

Global weirding in British Columbia: Climate change and the habitat of terrestrial vertebrates

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Abstract

The authors summarize the distribution of terrestrial vertebrates of British Columbia across major habitat types and present empirical and projected effects of global weirding within two particularly vulnerable habitats—alpine and wetland. Global weirding embraces all phenomena associated with climate change: increases in average temperatures, heat waves, cold spells, floods, droughts, hurricanes, blizzards, plant and animal die-offs, population explosions, new animal migration patterns, plus dramatic regional differences. Current data suggest that many alpine species will be lost to changes in habitat wrought by climate, particularly increases in average temperatures. For many wetlands, particularly in the central and southern interior of the province, the basic issue is simple—the incoming water is decreasing and the outgoing water (evaporation) is increasing. The authors illustrate three approaches to projecting trends in wetland habitat, elaborating on the “drying index” approach, in which they have most confidence. For wetland species, they say management will struggle with the concept of a real-world triage—allocating conservation efforts where they are most likely to succeed and have the most benefit. They conclude that several conservation approaches for wetland species will face the difficulty of allocating water between needs of these species and of humans.

KEYWORDS: *alpine; British Columbia; climate change; global weirding; wetlands.*

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Introduction

Several writers (e.g., Friedman 2008; Bunnell 2009) have found the terms “global warming” and “climate change” insufficiently descriptive of the changes occurring to global environmental conditions. “Global warming” connotes something gradual, gentle, and almost soothing. “Climate change” is more complete but obscures the drama of what is likely to happen. “Global weirding” embraces all phenomena associated with climate change: increases in average temperatures, heat waves, cold spells, floods, droughts, hurricanes, blizzards, plant and animal die-offs, population explosions, new animal migration patterns, plus dramatic regional differences. It is unwise and unhelpful to be comfortable in the face of these changes. Although global warming communicates too little, global weirding may not be serious enough. *Weird* implies something bizarrely unexpected, supernatural, or very rare. There is nothing supernatural about climate change; the science is rather mundane. The science also is sound and predicts that events now weird and rare will become far more commonplace. *Weird* is appropriate simply because we are going where we have never been and some consequences are likely to be totally unexpected.

Analyses described in this article employ projected means of climate variables so do not encompass the erratic extremes that global weirding can generate. Nor do they evaluate consequences of the rugged topography of British Columbia that will create local departures from mean projections. Many of the weirder or more unexpected consequences of climate change for both plants and animals result from the responses of their pathogens to climate. These responses also are not addressed by our analyses. In this article we consider changes in mean climate variables and broad distributions of vertebrate habitat. Given the variability that cannot be satisfactorily addressed, what is likely to happen will be even more varied and weird than is presented.

Despite the variety of global weirding, consequences derive primarily from two weather variables—temperature and precipitation—along with their amounts and timing. Individual weather events may cause direct mortality to vertebrates (e.g., cold, wet springs; prolonged snowpack), but the largest and most pervasive effects of climate change are indirect, acting on habitat availability and suitability. Within British Columbia, grasslands and steppe lands appear destined to increase. Forests are likely to diminish in extent, and their species composition

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will shift, but only subalpine and boreal forests appear significantly threatened (see Hamann and Wang 2006; Soja et al. 2007; Tchebakova et al. 2009). Two very different habitat types are particularly vulnerable to global weirding: alpine and wetlands.

We report the distribution of native terrestrial vertebrates across major habitat types and present empirical and projected effects of global weirding for the two most vulnerable types—alpine and wetlands. We emphasize relative vulnerability because that helps to focus conservation efforts where they are most likely to be effective. Alpine is considered province-wide; wetlands examples are from the Central and Southern Interior ecoprovinces.

Vertebrates of British Columbia and their habitats

At least 282 native bird species breed every year in British Columbia (records of the Biodiversity Centre of Wildlife Studies, Victoria, B.C.). The total number of mammal species breeding in the province is unclear, because it is contentious whether one or two species of *Phenacomys* are present in British Columbia (Nagorsen 2005). We have assumed one, yielding a total of 106 terrestrial mammal species. Reptiles and amphibians contribute 33 species. The BC Conservation Data Centre considers the pygmy short-horned lizard (*Phrynosoma douglasii*) extirpated, but there is recent evidence it may still be present (Ryder et al. 2006). We included it in our tallies. Table 1 summarizes major breeding habitats for these species. Species often breed in more than one habitat. We chose the habitat type that literature suggests is most favoured within the

TABLE 1. Major breeding habitats of terrestrial vertebrates in British Columbia

Breeding habitat	Amphibians	Reptiles	Birds	Mammals	Total
Grasslands/meadows	0	3	16	15	34
Shrublands	0	3	14	3	20
Forests	4	4	118	59	185
Subalpine/alpine	0	0	15	12	27
Freshwater/riparian	16	3	79	14	112
Agriculture	0	0	10	3	13
Urban plus rural	0	0	11	0	11
Marine environs	0	0	19	0	19
Total	20	13	282	106	421

province. Distinction between riparian and forest is particularly fuzzy; species such as the Yellow Warbler (*Dendroica petechia*) often seek riparian sites but will breed in upland forests. In Table 1, birds using forested riparian areas are tallied under forests.

Most terrestrial species breed in forested or freshwater/riparian habitats (Table 1). For some groups, a larger portion favour freshwater/riparian sites. For example, about 90 species of damselflies and dragonflies reside in the province—all of them restricted to wetlands or riparian habitat during breeding.

What goes up can't come down

The global Millennium Ecosystem Assessment (2005a) defines ecosystem services as “the benefits people obtain from ecosystems.” For subalpine or alpine areas, the assessment recognizes three groups of services provided to lowland and highland communities. “Provisioning” services include extractive resources that primarily benefit lowland populations (water for drinking, irrigation, and power production; sometimes timber) and ecosystem production (agricultural and livestock production, pharmaceuticals, and medicinal plants). “Regulating and supporting” services include biodiversity, watershed protection and landslide prevention, climate modulation, and soil as a storage reservoir for water and carbon. “Cultural” services include the spiritual role of mountains, biodiversity, recreation, and cultural and ethnological diversity. Mountains play a key role in the water cycle, by influencing the regional climate and by altering the runoff regime.

Because most habitat loss has been generated by human activities, historic loss has been largely restricted

to lower elevations. However, the time when habitat at higher elevations conferred some immunity to loss has passed. As rugged as it is, little of British Columbia is very high. The province covers about 98.5 million ha (surface not plan area). Figure 1a reveals that most of this area is in the range of 700–1500 m amsl (above mean sea level); only about 14 million ha are above 1600 m amsl, the approximate average lower boundary of alpine in British Columbia (Figure 1b).

Most range maps for species do not consider elevation. They are derived as minimum convex polygons drawn to encompass all known, inferred, or projected sites of occurrence. It is possible that no species is found throughout a range delineated by a minimum convex polygon. Despite the slope of the terrain, actual ranges of species restricted to a particular elevation band are invariably smaller than map projections. This is particularly important because small range size is the single best predictor of extinction risk for terrestrial species (Manne et al. 1999; Harris and Pimm 2007). Figure 1b reveals how limiting confinement to upper elevations can be.

