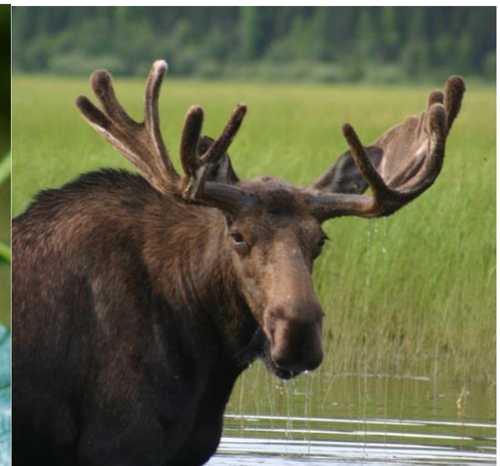
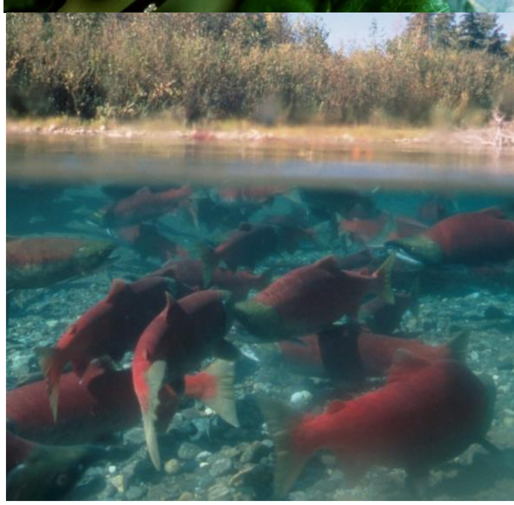
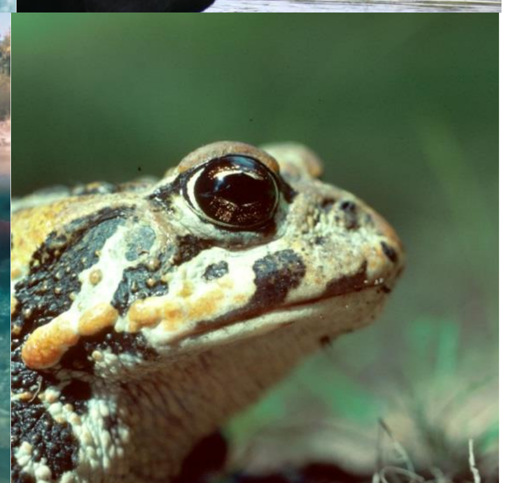
Climate Change Vulnerability of BC's Fish and Wildlife: First Approximation

This first approximation describes and tests an approach for assessing vulnerability. An Excel database with comments and detailed ratings accompanies this report. Please refer to the database for further information on the 63 species assessed to date. The database is intended to be refined and expanded.

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BRITISH COLUMBIA

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Disclaimer: Due to the short time available to complete this project, most information is drawn from existing compilations rather than from primary literature.

Summary

This report outlines a framework to assess climate change vulnerability for BC's fish and wildlife species and ecosystems, and uses the framework to assess vulnerability for selected species. An accompanying database includes detailed ratings and rationales. The report also identifies high-level adaptation strategies to reduce risks associated with climate change.

BC's climate is changing with implications for ecosystems and fish and wildlife health. Climate-change vulnerability assessments measure the susceptibility to, and ability to cope with, adverse climate change effects[1]. Vulnerability depends on the level of **exposure** to changed conditions (e.g., increased temperature, decreased stream flow), the **sensitivity** of a system to change (e.g., dependence on sensitive habitats, physiological tolerance), and the **adaptive capacity** to recover or adjust following change (e.g., reproductive rate, dispersal capability).

This report proposes a simple, transparent framework for application to BC. Existing assessment frameworks produce inconsistent results, require substantial detail and lack transparency. Impacts of climate change are challenging to predict due to non-linear responses, extreme events and interactions. A simple framework provides a level of detail appropriate for the uncertainty associated with climate change. The described framework assesses species' **sensitivity** to changes in **habitat** and in the **abiotic** and **biotic** environment related to climate change. It also assesses sensitivity to **non-climate stressors** which combine with climate to create cumulative effects. Finally it rates **adaptive capacity**.

