Climate Change Impacts on Biological Systems

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Abstract: Climate change includes changes in long-term average climate, in year-to-year climate variability, and in frequency and severity of extreme events. A substantial number of observational and experimental studies have found evidence that the 0.6°C warming in average global temperature during the 20th century has affected physical and biological processes. In British Columbia, changes in climate may be linked to observed changes in sea surface temperature, growing degree days, and hydrology, and with changes in seabird, mountain pine beetle (*Dendroctonus ponderosa*), and sockeye salmon (*Oncorhynchus nerka*) populations. Climate scenarios project global temperature increases in the range of 1.4–5.8°C by 2100. Both the degree and the rate of warming are of concern. Future impacts of climate change on biodiversity and species at risk will be additional to the impacts of other processes such as habitat loss. The Intergovernmental Panel on Climate Change concluded in its Third Assessment Report that "while there is little evidence to suggest that climate change will slow species losses, there is evidence it may increase species losses". For many species at risk, climate change will increase vulnerability to extinction, although for a few it will relieve pressure. Species most vulnerable to extinction are those with limited climatic ranges, geographically restricted habitats, small populations, climate-sensitive traits, and slow dispersal rates. Biodiversity managers have a number of options to ensure that natural systems are able to adapt to climate change to the limits of their capabilities.

Key Words: climate change, impacts, biodiversity, adaptation options

Historic Climate Trends and Impacts on Biological Systems

Climate change includes changes in any or all of the elements of the climate system, including

- surface air, land, water, and ice temperatures;
- water content of air, clouds, snow, and ice;
- wind and ocean currents;
- atmospheric pressure, density, and composition;
- ocean temperature, pressure, density, and salinity; and
- physical processes such as precipitation and evaporation.

Climate change manifests as changes in long-term average climate, in year-to-year climate variability, and in frequency and severity of extreme events such as drought, flooding, heat waves, and severe storms. Small changes in average temperature or in climate variability can cause a large change in the frequency of temperature extremes. Climate change may also include potentially irreversible threshold events, such as rapid changes in ocean circulation patterns (Working Group II 2001).

The Intergovernmental Panel on Climate Change (Gitay et al. 2001) states that “climate is the major factor controlling the global patterns of vegetation structure, productivity, and plant and animal species composition” and that “changes in mean, extremes, and climate variability determine the impacts of climate change on ecosystems”. A substantial number of observational and experimental studies have found evidence that the 0.6°C warming in average global temperature during the 20th century has affected physical and biological processes.

Parmesan and Yohe (2003) looked for a climate change signal in more than 1700 species. In 279 species, they found “significant range shifts averaging 6.1 km per decade towards the poles (or meters per decade upwards in altitude), and significant mean advancement of spring events by 2.3 days per decade”. They concluded with “very high confidence” that climate change is already affecting living systems, and that small persistent forces such as the changes observed in climate “can alter species interactions, de-stabilize communities, and drive major biome shifts”.

Root et al. (2003) reviewed data from 143 studies and found that more than 80% of species or populations studied showed patterns of change consistent with climate warming. They concluded that the balance of evidence “strongly suggests a significant impact of global warming is already discernible in animal and plant populations”.

Climate change can affect biological systems and organisms either directly or indirectly. Change in temperature or precipitation can produce physiological stress and phenological changes in organisms, which can lead to changes in species abundance and, ultimately, in ecosystems. In addition, climate change affects sea level, hydrology, natural ecosystem disturbance patterns, and other physical factors, and regional changes in these factors affect biological systems.

Historic Climate Trends in British Columbia and Related Biophysical Impacts

British Columbia (B.C.) is a leader in documenting 20th century climate trends and associated impacts on biophysical systems within the province. This work is based on observational data from each provincial ecoprovince—an area delineated by similar climate, topography, and geological history.

The ‘signal’ of long-term climate change occurs against the ‘noise’ of natural climate variability. In British Columbia, such variability includes the El Niño Southern Oscillation, which has a two- to seven-year cycle, and the Pacific Decadal Oscillation, which has a 50- to 60-year cycle. To detect a climate or biophysical trend, and to attribute it with some confidence to climate change, requires an observation record that spans these natural cycles, or requires reliable proxy data.