Trends in habitat

All organisms have a temperature range in which they do best and that also limits their occurrence. For a variety of reasons, alpine species of Table 1 prefer environments with cooler temperatures. Generally, temperature decreases with increasing elevation; as the climate warms, the lower boundary of any elevation band of favourable habitat must retreat higher. The International Civil Aviation Organization defines an international standard atmosphere with a temperature lapse rate of 6.49°C per 1000 m; that is, for every

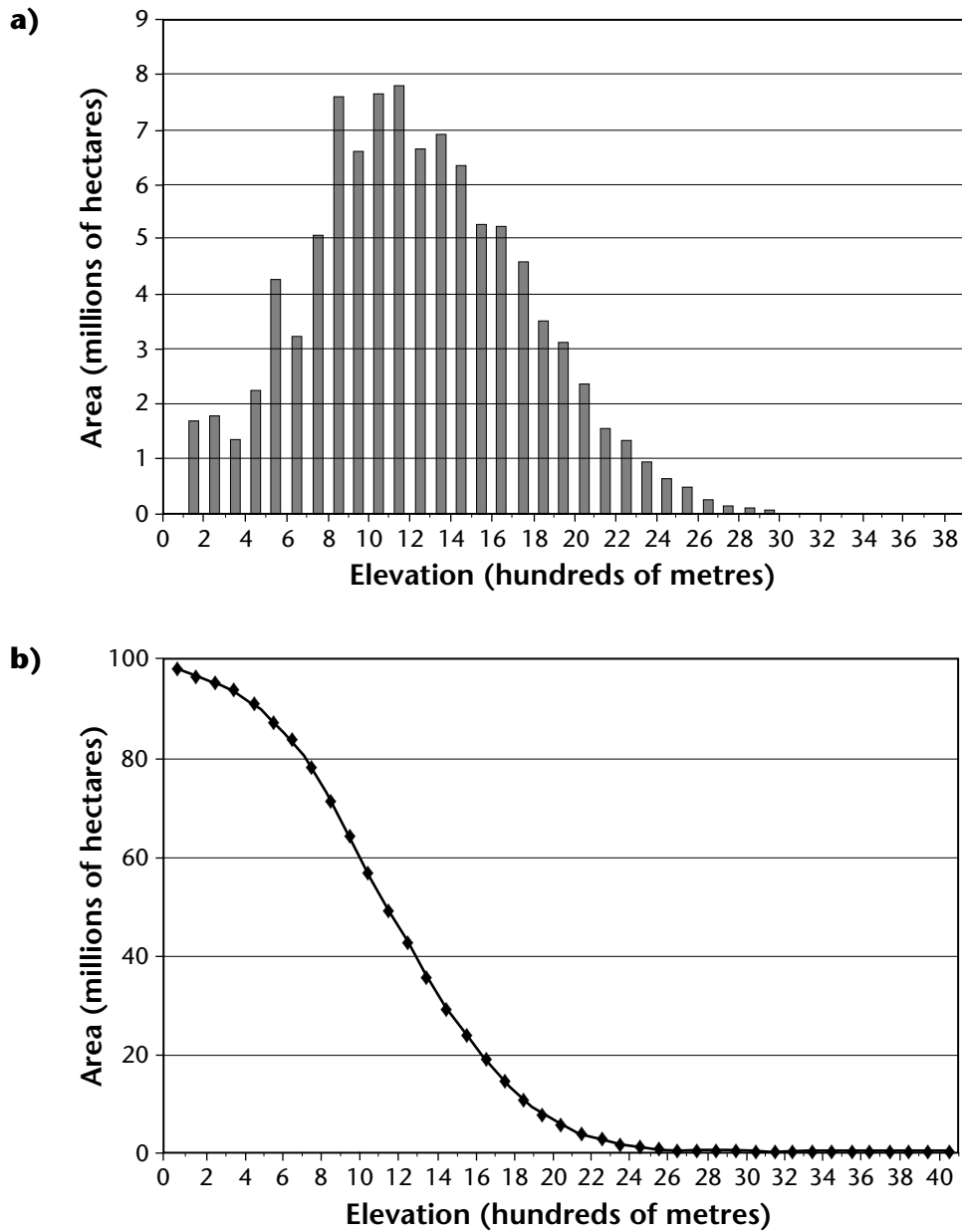


FIGURE 1. Habitat and elevation in British Columbia: (a) total surface area per 100 m elevation band; and (b) cumulative surface area above specific elevations.

1000 m of elevation gain, the air cools by 6.49°C. This rate varies somewhat with dry or moist air masses and there can be short-lived temperature inversions; we use the standard rate. Suppose we could limit the increase in Earth’s atmospheric temperature to 2°C. The 2009 G8 meeting almost agreed upon a limit of 2°C, but this limit was opposed by the Canadian government, which favoured a 3°C increase in global temperature. A 2°C increase in atmospheric temperature means

that to attain the same environmental conditions, a subalpine or alpine species must move up about 310 m (2.0/6.49 km). Figure 1b illustrates that one consequence of this temperature increase is a dramatic decrease in habitat. There is no sleight of hand—these are simple, physical relationships. The physical simplicity of this relationship led to the “rapture hypothesis” (Nash 2010).

Briefly, the rapture hypothesis notes that plants and animals attempt to escape rising temperatures by

migrating upwards until they can go no further, after which they vanish into the ether and are not seen again. Fortunately, reality is not as simple as that (see section “Adapting to global weirding”). Nonetheless, the hypothesis contains a strong element of truth.

When climate models are used to project the area of alpine tundra in British Columbia, the outcomes are troubling. The Intergovernmental Panel on Climate Change (IPCC) acknowledges the uncertainty in projecting climate by using 23 different global circulation models and a number of scenarios. Nature, of course, is under no obligation to follow any of the models. Using five global circulation models and a range of scenarios, Nogués-Bravo et al. (2007) found that the rate of warming in mountain systems is projected to be two to three times higher than that recorded during the 20th century. Higher latitudes, such as British Columbia, show the greatest increase in temperature.

Projections of individual climate variables for different global circulation models and scenarios are found on the ClimateWNA website.¹ Current projections using CGCM2 and the A2X scenario suggest that within four decades about 80% of the alpine tundra will be lost from British Columbia. CGCM2 is the second version of the Coupled General Global Circulation Model of the Canadian Centre for Climate Modelling and Analysis; A2X is the average of A2 scenarios, under which nations do not spring into action to control greenhouse gas emissions. Some of the projections by the IPCC would produce less favourable responses; others would produce more favourable responses. The CGCM2 projection suggests that within four decades alpine tundra will disappear from almost all provincial mountains other than in northwestern British Columbia, near Alaska.²

Given that scenario A2X is a mean of optimistic and pessimistic conditions under the assumption that little is done to reduce emissions, this projection appears startling. Simple geometry indicates it is entirely reasonable. If mountains were perfect cones with a slope of 30°, the “upslope” area lost would be 12.57 square units for every unit of increase in elevation from the base of the cone. The area lost would be only 7.26 units if the slope of the cone

were 60°. Our mountains are not perfect cones, but the prevailing slopes represent a significant loss in area as the elevation of suitable habitat increases.

Vulnerable species

No consistent elevation distinguishes subalpine from alpine. The distinction varies between coastal and more inland sites and from south to north throughout the province. For this reason, Table 1 groups species as subalpine/alpine. Whatever the regional elevation limit, species largely restricted to alpine communities will suffer the greatest reduction in area. As the number of scattered areas high enough to support alpine tundra declines, favourable sites also will become more scattered and isolated. Birds are the most mobile vertebrates and will be least affected by the increased isolation. The major consequence to them will be a dramatic reduction in area of suitable habitat, thus reduced population size and increased risk of extinction. Alpine plants and mammals are less fortunate; they cannot flit from peak to peak. Moreover, for many of these species lower elevations are hostile.