The report uses the framework to assess vulnerability for a suite of species and ecosystems, including species with a high priority for conservation, keystone and characteristic species and species likely to be sensitive to climate change. The assessment groups species by climate-relevant traits to create a coarse-filter classification and to identify broadly-applicable mitigation options. Although species are assessed individually, the focus on groups of species and their habitat follows the recommendations of the Species-At-Risk Task Force: "*both science and experience indicate that this single-species approach is not the best way to proceed in the interests of species themselves*."[2]

Results

Climate change increases unpredictability in weather and resources. Generalist species, and those adapted to unpredictability, will likely benefit; coyotes and crows, bullfrogs and warm-water fish will be able to exploit new conditions. Most specialised species, however, will face stressors. Even species able to migrate to newly-suitable climates will be challenged by atypical ecosystems arising from changed disturbance patterns, increased variability, invasive species and new patterns of disease. Although some changes are predictable (e.g., loss of small wetlands, increased water temperature), surprises will be unavoidable. For example, some bird species assessed as low risk and resilient to anthropogenic disturbance may be sensitive to high nestling mortality due to increased spring storms and changes in the timing of insect prey. Disease outbreaks and ecosystem regime shifts may change conditions rapidly. Most amphibians, alpine and riparian-dependent mammals, aerial insectivores and marine birds, and anadromous and cold-water fish are highly sensitive to climate change (Table S1).

Table S1. Climate change sensitivity and adaptive capacity of selected priority species.

Assessed Species	*Climate Change Sensitivity*[1]	*Non-Climate Stressors*	*Adaptive Capacity*[2]
AMPHIBIANS			
Steep stream dwelling			
Rocky Mountain Tailed Frog	M-H	H	V Poor
Coastal Tailed Frog	M-H	H	V Poor
Coastal Giant Salamander	M-H	M-H	V Poor
Small wetland breeding			
Western Toad	M-H	H	Poor
Northern Leopard Frog	M-H	H	Mod-poor
Wood Frog	M-H	M	Poor
Northern Red-legged Frog	M-H	M-H	Mod-poor
Great Basin Spadefoot	H	M-H	Mod-poor
Blotched Tiger Salamander	M-H	H	V Poor
Northwestern Salamander	M-H	M	NA
Large wetland frogs			
Columbia Spotted Frog	M	M-H	Mod-poor
Oregon Spotted Frog	M	H	Poor
Terrestrial salamanders			
Wandering Salamander	M-H	M-H	V Poor
Ensatina	M	M	NA
Coeur d'Alene Salamander	H	H	V Poor
MAMMALS			
Generalist			
Coyote	L	L	Mod-good
Grey Wolf	L	M	Mod-good
North American Porcupine	L	L	Mod
Snowshoe Hare	L	M	Mod-good
White-tailed Deer	M	M	Mod-good
Mule Deer	M	M	Mod-good
American Black Bear	L	M	Mod
Canada Lynx	M	M	Mod-good
Elk	M	M	Mod-good
Grizzly Bear	M-H	H	Mod-poor
Alpine specialists			
Hoary Marmot	H	L	Mod-poor
Mountain Goat	H	M-H	Mod-poor
Northern Bog Lemming	H	NA	Mod-poor
Wolverine	H	M_H	Mod-poor
American Pika	H	L	Mod-poor
Grassland specialists			

Assessed Species	*Climate Change Sensitivity*[1]	*Non-Climate Stressors*	*Adaptive Capacity*[2]
Wood and Plains Bison	M	H	Poor
Bighorn Sheep	M	M-H	Moderate
Thinhorn Sheep	M	M	Moderate
American Badger	M	H	Moderate
Old forest specialists			
Southern Red-backed Vole	M	M	Moderate
Caribou	M-H	H	Moderate
Riparian specialists			
American Beaver	M	M	Moderate
American Water Shrew	M	M	Mod-poor
Pacific Water Shrew	M	H	Mod-poor
Fisher	M	H	Moderate
North American Water Vole	M-H	M	Moderate
Moose	M-H	M-H	Mod-good
Mountain Beaver	M-H	H	Poor
Bats			
Hoary Bat	M	M	Mod-good
Pallid Bat	M	M-H	Moderate
Townsend's Big-eared Bat	M	M-H	Moderate
Little Brown Myotis	M	H	Moderate
Northern Myotis	M	H	Moderate
BIRDS			
Aerial insectivores			
Barn swallow	M-H	M	Mod-good
Forest birds			
Northern goshawk	H	H	Moderate
Marine birds			
Marbled murrelet	M-H	H	Mod-poor
Waterfowl			
Barrow's goldeneye	M	M-H	Mod-good
Other water birds			
American bittern	M	M-H	NA
FISH			
Anadromous			
Coho salmon	H	M-H	Mod-good
Chinook salmon	H	M-H	Mod-good
Sockeye salmon	H	M-H	Mod-good
Eulachon	H	M-H	Mod-good
Cooler, steeper streams			
Bull trout	H	M-H	Moderate