From 1895 to 1995, average annual temperatures in British Columbia warmed by 0.6°C at the coast, 1.1°C in the interior, and 1.7°C in the north. Between 1929 and 1998, precipitation increased in southern B.C. by 2–4% per decade (B.C. MWLAP 2002). These climate changes may be linked to observed changes in sea surface temperature (SST), growing degree days, and hydrology in the province, and with changes in seabird, mountain pine beetle (*Dendroctonus ponderosa*), and sockeye salmon (*Oncorhynchus nerka*) populations.

From 1914 to 2001, SST along the British Columbia coast increased by 0.9–1.8°C (B.C. MWLAP 2002). SST warming may be responsible for an observed decline in southern populations of Cassin's auklet (*Ptychoramphus aleuticus*). Copepods, a type of marine crustacean, are a primary food source for auklet chicks. In years of relatively warm SST, copepods emerge, grow to adult size, and return to deeper water earlier in the season than normal. In cooler years, the timing of copepod emergence corresponds more closely with that of chick hatching. SST warming thus reduces the food supply for chicks, and hence, their viability (Bertram 2001).

During the 20^{th} century, minimum air temperatures in B.C. increased by 0.9°C at the coast, 1.3–1.7°C in the interior, and 2.1°C in the north. Growing degree days, a measure of the heat energy available for plant and insect growth, increased by 5–13% during the past century (B.C. MWLAP 2002). Warmer winters and longer growing seasons are associated with the current outbreak of the mountain pine beetle in British Columbia. This species overwinters in its larval stage. In the early larval stage, larvae are vulnerable to cold winter temperatures, while in the late larval stage they can withstand temperatures close to -40°C. With a longer growing season, more larvae reach the late larval stage before winter sets in, and with fewer cold winters, more survive through to the following year (Carroll et al. 2002).

The limited observational record suggests that between 1935 and 2000, snow depth and snow water content decreased in some parts of British Columbia. Between 1945 and 1993, lakes and rivers throughout B.C. became free of ice earlier in the spring (B.C. MWLAP 2001). These trends are consistent with global trends, and are associated with changes in hydrology. The Fraser River discharges more of its total annual flow earlier in the year (Morrison 2001). Similar patterns have been documented for other snowmelt-dominated systems in B.C. and the Pacific Northwest (Mote 2003). Higher flows in spring and early summer are associated with water turbulence and scouring. Lower flows in late summer and early fall are associated with declining water quality and higher water temperatures, which pose a threat to cold-water fish. Warm-water years are linked to lower reproductive success in sockeye salmon; southern stocks may be vulnerable to long-term warming (Macdonald and Grout 2001).

Projections of Future Climate Change and Species-level Impacts

The Intergovernmental Panel on Climate Change (Houghton et al. 2001) projects global temperature increases in the range of 1.4–5.8°C by 2100; however, there are many sources of uncertainty regarding the rate of future warming. Among these is the level that future greenhouse gas emissions will attain.

The impacts of climate change on biodiversity and species at risk will be additional to the impacts of other processes such as habitat loss. The general conclusions of the Intergovernmental Panel on Climate Change (Gitay et al. 2002) are that “while there is little evidence to suggest that climate change will slow species losses, there is evidence it may increase species losses”.

Projections of climate change impacts on biodiversity are based on two paradigms of how ecosystems will respond. One paradigm assumes that ecosystems will migrate relatively intact to new locations where the climate and environment is similar to their historic location. Most studies of global and regional impacts use this ‘ecosystem movement’ approach to identify potential climate refugia and areas where the potential for disruption is high under various future climate scenarios. This paradigm assumes that climate is the primary determinant of species distribution, and that the distribution of a species will shift as its climate-space shifts. The paradigm’s limitation is that it does not take into account the different climate tolerances, life spans, reproductive strategies, and migration abilities of individual species (Gitay et al. 2001).