Table 1 indicates that 27 terrestrial vertebrates in the subalpine and alpine areas of the province will be negatively affected by a simple increase in temperature. Only birds and mammals consistently seek subalpine/alpine areas as breeding sites. Some populations of the coastal tailed frog (*Ascaphus truei*) seek out alpine regions but others breed lower down, and the species is designated freshwater/riparian in Table 1. Examples of subalpine/alpine species include the Rock Ptarmigan (*Lagopus muta*), Gyrfalcon (*Falco rusticolus*), and American Pipit (*Anthus rubescens*) among birds, and the tundra shrew (*Sorex tundrensis*), marmots (*Marmota vancouverensis* and *M. caligata*), and thinhorn sheep (*Ovis dalli*) among mammals. The number of species is small in a global context. Relatively conservative projections of climate change and the consequences of elevation estimate that globally 400–550 species of land birds will be extinct by 2050; they further estimated that 97% of the likelihood of extinction risk was accounted for by elevation (Sekercioglu et al. 2008). The authors invoke the “rapture hypothesis,” assuming species cannot adapt to the new climate.

1 Centre for Forest Conservation Genetics. n.d. ClimateWNA: A program to generate climate normal data for geneecology and climate change studies in western North America. Faculty of Forestry, University of British Columbia, Vancouver, B.C. <http://www.genetics.forestry.ubc.ca/cfcg/ClimateWNA/ClimateWNA.html> (Accessed August 2011).

2 http://www.geog.ubc.ca/courses/geog376/students/class07/bec_pred/ (Accessed June 2011; a project of University of British Columbia Geography students that is no longer posted).

Given the flexibility of species and the variety in nature, habitat designation in Table 1 is necessarily fuzzy. Figure 1 shows that suitable habitat begins to diminish quickly above 800 m amsl, the approximate lowest boundary of alpine in northwestern British Columbia. But there is flexibility within species and variation in preferred elevations across the latitudinal range of the province. The apparent option of more mobile species, such as birds, to move farther north within the province is limited. Although higher latitudes encourage a lower elevation band of favourable habitat, higher latitudes are precisely where global warming is greatest. It is more likely that species such as Rock Ptarmigan and the American Pipit will move into tundra, north of the province. Because the Gyrfalcon specializes in hunting ptarmigan, it is comforting to imagine those Gyrfalcon breeding in British Columbia also moving north. Unfortunately, the Gyrfalcon's nesting requirements for cliffs reduce its options. There is a further challenge to alpine nesting species moving into tundra to the north. Many of these species nest on the ground, and predators, such as the red fox (*Vulpes vulpes*), will follow.

The less mobile plants, some coastal tailed frog populations, and mammals will experience not only a significant reduction in area of favourable habitat but an increasingly isolated, patch-wise distribution of habitat within a hostile matrix. The coastal tailed frog seeks higher elevations in some areas primarily because it requires cool water; maximum water temperature of streams containing *Ascaphus* normally ranges from 10 to 16°C (review in Clausen 1973). The survival of *A. truei* on the coast likely depends on the duration of glaciers. The Rocky Mountain tailed frog (*A. montana*) breeds in mid-elevation forests of the southeastern interior and may have the opportunity to move upwards.

Among mammals, marmots are possibly in the greatest trouble. Their relatively sedentary nature leaves them ill-prepared to seek higher or more northerly mountain ranges. They also appear to be dying of weirdness and resultant confusion. Marmots tend to terminate hibernation based on temperature. Climate variables, however, are not changing synchronously. In parts of Colorado, yellow-bellied marmots (*Marmota flaviventris*) are emerging from hibernation, finding abundant forage, and growing in both body mass and numbers (Ozgul et al. 2010). In other parts of Colorado, the same species is in trouble. There they are emerging 38 days earlier to find the larder empty (Inouye et al. 2000). The plant growing season is not initiated by spring air temperature but by snowmelt that has not yet occurred when the marmots emerge.

The marmots are ready but the plants are not. The weirdness among climate variables may also lead to asynchrony between the arrival and food resources of migratory alpine birds, such as the American Pipit. Similarly, alpine plants may begin to grow in response to snowmelt when the danger of frost is still high.

Pikas do not hibernate but are uncommonly temperature sensitive. Because we often see them there, we typically think of pikas as subalpine/alpine species. In British Columbia, the range of the American pika (*Ochotona princeps*) currently extends from sea level (on the coast) to about 2500 m amsl; the collared pika (*Ochotona collaris*) extends from about 700 to 1200 m amsl. Limiting factors for pikas appear to be talus or other rock piles; they are not designated subalpine/alpine in Table 1. Although widely distributed, pikas appear to be responding to climate changes (see "Alpine habitats and species" in the section "Adapting to global weirding"). The wolverine is designated as subalpine/alpine in Table 1 because it frequently dens and breeds there. Research in the United States (Aubry et al. 2007) documents that the wolverine has been gradually declining as the snowpack has declined, and the authors suggest it has little option but to move north. The decline, however, began in the 1900s and appears to be largely due to human impact. V. Banci (pers. comm., May 7, 2010) believes wolverines choose higher elevations at which to den primarily to avoid disturbance. If this is true, they could survive in large, undisturbed forest areas at lower elevations.

Wetlands—going, going, gone

The provincial *Freshwater Atlas* (B.C. Ministry of Natural Resource Operations 2009) indicates that the province hosts about 760 000 water bodies, many of them wetlands. This number is known to be an underestimate, and the inventory is improving. Besides supporting many species (Table 1), wetlands provide an abundance of ecosystem services. The Millennium Ecosystem Assessment (2005b) notes that the range of ecosystem services delivered by wetlands is wide, including fish and fibre, water supply, water purification, climate regulation, flood regulation, coastal protection, recreational opportunities, and, increasingly, tourism. Basically, wetlands are a significant buffer in natural systems, absorbing water quickly and releasing it slowly and in a cleaner form.

As humans we made serious inroads into wetlands before global weirding was irrefutable. Most wetlands, and many of the more productive ones, occur in low-lying areas, where they are most exposed to

human activities. About 85% of the wetlands in both the south Okanagan and the Fraser River delta have been lost through channelling rivers, digging drainage, and building dykes (Austin et al. [editors] 2008). Projecting the additional impacts of climate on wetlands lacks the physical simplicity that governs impacts to alpine habitat. We illustrate three approaches to projecting trends in habitat, elaborating on the approach for which we have most confidence.

Biogeoclimatic zone climate envelopes

The approach illustrated for zonal climate envelopes (Figure 2) is analogous to that of Hamman and Wang (2006) for biogeoclimatic (BEC) zones and tree species. MacKenzie and Moran (2004) provide a classification of wetlands in British Columbia and their relative frequency within BEC zones. The future distribution of BEC zones was projected using ECHAM5 under IPCC scenario B1. ECHAM5 is the fifth generation

of a general circulation or climate projection model developed by the Max Planck Institute for Meteorology and the German Climate Computing Centre (DKRZ; see Roeckner et al. 2003). The B1 scenario describes a convergent world, with the global population peaking mid-century and declining thereafter but with rapid change in economic structures toward a service and information economy, with reductions in material use, and with the introduction of clean and resource-efficient technologies. Present trends suggest that this scenario is overly optimistic in terms of actual emissions reduction.