Assessed Species	*Climate Change Sensitivity*[1]	*Non-Climate Stressors*	*Adaptive Capacity*[2]
Columbia sculpin	M-H	M-H	Mod-poor
Arctic grayling	M-H	M-H	Moderate
Warmer, gentler streams and rivers			
Coastal cutthroat trout	H	H	Mod-poor
Sturgeon	M-H	H	Mod-poor
Lake and/or stream residents			
Threespine stickleback	M	M	Mod-good

1. The highest value for sensitivity based on habitat, abiotic and biotic factors
2. Based on reproductive and dispersal capacity.

Mitigation[a]

Many mitigation strategies are similar across BC. With the exception of assisted migration, most are not novel, but are common-sense elements of ecosystem management that require broader application. It is not possible to change an organism's sensitivity, but it is possible to reduce exposure and to maintain adaptive capacity. Strategies to address exposure include buffering ecosystems from rapid change by, for example, maintaining old forest to buffer microclimate, and conserving riparian buffers to minimise changes to water flow and temperature. Strategies that favour adaptive capacity include maintaining connectivity to facilitate dispersal to suitable ecosystems.

Strategies to reduce overall risk include

1. **promoting resilience** by maintaining or increasing ecological diversity, with a focus on enduring features of the landscape as the core of climate adaptation areas;
2. **combating detrimental change** by providing thermal and hydrological buffers, avoiding water withdrawals from sensitive wetlands, controlling invasive plants (particularly in ecosystems undergoing ecological transformation), avoiding disease transmission from domestic livestock;
3. **guiding ecological transformation** by facilitating dispersal through maintaining latitudinal, longitudinal and altitudinal corridors with minimised barriers, and assisting migration if appropriate;
4. **limiting cumulative effects** of multiple land-use activities, including for example limiting industrial, agricultural and urban development in climate adaptation areas, avoiding excessive increases in rate-of-cut following disturbances (e.g., salvage), limiting density of roads and linear corridors to reduce barriers to dispersal, regulating recreational activities in sensitive ecosystems, ensuring that conservation levels are maintained before water is drawn down, avoiding pesticides that kill insect prey bases and other pollution-creating activities, preventing overharvest, and following already-developed best management practices.

[a] Cumulative effects literature uses "mitigation" to refer to strategies designed to reduce impacts of climate change and other pressures on species (i.e., impact mitigation), while climate change literature reserves "mitigation" for strategies that reduce greenhouse gases, and uses "adaptation" for strategies that reduce impacts.

Increased planning for cumulative effects of climate change and other factors will be critical to prioritise appropriate strategies. As recommended by the 2011 Species-At-Risk taskforce, planning should **take an ecosystem-based approach to species at risk**. Increased **watershed assessments** will facilitate maintenance of resilient hydrological functions and identify priority actions and locations.

Increased monitoring will also be important to track and respond to unpredictable and changing conditions, including changed hydrology, natural disturbance and patterns of disease.

Contents

1 Context

The Ministry of Forests, Lands and Natural Resources Operations (FLNRO) is responsible for stewardship of Provincial Crown land and natural resources, supporting sustainable management of these resources. BC's natural resource values are currently experiencing the effects of a changing and more variable climate, with more severe droughts, longer fire seasons and increased flooding. FLNRO has developed Climate Action Plans to direct climate change adaptation in order to enable the ministry to continue to deliver sustainable natural resource management services to BC citizens. This project builds on FLNRO Climate Action Plans and fills a gap in knowledge related to potential impacts of climate change on BC's fish and wildlife.

2 Introduction

Natural resource managers everywhere face the wicked challenge of managing species and ecosystems through a period of unprecedented climate change. Resource managers in BC bear a large stewardship responsibility due to the province's extraordinary ecological diversity[3], and are fortunate to have opportunities for adaptation that are unavailable in less wild regions. This report, and accompanying database, proposes a framework to assess climate change vulnerability for BC's fish and wildlife species and ecosystems, and provides a preliminary high-level assessment for selected species. The report also identifies high-level mitigation[b] strategies to reduce risks associated with climate change, and highlights future steps to build on the proposed preliminary framework.

