraction of climatically-suitable range is projected to cause extinction for a range of taxa (Thomas et al. 2004). As well, climate change is contributing to increased

exposure to pathogens (Pounds et al. 2006) and there is growing evidence that climate-driven changes in wildlife distribution and health are having direct impacts on humans (Haines et al. 2006).

There is some criticism of predicting shifts in species' range in response to climate change. Davis et al. (1998) note that climate change studies commonly ignore population dynamics and the influence and interactions among species. Variation in range shift among species and interactions with community and population dynamics are likely to result in novel community structures that do not have any contemporary analog, with population loss in the southern part of a species' range likely to occur due to interactions with competitors and invasive exotics (McCarty 2001). Furthermore, models predicting a species' range shift under a future climate can also be misleading. Peterson et al. (2002) identified three alternative assumptions of species' future range occupancy that substantially influence model results: 1) universal dispersal, where species will occupy all of their potential future range; 2) contiguous dispersal, where species will only occupy areas adjacent to their current range; and 3) no dispersal, where species will only occupy their future range where it overlaps with their current range. Other modelling efforts evaluating the impact of changing climate suggest that species, such as white-tailed deer (*Odocoileus virginianus*), elk (*Cervus canadensis*), Columbian ground squirrel (*Spermophilus columbianus*), and chipmunk (*Tamias striatus*), may be more limited by availability of habitat than by thermal constraints (Johnston and Schmitz 1997).

Habitat Availability

A wildlife species' habitat is the physical environment within its range where it can access resource requirements such as cover and food. Present habitat availability is a product of current conditions and the historic landscape processes that govern the frequency, spatial extent and severity of landscape scale disturbances. In the past, individuals responded to natural disturbances by dispersing to new habitat within their range subject to their level of mobility, inter- and intra-specific competition and predation. Under climate change the rate of disturbance is expected to increase in British Columbia (Ayres and Lombardero 2000, Hawkes et al. 2005, Carroll et al. 2006). For many species this will result in loss of habitat and subsequent increases in mortality from disruptions in food supply and increased exposure to predators. Along with other drivers of environmental change – land use change, pollution and invasive species – climate change is a dominant agent shifting habitat occupancy (Bunnell et al. 2011, Carroll 2007, Sala et al. 2000).

A legacy of past human activities on the landscape has led to the loss, degradation and fragmentation of wildlife habitat. Human responses to increased natural disturbance (e.g., salvage harvesting) have added additional stress to wildlife, affecting their ability to adapt to climate change. These anthropogenic fast drivers of change have an immediate and profound effect on wildlife and they mask the slower, climate-change driven landscape alterations that impact availability of wildlife habitat, such as the northerly migration of vegetation and changes in landscape structure (Parmesan and Yohe 2003). For example, salvage harvesting following disturbances, such as the current mountain pine beetle (*Dendroctonus ponderosae*; MPB) outbreak in central British Columbia, negatively impacts old seral dependent species like woodland caribou by aggravating habitat loss (Bunnell et al. 2004). Human settlement, development, and agriculture could also further encroach on existing wilderness areas. The IPCC (2007)

indicates that northern latitudes may support improved crop yields. This could result in the conversion of currently marginal growing sites in northern British Columbia to agriculture, further constraining wildlife habitat.

Population Dynamics and Community Structure

Wildlife population dynamics will be impacted by changes in the availability and quality of habitat that result from climate change. For example, the spatial effects of climate change influence the functioning of metapopulations (Epps et al. 2004). A metapopulation, a collection of interacting local populations of the same species, occurs naturally due to landscape heterogeneity and through the loss and fragmentation of habitat (Levins 1969). Sub-populations within a metapopulation may become unviable or extirpated due to a variety of factors, such as localized landscape disturbance resulting in habitat loss, short-term habitat degradation due to an extreme weather event, or a local population becoming diseased. At a later time when the habitat becomes favourable, these unoccupied areas can be re-colonized by dispersers from other sub-populations (Levins 1969). This “rescue” effect is only viable if the intervening habitat is favourable to dispersers. From a conservation stand point, if this intervening habitat has become fragmented or degraded due to human activities and climate driven increases in disturbance, it will effectively block the capacity of the metapopulation to rescue extirpated local populations or to colonize newly available range resulting from climate change (Opdam and Wascher 2004).

The spatial effects of climate change can also cause a shift in the distribution and availability of high quality habitat within a species’ range. High quality habitat can act as a population “source” that produces migrants that disperse to other parts of a species’ range. Alternatively, lower quality habitat may act as a population “sink” where individuals may reproduce, but the population recruitment rate will not be enough to maintain the population. A species’ population is maximized when there is a minimum of sink habitat (Pulliam and Danielson 1991). If a significant portion of wildlife habitat becomes degraded due to the cumulative effects of climate change and anthropogenic land use, the landscape may be dominated by sink habitat, leading to a population decline even though habitat is available.

Altered landscape structure and pattern resulting from climate change interacting with human and other pressures can have long-term impacts on community structure by causing a slow shift in predator-prey relationships (Parmesan 2006). For example, woodland caribou populations become more heavily depredated by wolves (*Canis lupus*) when wolf numbers increase following a post-disturbance increase in moose (*Alces alces*), their primary prey (Seip and Cichowski 1996). As well, Post et al. (1999) described a link between climate change and ecosystem function. The wolves of Isle Royale changed their pack behaviour in response to increases in winter snow resulting from climatic variability (North Atlantic Oscillation). By forming larger packs in high snow years the wolves were able to kill three times as many moose per day compared with low snow years. This resulted in an increase in the growth of balsam fir (*Abies balsamea*) understory due to the decline of moose browse. Further, Post and Forchhammer (2001) studied the temporal dynamics between balsam fir, moose and wolves and found that the community could be affected through climate change by disrupting the dynamics and stability of trophic levels.

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