Given the projected climate, the probable future distribution of wetland types was calculated using the relative frequencies of specific wetland types within BEC zones from MacKenzie and Moran (2004). The method is coarse but illustrates the potential direction and magnitude of change. The example illustrated in Figure 2 is the great bulrush marsh, a widely spread type in BEC subzones with warm and

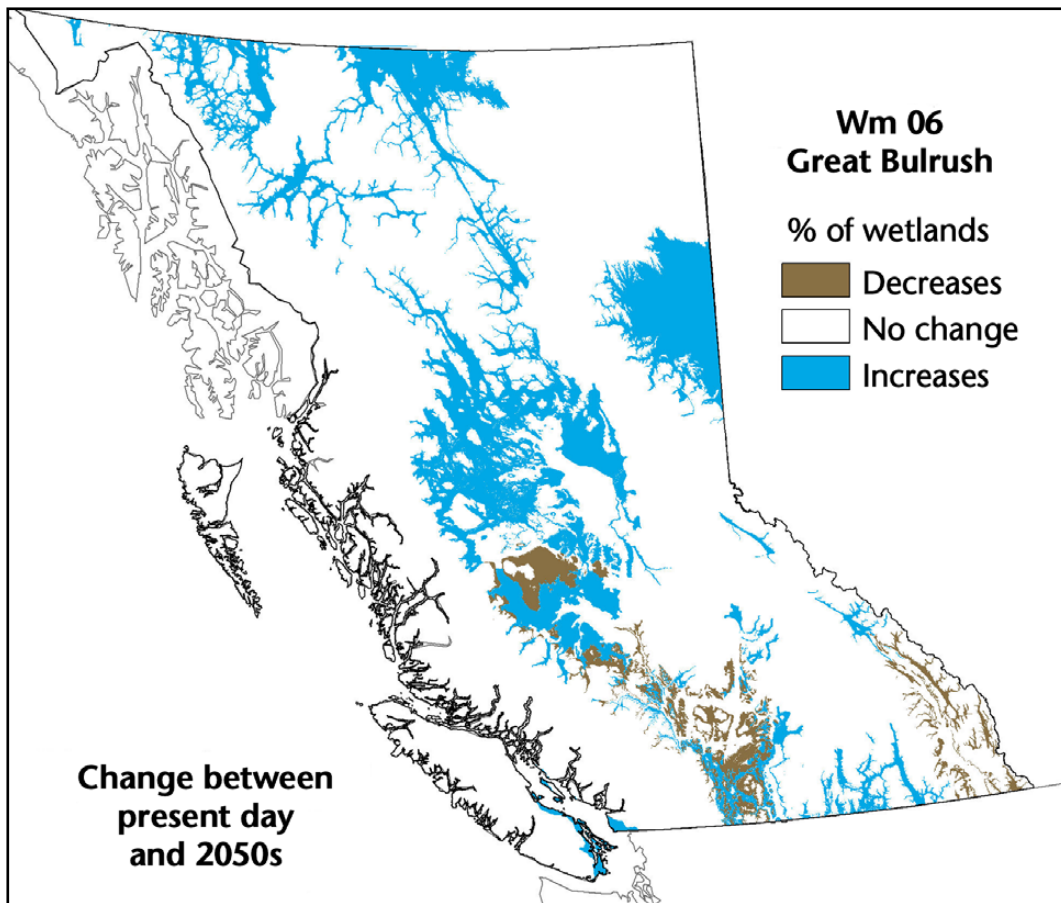


FIGURE 2. Projected changes in the relative distribution of the great bulrush marsh from the present to the 2050s, as projected by ECHAM5 under the B1 scenario of IPCC.

dry summers. This type of wetland is commonly used by amphibians, waterfowl, and other waterbirds.

The advantage of this approach to projecting trends in habitat is that it is relatively simple. But the method has significant disadvantages, primarily because wetlands are not simply a product of climate. One disadvantage is obvious in Figure 2. Only the declines in frequency of wetlands can be predicted with some accuracy; any potential expansion of a particular wetland type depends greatly on fine-scaled topography that creates potential receiving sites. Equally problematic is the fact that wetland types are a product of more than climate variables, including flow rate, nutrient levels, and pH, which are themselves a function of underlying geology. We conclude that this approach is reasonably accurate in predicting regions that will experience reductions in a particular wetland type. However, projecting the probable distribution of wetland types in the face of climate change requires considerably more kinds of data and data at a finer scale than are readily available.

Climate envelopes of wetland plants

Using plot data for individual wetlands, it would be possible to create empirical climate envelopes for wetland plants similar to those Hamman and Wang (2006) created for tree species. Given the number of site features than can influence the types of wetlands, we chose a simpler approach directed to expected trends. In their description of wetland types, MacKenzie and Moran (2004) report dominant species for each type. Kremsater and Bunnell (2010) collated literature on the relative response of these plant species to temperature (heat and cold tolerance) and drought (including rooting depth). For each major wetland type, they summarized the likely response of these species to climate trends. An abbreviated example for marsh plants is given in Table 2.

The advantage of this approach to projecting habitat trends is that it reveals the probable trajectories of plant species that give wetlands their specific character and determine the invertebrate and vertebrate species likely to be present. The major disadvantage is that it

TABLE 2. Probable responses of main marsh plant species to increased moisture stress and drying of marshes

Dominant marsh plants		
Common name	Scientific name	Response
Foxtail barley	<i>Hordeum jubatum</i>	↑
Common silverweed	<i>Potentilla anserina</i>	↑
Pacific water-parsley	<i>Oenanthe sarmentosa</i>	↓
Small bedstraw	<i>Galium trifidum</i>	↓
Swamp horsetail	<i>Equisetum fluviatile</i>	↓
Beaked sedge	<i>Carex utriculata</i>	↔
Water sedge	<i>Carex aquatilis</i>	↓
Awned sedge	<i>Carex atherodes</i>	↓
Common spike rush	<i>Eleocharis palustris</i>	↓
Common cattail	<i>Typha latifolia</i>	↔
Great bulrush	<i>Schoenoplectus acutus</i>	↓
Baltic rush	<i>Juncus balticus</i>	↓
Sitka sedge	<i>Carex sitchensis</i>	↓
Yellow pond-lily	<i>Nuphar lutea</i>	↓
Threeway sedge	<i>Dulichium arundinaceum</i>	↓

NOTE: Plants include only those ranked by MacKenzie and Moran (2004) as: “**Abundant:** occurs on most sites (> 60%), occasionally prominent on some sites (± 10%); **Very abundant:** occurs on nearly all sites (> 80%); prominent species (± 10%); and **Dominant:** occurs on all sites (> 95%); the most abundant species on most sites (> 25% cover).” Under the Response column, ↑ means the species will likely increase in abundance and distribution if wetland dries; ↔ indicates no likely change; and ↓ indicates a likely reduction in the species abundance and distribution within the wetland as drying occurs.

employs only climate. Specific wetland communities are equally a product of features such as flow rate, pH, and nutrient levels in the water. The approach is limited to establishing boundaries within which other environmental features will be influential. That can still be useful, for example, by focussing monitoring on areas most favourable to some invasive species.

Projecting drying indices

We have the most confidence in the following approach, which projects drying indices, for two reasons. First, it does not attempt to project the probable distribution of wetland types under different climate regimes; instead, it focusses on the likely future of existing wetlands. Second, we have been able to evaluate the accuracy of the approach empirically for wetlands of the Central and Southern Interior ecoprovinces (Bunnell et al. 2010a and 2010b). We present this approach in more detail.

Bunnell et al. (2010d) proposed a simple drying index applicable to moisture stress generally but specifically for wetlands. Two climate variables are employed: (1) annual precipitation as snow (PAS) and (2) summer heat-moisture index (SHM index). These variables were selected because they were expected to have the greatest effect on the water balance of wetlands. PAS was expected to provide a major water source for wetlands, whereas SHM provides an index of drying trends for wetlands.

- PAS is a direct measure of snow precipitation (mm) measured over the period between August in the previous year and July in the current year. Higher values of PAS represent greater input.
- SHM is generated by ClimateWNA using the equation $MWMT/(MSP/1000)$, where MWMT is the Mean Warmest Month Temperature (°C) and MSP is Mean Summer Precipitation (June through August, mm). The SHM index is a derived variable, used as a proxy for direct measures of humidity or evaporation and transpiration that usually are unavailable (Tuhkanen 1980). Higher values of the SHM index represent a stronger drying tendency (output) relative to lower values, due to less precipitation and (or) higher temperature.