The other paradigm assumes that as climate and related systems change, there will be *in situ* changes in species composition and dominance, and that ecosystem types that are quite different from those we see today will emerge. This ‘ecosystem modification’ paradigm is supported by paleo-ecological data which show that ecosystems both similar to and different from those present today existed in the past. This paradigm is difficult to apply, however, because there is limited information about the current distribution of individual species, and limited understanding of how species interact (Gitay et al. 2001). For example, a species’ distribution may reflect the source/sink and competition dynamics of a location rather than its climate (Davis et al. 1998).

Species respond to climate change through changes in physiology (e.g., the rate of photosynthetic activity), phenology (e.g., the timing of bud appearance, flowering, leaf sprouting, and leaf fall in plants, and of reproduction, migration, and moulting in animals), relative abundance and distribution, and population size and demographics. The Intergovernmental Panel on Climate Change (Gitay et al. 2001) suggests that changes in phenology will occur in many species; habitats of many species will move towards the poles or upwards in altitude; biological communities are unlikely to shift together; and ecosystems dominated by long-lived species will tend to be slow to show evidence of change and to recover from climate-related stresses.

For many species at risk, climate change will increase their vulnerability to extinction, although for a few, it will relieve pressure. Species most vulnerable to extinction are those which have some or all of the following characteristics:

- limited climatic ranges;

- requirements for habitats that are geographically restricted (e.g., alpine habitats or native grasslands);
- patchy habitats;
- small populations;
- climate-sensitive physiological traits such as temperature-dependent sex determination; and
- slow dispersal rates (Gitay et al. 2002).

The impacts of climate change, relative to other threats to biodiversity, will vary from one region to another (Gitay et al. 2002).

The risks of adverse impacts increase with the magnitude of climate change. Some highly sensitive species and ecosystems are likely to be affected by warming of less than 1°C. Warming of 1–2°C would result in more numerous and more serious impacts. The greater the warming, the higher the probability that critical thresholds would be surpassed (Gitay et al. 2001).

The threat to biodiversity also increases with the rate of climate change. Even the most moderate rate of global warming projected for the 21st century is faster than that observed during the 20th century (Houghton et al. 2001). Future shifts in species ranges may exceed the capacity of some endangered and vulnerable species to migrate to more favorable locations (Schneider and Sarukham 2001).

Although climate models and scenarios for British Columbia are still under development, global results project that average annual temperatures in western North America will increase by 1–4°C by 2100, and minimum temperatures will continue to warm faster than maximum temperatures. Average annual precipitation will increase by 10–20%. There will be more precipitation in winter, and a greater proportion of that precipitation will fall as rain rather than as snow (Gitay et al. 2001). Snowmelt-dominated watersheds will continue to experience earlier peak flows and reductions in summer flow (Working Group II 2001). The climate British Columbia actually experiences will reflect regional differences, with the interior and north of the province likely continuing to warm faster than the coast.

Adaptation to Climate Change

An effective response to climate change requires both reduction in greenhouse gas emissions and adaptation. The 1992 United Nations Framework Convention of Climate Change states that atmospheric concentrations of greenhouse gases must be stabilized at a level to which ecosystems can naturally adapt. This level has not yet been defined. Global emissions of most greenhouse gases have continued to rise since 1992 (Houghton et al. 2001).

The goal for biodiversity managers is to ensure that natural systems, including species at risk, are able to respond to climate change to the limits of their capabilities. Adaptation options include

- establishing interconnected reserves (Gitay et al. 2001) including climate refugia that are likely to experience less change than other areas (Hansen and Biringer 2003);
- increasing local resilience by eliminating specific stressors (Hansen and Biringer 2003);
- incorporating biodiversity considerations into other adaptation strategies (Gitay et al. 2001);
- using active intervention such as assisted migration, breeding, and reintroduction of species, non-chemical control of pest or disease outbreaks, fire management, control of invasive species, and reduction in nutrient runoff into marine and freshwater ecosystems;
- using an adaptive management approach which incorporates new information; and
- conducting ongoing monitoring to ensure the effectiveness of management strategies (Hansen and Biringer 2003).

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