2.1 BC's Rich Biodiversity

BC's varied physiography and location at the nexus of three climatic regions have combined to create a region defined by an ecological diversity that is disproportionate nationally and internationally among northern temperate regions[4]. Globally significant ecological diversity includes 16 biogeoclimatic zones, with ecosystems ranging from temperate rainforests to dry grasslands, and from cold tundra to seasonally-hot desert. Abundant freshwater and an intricate coastline increase diversity and productivity. BC's vast array of habitats is matched by its high native species diversity. BC is home to three quarters of Canada's bird and mammal species, 70% of its freshwater fish and 60% of its evergreen trees[5]. A quarter of Canada's mammals, 30% of its amphibians and 40% of its hardwood tree species are found only in BC[6].

BC has global stewardship responsibility for ecosystems with disproportionately high representation in the province, including oldgrowth temperate rainforest, wild rivers and rich marine ecosystems. It also has global responsibility for those species found primarily within its borders, such as mountain goat and Barrow's goldeneye, as well as for formerly widespread species, such as grizzly bears and wolverines, with ranges that have contracted towards BC[7].

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[b] This report uses "mitigation" to refer to strategies designed to reduce impacts of climate change and other pressures on species, consistent with the cumulative effects literature (i.e., impact mitigation). Within the climate change literature, "mitigation" is reserved for strategies that reduce greenhouse gases, and strategies that reduce impacts are termed "adaptation".

2.2 BC's Changing Climate

The BC climate is changing, and impacts are already being felt. The province has become warmer and wetter over the last century. Extreme rainfall and dry conditions have increased. These trends are expected to continue, with variation over shorter time periods, and among regions. More winter precipitation is expected to fall as rain, and spring snowfall will decrease, resulting in lower snowpacks, earlier snowmelt, and longer fire seasons in many regions[8]. As the climate changes, natural disturbances and hydrological regimes will respond. Fish and wildlife health will be impacted. Species' distribution will change as maladapted populations decline, migrate or adapt over time, and as generalists spread to take advantage of higher rates of disturbance. Ecosystems will likely undergo both predictable and unpredictable ecological shifts as communities disassemble and reassemble, sometimes into novel combinations.

2.3 Vulnerability to Climate Change

"*Vulnerability is the degree to which systems are susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes*"[9]. Vulnerability depends on the level of **exposure** to changed conditions, the **sensitivity** of a system to change, and the **adaptive capacity** to recover or adjust following change. Exposure estimates the type and magnitude of climate change that a species or ecosystem is likely to experience, including factors such as increased mean or extreme temperature, decreased stream flows, increased drought, decreased snowpack and changed habitat. Sensitivity estimates how much a species or ecosystem will be affected by a given amount of change, due to traits such as dependencies on sensitive habitats, physiological tolerance to abiotic factors, important interactions with other species and population size. Adaptive capacity estimates how well a species or ecosystem can cope with a given amount of change over the longer term by modifying behaviour, acclimating, adapting via natural selection or migrating, and depends on factors such as reproductive rate, dispersal ability, genetic diversity and phenotypic plasticity. Some traits could be considered as contributing to both sensitivity and adaptive capacity (e.g., reliance on specific habitats).

2.4 Cumulative Effects and Uncertainty

Impacts of climate change are challenging to predict for several reasons. First, although some factors will likely change fairly linearly and gradually (e.g., average temperature), many will not, instead exhibiting threshold responses (e.g., average water temperature in glacier-fed streams). Second, averages do not reflect the increased variability and extreme events that are the signature of climate change and that reflect the day-to-day experience of organisms and ecosystems. Third, climate impacts will interact with each other and with non-climate pressures in complex, non-linear, and often unpredictable ways. For example, at an ecosystem scale, increased fire disturbance, combined with warmer temperatures and spread of invasive weeds, may lead to an ecological regime shift when a forest fails to regenerate and instead switches to an ecologically-simplified grassland, dominated by exotic, non-nutritious, species. Similarly, multiple pressures will combine to impact fish and wildlife health in suites of cascading effects: for example, individuals stressed by changed abiotic conditions will be more susceptible to disease and less able to disperse or reproduce, limiting adaptive capacity. At a species scale, changes in disease prevalence or in timing of critical processes may tip species over a threshold. For example, an almost complete failure of northern goshawk breeding success in the Skeena and Nadina Resource Districts is likely linked to the cumulative effects of a climate-mediated timing mismatch between blackfly abundance and nestling period combined with habitat loss due to mountain pine beetles and forestry[10]. The crash was unexpected (a 2013 COSEWIC report includes no hint of threat); essentially, it represents an "unknown unknown".