Using unpublished data of the Canadian Wildlife Service, Bunnell et al. (2010b) evaluated these variables against measured water depths for 33 wetlands in the Central Interior Ecoprovince over a period of 11 years. They concluded that because extremes

of either variable influence drying, the simplest combination would allow inputs and outputs of moisture to have equal effect. The most appropriate form of the index is simple and multiplicative but inverses the rank of PAS when predicting drying:

$$\text{Drying index} = (\text{normalized SHM} \times \text{inverted normalized PAS})$$

Variables are normalized (0 to 1) to permit generality over broad areas. The index itself also is normalized from 0 to 1.

The large majority of water bodies in the *Freshwater Atlas* are small: 75.8% are less than 2 ha and 62.1% are less than 1 ha (Figure 3). From the perspective of waterbirds, many “lakes” share attributes of “wetlands” by having emergent vegetation sought by waterbirds, particularly at their margins. Where we did not have field observations, we arbitrarily classified water bodies as wetlands if they were less than 10 ha in size; that omits the largest water bodies having wetland attributes. Wetlands with measured depths ranged from 1.56 to 5.55 m in maximum recorded water depth and from 0.6 to 47.97 ha in size. Four key findings emerged from the work of Bunnell et al. (2010b, 2010d):

1. Wetland depth has a strong effect on the proportion of water lost from the wetland. Shallower wetlands lose a greater proportion of maximum potential depth. Because the gradient of most wetlands is shallow, the area of suitable habitat around shallow wetlands that is lost is disproportionately large.

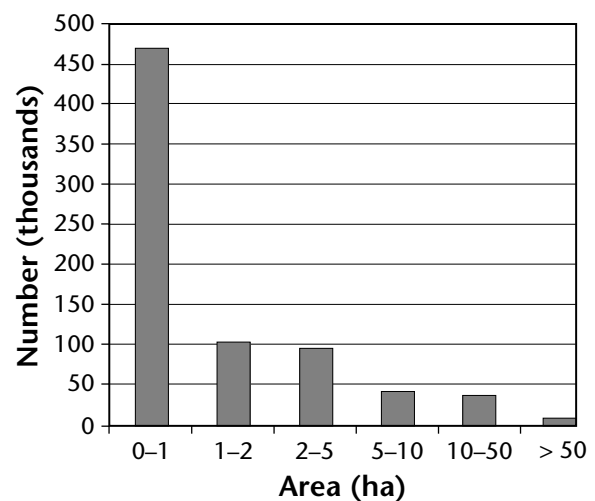


FIGURE 3. Size distribution of freshwater bodies in British Columbia (data from provincial *Freshwater Atlas*).

2. Among the study wetlands in the Central Interior Ecoprovince, wetland size was a useful correlate of wetland depth. Across the 33 wetlands, the relationship was as follows:

$$\text{Maximum depth (m)} = 1.85 + 0.11 \text{ Size (m/ha)}$$
adjusted $r^2 = 0.63$; $p < 0.001$
3. As the SHM index increased, water output increased and measured water levels declined. For the same increase in SHM, the decline was greater in wetlands less than 2 ha. Maximum summer temperature (a component of the SHM index) did not have any apparent influence on its own—it was the combined effect of summer heat and moisture that showed relationships with water level. That finding emphasizes the important role of summer drought.
4. The most productive wetlands were those less than 2 ha (Bunnell et al. 2010d). Productivity was measured as ducks per hectare, but the relationship is likely general for all waterbirds and many other organisms as well. Smaller wetlands generally are more shallow, with smaller volumes of water that permit greater warming. The warming, in turn, encourages greater primary and secondary productivity.

Bunnell et al. (2010b) could not effectively assess the role of snowfall because the elevation range of measured wetlands was only 50 m. It is noteworthy that significant reductions in snowfall between the 1970s and the measurement period (1997–2006) obscured potential influences of snowfall within the measured wetlands (Table 3). This observation reveals that inputs of water via snowmelt to wetlands below 1000 m in the study area have already become significantly reduced; projected climate variables suggest they will decline further.

Trends in weather with elevation during the measurement period (1997–2007) and the 1970s are

as expected, with the warmest summer temperature and SHM index at the lowest elevation and declining with increasing elevation, while snowfall increased with increasing elevation. When tested by one-way analysis of variance (ANOVA), climate variables did not differ significantly across the three elevation classes during either the measurement period or the 1970s, but the range in elevation was very small (Table 3). Despite wetter summers during the measurement period, the analyses imply that the empirical drying of the measured wetlands was primarily a function of summer drought, exacerbated by the decreasing snowpack, to the point where the SHM index was the dominant influence. At these elevations in the Central Interior Ecoprovince, summer drought is becoming increasingly important (see Figure 4). Scatter around the regression line indicates inter-annual variation in weather for particular wetlands; the long-term trend of decreasing water depth is significant ($p < 0.01$).

Some wetland types frequently dry out in a particular year, only to reappear the next year. Prolonged drying may change a seasonally wet wetland to one that is permanently dry or alter a formerly year-round wetland to a seasonal one or one that is completely dry in some years. The process appears to have begun in the measured wetlands of Riske Creek. Values of 0 in Figure 4 indicate no water and occur for two wetlands. In one case, 0 was first measured in 2002 and then repeatedly through the entire measurement period. Only wetlands less than 2 ha dried up during the measurement period. Unfortunately, these smaller wetlands are the most productive.

Wetlands in the Southern Interior Ecoprovince appear most at risk to drying. Figure 5 projects the drying index evaluated for Riske Creek wetlands in the Central Interior Ecoprovince to wetlands of the

TABLE 3. Mean annual values of selected climate variables over a 10-year sample period (1997–2006) and during the 1970s (1970–1979) for measured wetlands in three elevation classes, Riske Creek, B.C.

Elevation	N ^a	Mean warmest summer temperature (°C)		Snowfall (mm)		Summer heat-moisture Index	
		Sample	1970s	Sample	1970s	Sample	1970s
950–965 m	80	16.9	16.5	79.0	164.7	75.1	101.7
966–975 m	90	16.7	16.4	82.3	172.2	73.1	97.4
> 976 m	70	16.4	16.0	88.5	185.1	69.2	89.8
Range—all wetlands	240	14.5–20.4	11.9–19.4	49–138	77–412	31.3–151.2	31.6–189

^a N = number of measures for the elevation class (Bunnell et al. 2010b).

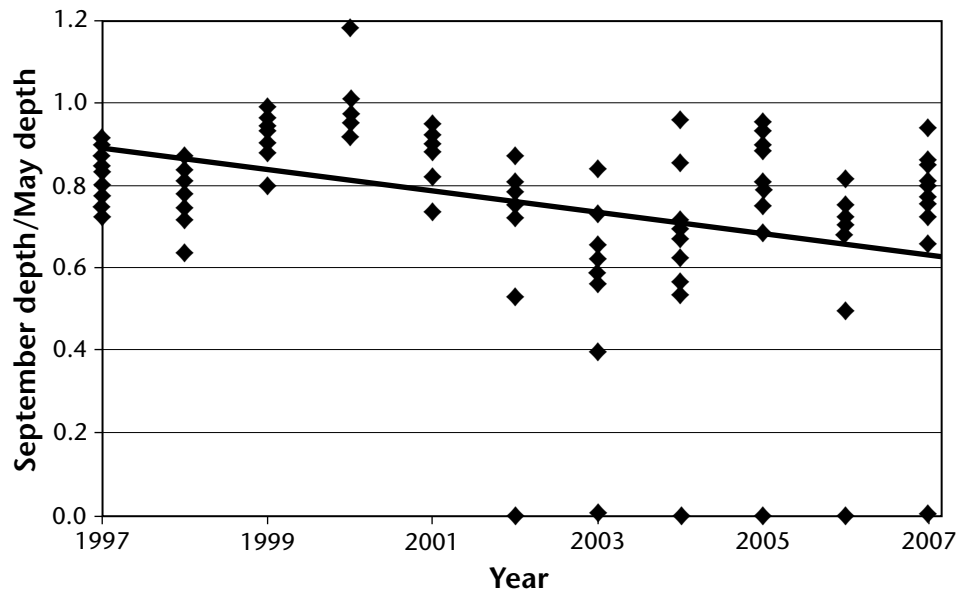


FIGURE 4. The ratio of September water depth to May water depth in wetlands of less than 2 ha at Riske Creek, B.C., from 1997 to 2007; $r^2 = 0.12$; $p < 0.01$.

Southern Interior Ecoprovince. Climate variables defining the drying index were projected by ECHAM5 and are illustrated for the A2 scenario of the IPCC. The A2 scenario describes a very heterogeneous world. The underlying theme is self-reliance and the preservation of local identities. Fertility patterns across regions converge slowly, which results in a continuously increasing global population. Economic development is primarily regionally oriented, and per capita economic growth and technological change are more fragmented and slower than in other storylines. Thus, the A2 scenario more closely approximates current conditions than does the B1 scenario of Figure 2.

Four time periods are illustrated in Figure 5: climate normal (the IPCC baseline of 1961–1990), 2020 (representing the period from 2010 to 2039), 2050 (representing 2040–2069), and 2080 (representing 2070–2099). A halo of 100 m is placed around each wetland to permit visualization of otherwise tiny dots. A clear trend is seen over time from dark and light blue (little drying) toward orange and red (severe drying). This ability to predict drying has been tested and found broadly accurate (Bunnell et al. 2010b). Smaller wetlands lose more water and more surrounding habitat with the same drying index. Most of the wetlands in the region (70.2%) are less than 1 ha. It is very likely that within four decades many of these will have dried up and a significant portion of the most productive habitat will have been lost.

Vulnerable species

Of the native terrestrial vertebrate species in the province, 112 species live in wetlands or riparian areas. This value excludes many bird species that preferentially breed in forested riparian areas because many of these also use upland sites. The four key findings noted above have strong implications for these species. Waterfowl, and likely many other members of the group, are most productive in shallow wetlands. The shallow wetlands experience a disproportionate effect of drying in terms of both depth and surrounding vegetation. Size is a useful predictor of wetland depth, and the vast majority of the province's wetlands are small (see Figure 3). In short, many of our wetlands, and the most productive ones, are threatened by climate change. Figure 5 illustrates that the threat is serious.

Vertebrates that will be affected most seriously are those that prefer shallow wetlands; these include the dabbling ducks, other waterbirds such as western grebes, marsh birds such as bitterns and rails, and some amphibians. Birds, however, are highly mobile and have the opportunity to extend their ranges into more hospitable climate. Some vertebrates using shallow, and even ephemeral, wetlands are far less mobile. The Great Basin spadefoot toad (*Spea intermontana*), for example, frequently uses ephemeral ponds and does not disperse widely. Adults, however, behave more like seeds than animals and can withstand

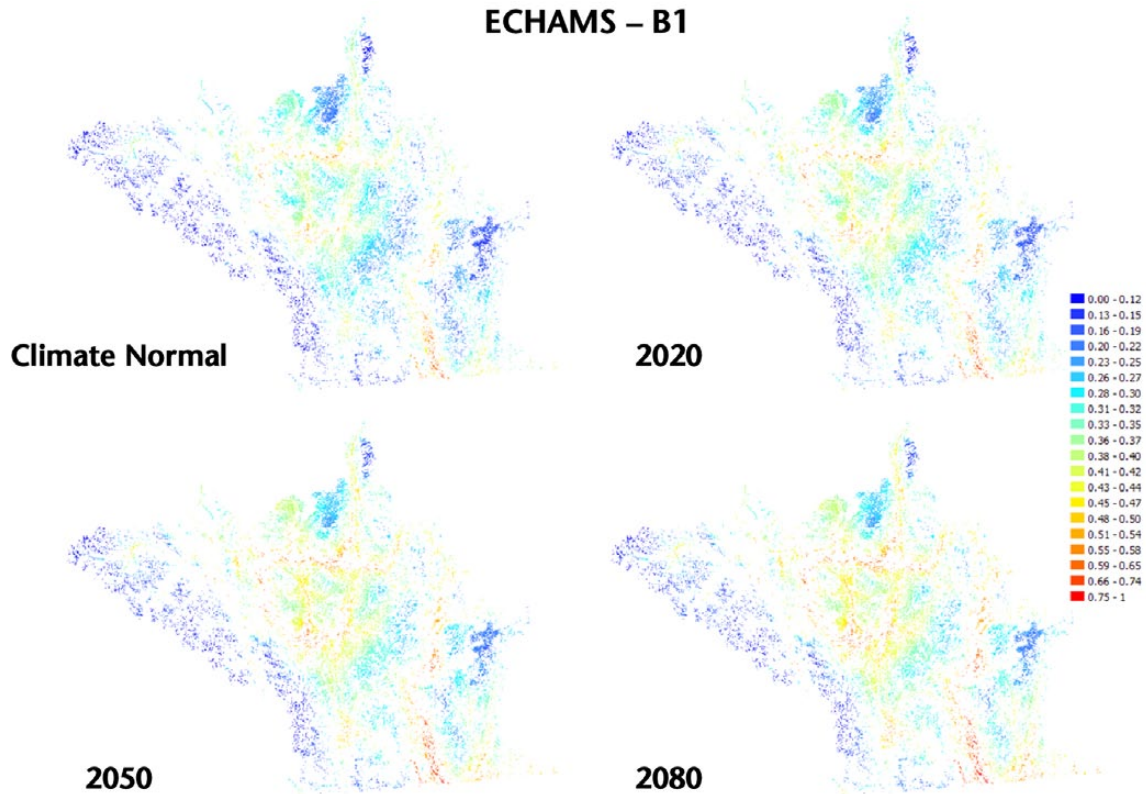


FIGURE 5. Maps of the projected climate drying index for wetlands of 10 ha and less in the Southern Interior Ecoprovince for climate normal, 2020, 2050, and 2080. Projections employ ECHAM5 under the A2 scenario. The legend represents increasing drying tendencies from dark blue to red. Source: Bunnell et al. (2010c).

drought for 7–8 months, buried in the soil, neither eating nor drinking. The tiger salamander (*Ambystoma tigrinum*) is more challenged by warming and drought. The tiger salamander currently breeds, and juveniles metamorphose, in water bodies sufficiently shallow that they often are semi-permanent. This may not always have been true. Fish introductions into deeper water bodies formerly used by the salamander have made those areas ineffective as rearing spots for the salamander. There are clear limitations on how long the water must be available. It takes 3–4 months for young tiger salamanders to acquire lungs and become terrestrial. Tiger salamanders can reproduce as larva (neotony) in permanent ponds, but this seldom occurs in British Columbia. Under changing climate, many existing vernal water bodies will become too short-lived to contribute effectively to amphibian reproduction, and some currently permanent wetlands will disappear. The Committee on the Status of Endangered Wildlife in Canada designates the spadefoot toad as threatened and the tiger salamander as endangered.