2.5 Approach

BC is home to more than 50,000 species[11]; nearly 8,000 have been assessed for conservation status[12]. Vertebrates are relatively well-known, and form a small portion of this biodiversity (around 1,000 species). Analyses of global and provincial conservation status exist for species, sub-species and distinct populations of freshwater fish, amphibians, reptiles, birds and mammals. **In designing and implementing a high-level assessment of the vulnerability to climate change of BC's fish and wildlife, we focused on the sensitivity and adaptive capacity of a limited suite of species and ecosystems, developing and testing a framework that can be updated and refined over time.** We began with species with a high priority for conservation (e.g., rare species, species for which BC has a high stewardship responsibility), keystone species, species of particular interest to people, and species likely to be sensitive to climate change.

An important part of our assessment was to group species by climate-relevant traits to create a coarse-filter classification and to group mitigation options. Although species are assessed individually, the approach focuses on groups of species and their habitat, following the recommendations of the Species-At-Risk Task Force: "*both science and experience indicate that this single-species approach is not the best way to proceed in the interests of species themselves. Management of a bundle of species and their habitats, though complex, appears to afford a better prospect of success*."[13]

3 Methods

3.1 Selecting Species to Assess

3.1.1 Candidate Species

We created a list of candidate species from **BC Species and Ecosystems Explorer**[14], excluding exotic and accidental species as well as marine fish and mammals. The initial list included nearly 700 species of native freshwater fish, amphibians, reptiles, birds and mammals.

The BC Species and Ecosystems Explorer, maintained by the Conservation Data Centre, includes information on conservation status, taxonomy and distribution for about 7,700 species of BC's vertebrates, invertebrates, plants and lichens, and for over 600 ecological communities. The Conservation Data Centre is part of the BC Ministry of Environment and is associated with NatureServe Canada and the international NatureServe organisation; information within the database is thus consistent with similar information worldwide. The database is updated regularly based on research and monitoring, most recently in June 2015[15].

3.1.2 Species of Conservation Interest

BC has a high number of species at risk, in part because its biogeographical diversity leads to a fragmented distribution of species and populations (e.g., islands and high elevation habitats), but also because ecosystems ignore jurisdictional boundaries. Some ecosystems have small portions in BC and provide habitat for peripheral populations. Peripheral species are one of the main challenges to basing priorities on at-risk lists[16]. Sub-division of species into sub-species and populations presents an additional complexity. In essence, other criteria must be considered alongside risk status[17].

The **Report on the Status of Biodiversity in BC**[18] includes information useful for prioritising species beyond risk ranking. For example, information on BC's stewardship responsibility for species[19] examines species' distributional patterns. Species with most of their range in BC, whether they are endemic or widespread, vulnerable or secure, are best conserved in BC. This information has been developed into a **Conservation Framework** tool[20] used to assign conservation priorities to all species and ecosystems on the list. This tool prioritises efforts within three goals:

1. Contribute to global efforts for species and ecosystem conservation
2. Prevent species and ecosystems from becoming at risk
3. Maintain the diversity of native species and ecosystems

Priorities for each goal are based on a combination of global and provincial conservation rankings, population isolation, stewardship responsibility, population trends, threats and feasibility. Priorities for all three goals are included in the BC Species and Ecosystems Explorer database. These conservation priorities aid species selection, and the prioritising methodology includes information useful for determining sensitivity to climate change.

From the perspective of climate change, peripheral species from the north and south should be treated differently[21]. Northern boreal species at the southern limit of their range will likely decline in BC as the climate warms. If these species have secure populations beyond the BC border, they need not be included in lists of BC's vulnerable species. However southern species, at the northern extent of their range in BC, could expand within BC. For these species, BC will have a greater stewardship responsibility, particularly because populations at the edge of a range may be important for the genetic diversity of a species, and hence increase adaptive capacity.

3.1.3 Keystone Species

Keystone species influence ecosystems disproportionately. They include predators that exert top-down regulation (including grey wolf, lake trout and falcons), ecosystem engineers (including beavers at a large scale, and woodpeckers at a smaller scale) that create habitat for other species, and abundant species that form a prey base (including snowshoe hares). Impacts on these species, most of which are not at risk, could have cascading consequences for other species and ecosystems[22].