Adapting to global weirding

Two different groups are trying to adapt—we humans and all other species. Our methods of adaptation should be cognizant of what other species are trying. Salmonid fish generally require well-oxygenated water to perform well; that means cooler water. Southern sockeye populations in British Columbia are near the southern limit of the species' range. Sockeye salmon (*Oncorhynchus nerka*) are particularly hard hit by climate change. Historically, late-run sockeye have staged and continued feeding in the lower Strait of Georgia for 4–6 weeks before entering the Fraser River en route to their spawning grounds. Sockeye are then plankton feeders, and plankton of the west coast of British Columbia tend to thrive when conditions are cold. The ocean has warmed, and since 1996 late-run sockeye have entered the Fraser with little or no delay to feed and replenish energy reserves (Pacific Salmon Commission 2010). During the strong El Niño of 2009, sockeye virtually disappeared from the Fraser,

but the strongest effects had likely occurred when the cohort entered the ocean or later at sea. The water in the Fraser also has warmed, reducing oxygen content. Salmon that do not die en route due to energy stress and infection can arrive too stressed to spawn. Some sockeye have responded by moving north. They are now more frequent in the Arctic Ocean and going up the Mackenzie, Arctic Red, and Peel rivers.³ Sockeye are changing and “learning.” We are learning that there is nothing we can do to make ecosystems “climate proof,” but in some instances we can make them “climate resilient” or focus efforts where they will achieve the greatest results. We use “resilience” in the same sense of other authors—the capacity of an ecosystem to absorb disturbance without shifting to an alternative state and losing function and services (e.g., Holling 1973; Carpenter et al. 2001; Ives and Carpenter 2007).

Alpine habitats and species

There appears little we can do to make alpine habitats more climate resilient. Earth’s temperature must keep rising (the temperature of the atmosphere has yet to equilibrate with current amounts of CO₂), and the rather dramatic decrease in habitat for these species (see Figure 1) is a product of simple physical laws. We can no more repeal the temperature lapse rate than we can repeal the law of gravity. Although relatively few vertebrate species breed primarily in alpine regions of British Columbia (see Table 1), all of them will experience habitat loss.

However we act, we will benefit from knowing why a species chooses alpine habitats to breed. In many instances, the causal mechanisms for the disappearance of local populations are too poorly understood to guide ameliorative actions. The pattern of wolverine breeding in the alpine is consistent with its persecution by humans; it may survive adequately in forests, provided persecution is absent. Because pikas cope poorly with heat stress, the area they occupy has gradually moved upward since the last ice age. Pikas have, however, found cooler temperatures in warm areas by exploiting rock piles where temperatures are 4–7°C cooler than on the surface and by becoming increasingly nocturnal (Nash 2010). Maintaining a vegetative buffer adjacent to rock piles and talus would help, provided meadows for foraging were also available. Pikas now are experiencing both heat and cold stress, the latter

We are learning that there is nothing we can do to make ecosystems “climate proof,” but in some instances we can make them “climate resilient” or focus efforts where they will achieve the greatest results.

where snow cover no longer provides insulation over talus or other rock piles during winter (Beever et al. 2010). This suggests that there are elevation limits at which vegetative buffering of rock piles would work.

Hunter (2007) noted that “assisted colonization”—physically moving species to new sites—may be the only option for species living near the end of climatic gradients, as do alpine species. Pikas, for example, are remarkably sedentary animals (Broadbooks 1965; Smith 1987). Where they inhabit alpine areas, help might be as simplistic, but impractical, as strewing a rocky corridor between talus slopes on each side of a mountain meadow—a form of “encouraged migration.” It would likely be more practical to assist colonization by moving individuals to north aspects where possible. Recognizing the challenges of conserving alpine species, Hunter (2007) acknowledged that *ex situ* conservation, in zoos, gardens, and aquaria, may have a role to play. He also noted that “if the ultimate goal is free-living populations, the dismal track record of restoring species that have become extinct in the wild clearly makes this an option of last resort” (Hunter 2007:1358). This record will not be improved by climate change.

Wetland habitats and species

At the most basic level, the issue is simple—the incoming water is decreasing and the outgoing water (evaporation) is increasing. The drying index used to create Figure 5 was evaluated against measured water depths. For wetlands, climate is creating a natural triage—some regions will have too little water to sustain smaller wetlands no matter what we do; wetlands in other regions will not be strongly impacted for decades. The invocation of triage in assigning conservation effort

³ Gwich’in Renewal Resource Board. n.d. Fish species of the Gwich’in settlement area. Inuvik, N.W.T. http://www.grrb.nt.ca/fisheries_species.htm (Accessed August 2011).

is exactly analogous to that of a wartime medic. Like the medic, we also can attempt to reduce effects of the wounds, and focus our efforts and limited resources where they will achieve their greatest gain. Because the drying index addresses water inputs and water outputs separately, the primary cause can be spatially isolated, thus helping to provide focus. In the Central Interior, analyses to date indicate that mid-elevations are a useful place to focus mitigative efforts. Water use already is becoming contentious in drier parts of the province. That will not lessen, emphasizing the need for focus. Drying also emphasizes the social dimensions of adaptation—we want the water for uses other than maintaining wetlands, and that demand for water increases as populations increase.

Potential adaptive measures begin with reducing our own use of water. Of the 29 nations in the Organisation for Economic Co-operation and Development, Canada ranks second in water consumption per capita, directly behind the United States. The average Canadian uses almost four times as much water as the average Swede and more than eight times as much as the average Dane (Organisation for Economic Co-operation and Development 1999).⁴ From 1991 to 2004, annual statistics show that, on average, each Canadian used at least 325 litres per day (Environment Canada 2007). British Columbia leads the nation in water use. Besides reducing water use, Canadians also need to recognize that water in the landscape is connected. Warming of small streams causes water loss to evaporation and warms the water bodies these streams enter. Buffers around small forest streams would help. Wetlands also could be buffered where opportunities exist. We have ample experience redirecting and retaining water for our direct use. That experience could be applied to conserving wetlands. Warming is changing the flow patterns of streams and rivers. The change from snow- to rain-dominated systems changes the period when water is most abundant and could be stored. The increasing frequency of rain-on-snow events and associated high rates of flow also change when and how water can be stored. We may be able to dam and retain some of that water for when it is most needed. We also may be able to deepen some wetlands without seriously disrupting them. We could (and should) become more careful and creative about storing water.

Us and all we depend on

Other species are attempting to adapt to climate. We face the same challenge. It is pointless being depressed that some fish and pikas are adapting more quickly than we are. Our salmon fishery has long been based on salmon returning to their natal stream, but a portion of the population has always been exploratory. Some salmon have chosen increased opportunities to reproduce and have moved (pink, chum, and coho are also appearing in Arctic waters).⁵ These fish may be forerunners signalling a major shift in range. Global weirding can make a mockery of our hard-won “facts.”

To guide our approaches to ameliorative measures, it would help to adopt a policy of “no regrets.” By that we mean acknowledge the variance, but consistent direction, of climate projections, and avoid focussing on a particular climate scenario by developing responses that seem reasonable regardless of the climate outcome. Examples for forested systems could be maintaining buffers around smaller streams or thinning and reducing stocking rates of trees so that moisture stress does not exacerbate the impact of pathogens and possibly fire. There would be benefits, regardless of the rate or degree of climate change. For governments, the notion of “no regrets” presents a particular challenge not easily overcome by increasing certainty in projections. Nature is gradually revealing an existing triage—some species and systems are not salvageable. But no sitting government will find it easy to terminate funding for conservation of a species or ecosystem that is still present. The regret in those instances will come later, when it is clear that scarce conservation funding was wasted and the species or ecosystem is gone.

Directly related to a policy of no regrets is how we respond as a society to what have been termed “novel” or “emerging” ecosystems. The concept is too young for there to be general agreement on a definition. Current definitions (e.g., Hobbs et al. 2006; Morris 2009; Theobald 2010) encompass three features:

1. emerging ecosystems contain new combinations of species arising from human action, environmental change, or the impacts of deliberate and inadvertent introduction of species from other regions;
2. the combinations have not occurred previously within a given biome; and

⁴ More recent updates of OECD environmental data do not include statistics on water use from Canada.

⁵ Gwich'in Renewal Resource Board Global, op. cit.

- change within the system is more rapid than has previously been measured at similar sites.

Key characteristics are novelty (new species combinations and the potential for changes in ecosystem functioning) and human agency (these ecosystems arise as a result of deliberate or inadvertent human action). Such systems are occupying ever larger areas. Morris (2009) reported 35% of the globe, Theobald (2010) about 67% of the conterminous United States. Historically, conservation biologists are more likely to have applied the adjectives “degraded,” “heavily invaded,” “anthropogenic,” or “trashed” than “novel” or “emerging” to these ecosystems, but this is changing.

Not long ago, conservationists were about equally split on the pros and cons of assisted colonization. The “con” camp has diminished as the facts about species, such as those in the alpine, became clearer. Now climate change has forced an apparent choice between ecosystems as they were 100 or so years ago or current, well-functioning systems with some brand new parts that have migrated into the area. Recent evidence for marine ecosystems suggests that “scratched and dented” ecosystems may show superior long-term survival to systems that “run like new” (Coté and Darling 2010). For conservation biologists, and possibly the public, accepting novel ecosystems will be a greater challenge than accepting assisted colonization. With climate change, our choice may be to fight something far bigger than us or to accept that well-functioning ecosystems, no matter their constituent parts, are a suitable, and often better, option than attempting to maintain historical parts and thwart newcomers. The latter choice will mean adapting much of our thinking, including how we can distinguish exotic species that replace a waning function from those that significantly modify functions.

A large and related issue connected to emerging ecosystems will challenge our abilities to adapt. In British Columbia, as in the United States, we have invested large portions of available agency budgets in the purchase, maintenance, and management of protected areas (e.g., see Raffaele 2010). Historically, various objectives have guided the creation of protected areas— aesthetics, recreation, conservation. The conservation objective has assumed that the environment was relatively stable and the investment was long term, intended for future generations. That assumption no longer holds.

We cannot be certain what some parts of the “natural” landscape will look like even a few decades

from now. Raffaele (2010) used dandelions (*Taraxacum officinale*) and how they respond to a rapidly changing environment to emphasize his point: assuming stability in the environment has become misleading and likely dangerous. We have abundant examples of our own. Of the 32 bird species we have tested in British Columbia, most have shifted their relative abundance and range between the 1960s and 1990s (e.g., Bunnell et al. 2008). Many once-migratory species are overwintering, and winter habitat is different from breeding habitat. Some species that formerly had a single clutch now have two. The latter change is altering relative species abundance and community structure. Protected areas will remain critical tools for species conservation, but we can no longer assume they will achieve their original intent.

It is clear (see Figure 1) that alpine parks will no longer protect many alpine species and that species relying on wetlands will have to shift location or decline (see Figure 5). Loarie et al. (2009) recently examined the velocity of temperature change (km/yr) derived from spatial temperature gradients (°C/km). Using the velocity of temperature change, they developed a metric of “climate residency” time in protected areas of different biomes. They estimated velocities of temperature change of 0.11, 0.29, and 0.43 km/yr for arctic tundra, temperate coniferous forest, and boreal forest/taiga, respectively. Climate residency times were defined as the diameter of each protected area (assuming a circle) divided by the velocity. Climate residency times (years) in protected areas were 74.6, 12.7, and 1.1 for arctic tundra, temperate coniferous forest, and boreal forest/taiga, respectively. The low residency within boreal forests is a product of high velocities of temperature change and small protected areas relative to other systems. The point is simple—our protected areas are not keeping pace with the changing climate. Nor can we create a practical system that chases changing climate. We can, however, try to integrate protected areas more closely with the surrounding matrix to facilitate the species migration already under way.

To maintain species, biologists will rely increasingly on two broad approaches. One is a commitment to broad, relatively unmanaged corridors, such as the developing Yellowstone to Yukon corridor. The second is being gentler on the entire landscape, avoiding irreversible land-use changes (adopting a policy of “no regrets” and thinking of safe failure rather than fail-safe) and shifting away from expensive, site-specific actions. The second approach is likely more important, because we cannot accurately anticipate where naturalness will be needed. In this approach,

we must include landscapes intensively occupied and used by us. Conventional thinking and social pressures will be major barriers, but we cannot evade acknowledging that the premise of fixed protected areas that for so long has guided us is no longer valid.

Conclusions

Current data suggest there may be no way to avoid losing many of our alpine species to changes in habitat wrought by climate. Many of these species are more likely to disappear from British Columbia than from the planet. The birds, in particular, may simply move north into arctic tundra. For plants and mammals, we typically know too little about why these species select those habitats to create effective *in situ* conservation measures or even assisted colonization. We concur with Hunter (2007) that *ex situ* measures are unlikely to be successful in the long run. For wetland species, we will struggle with the concept of a real-world triage and the allocation of water between us and them. But there are some conditions we can ameliorate with vegetative buffers.

The major challenge will be the changes in attitudes and thinking required. Evidence is mounting that we have no choice but to adapt, and that if we want to pick a fight, we should do it with something much closer to our own size than Nature. We might do far better to allow exotic strains of the grass *Phragmites* to provide habitat for wetland birds than engage in an expensive, and likely fruitless, attempt to eliminate them. The same is true of eliminating introduced beach or dune grass (*Ammophila*) from places like Long Beach (see Rejmánek and Pitcairn 2002). There are ample implications to accepting that novel ecosystems are a large part of our future. These implications range from changing the tactics of conservation methods to focussing science more closely on the functioning of ecosystems rather than on their component parts. It is the functions that service and sustain us, not the parts doing the functioning. Somehow, our attitudes and thinking must change faster than the climate. Dandelions, sockeye, and pikas have started; we should hasten after them.

Acknowledgements

The authors gratefully acknowledge assistance from the British Columbia Forest Sciences Program, the Canadian Wildlife Service, and Ducks Unlimited, Canada. Two anonymous reviewers provided helpful comments that improved the manuscript.

Evidence is mounting that we have no choice but to adapt, and that if we want to pick a fight, we should do it with something much closer to our own size than Nature.

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ARTICLE RECEIVED: October 13, 2010

ARTICLE ACCEPTED: February 1, 2011

Production of this article was funded, in part, by the British Columbia Ministry of Forests, Lands and Natural Resource Operations.

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Global weirding in British Columbia: Climate change and the habitat of terrestrial vertebrates

How well can you recall some of the main messages in the preceding Research Report?

Test your knowledge by answering the following questions. Answers are at the bottom of the page.

1. Temperature is the major determinant of the lower boundary of alpine regions. The Canadian federal government has argued for a 3°C rise in global temperature. This equates to an increase in the lower boundary of alpine areas of:
 - A) 150 m
 - B) 310 m
 - C) 460 m
2. Which features of wetlands augment the impact of climate change on them?
 - A) Wetland size and depth are broadly correlated, and smaller depths lose a greater portion of habitat with drying
 - B) Most wetlands are small and small wetlands are the most productive
 - C) All of the above
3. For which of alpine and wetland is a triage approach to management likely to be most successful?
 - A) Wetlands
 - B) It will work equally well for either
 - C) Neither, they are both “toast”

ANSWERS

1. C; The value is not given in the text, but the simple formula is and the 310 m change for a 2°C increase is cited. Note the associated dramatic decrease in the area of alpine (Figure 1b).
2. C; All four features are acting to increase the vulnerability of wetland habitat to drying.
3. A; Options to sustain alpine habitat are much more limited by simple physics; some options for wetlands are apparent—but not everywhere, thus triage.