3.1.4 Prioritisation Procedure

We designed and tested a framework using a representative set of species selected from the initial list of around 700 vertebrate candidates. In prioritising species to assess, we attempted to avoid the problems associated with focussing on rarity alone by using the Conservation Framework (that considers stewardship and isolation amongst other factors), by including other key species and by using a climate-change lens:

1. We created an initial shortlist focussed on species with **high conservation priority based on Goal 2 of the Conservation Framework**: "*Prevent ecosystems and species from becoming at risk*". These species are not currently threatened, but may be vulnerable. They seem an ideal starting place for proactive climate-change management.
2. We included some species with **high priority for other Conservation Framework goals**, particularly if these species represented populations at the northern extent of their range; these species are already facing threats due to small population, limited range or non-climate pressures, but may have opportunities for expansion and may represent important genetic diversity.
3. We expanded the shortlist to include **highly functional species** (e.g., keystone species), **characteristic species**, and species that **depend on climatically vulnerable habitats**.
4. We selected species from the shortlist in an attempt to be **representative** (e.g., including some generalists and some specialists, some large and some small species).

Although available information varies considerably among species, we did not select based on existing data.

3.2 Ecosystems

Downscaled climate models can be used to project the climate envelopes associated with BC's biogeoclimatic subzones. These models have been completed for combinations of climate models and are available elsewhere[23]. At a smaller scale, preliminary work has assessed the relative stress to site series related to climate change in the Nadina Forest District[24]. This work could be expanded to cover the entire BC, but is beyond the scope of this report. To provide a high-level assessment of ecosystem vulnerability, we summarised existing information for groups of ecosystems (e.g., wetlands, grasslands).

3.3 Assessing Climate Change Vulnerability

3.3.1 Existing Assessment Indices

We considered the suitability of four existing indices as candidates for assessing vulnerability of BC's fish and wildlife, with the hope of using existing ratings to populate a BC database (Table 1).

Table 1. Existing indices considered for BC vulnerability assessment.

Index	*Notes*	*Source*
Intrinsic Vulnerability	• Not specific to climate change	• BC Conservation Status Reports[25]
IUCN Threat Calculator	• Specific to climate change • Limited to 10-year time scope	• Recent COSEWIC reports (2010 and newer)[26]
NatureServe Climate Change Vulnerability Index (CCVI)	• Specific to climate change • Includes sensitivity, exposure and adaptive capacity • Designed to be used with NatureServe species rankings • Data intensive	• Published assessment for species living in Alberta[27]
Pacific Northwest Climate Change Sensitivity Index (CCSI)	• Specific to climate change • Focuses on sensitivity • Based on expert knowledge	• Database available for species living in the US Pacific Northwest[28]

3.3.1.1 Intrinsic Vulnerability (Conservation Status Reports)

Conservation Status reports usually rate the intrinsic vulnerability of a species based on their life history, genetic diversity, dispersal and habitat use. These ratings were not designed to address climate change, and hence do not include all relevant factors (e.g., thermal sensitivity, dependence on climate-sensitive habitats). The information provides useful input into a climate change vulnerability assessment, but cannot stand alone.

3.3.1.2 IUCN Threat Calculator

Recent COSEWIC reports include climate change explicitly as a component of an IUCN threat calculator[29]. Climate change threats are divided into four classes: habitat shifting and alteration, droughts, temperature extremes and storms and flooding. Unfortunately, the calculator uses a 10-year time scope, which limits its utility for proactive management. For most species, climate change impacts within a decade present a much lower immediate threat than habitat loss[30]. Hence, the climate threat is generally rated as “negligible” or “low”; several COSEWIC report authors note the inadequate time scale. This threat rating is of little use in its current form; our assessment suggests that variation among ratings seem to depend more upon how narrowly authors limited themselves to the 10-year time frame.

3.3.1.3 NatureServe CCVI and Pacific Northwest CCSI

Several climate change vulnerability assessment indices have been developed recently[31]. We examined and compared the NatureServe Climate Change Vulnerability Index (CCVI)[32] and a Climate Change Sensitivity Index (CCSI) developed in the US Pacific Northwest[33]. These indices have been used in areas adjacent to BC to assess species that also live in BC: CCVI has been applied to Alberta, while CCSI has been applied primarily to Washington, Idaho and Oregon.

Both indices use literature and expert input to populate answers to sets of questions and then sum weighted responses to each question into an overall assessment value. CCVI includes exposure to climate change, sensitivity and adaptive capacity in its questions while CCSI focuses on sensitivity, assuming that sensitivity varies with the biology and ecology of a species and will not vary with climate change. CCVI excludes factors used to determine risk status, following NatureServe's well-established methodology, to avoid double-counting; the CCVI is intended to be used in conjunction with existing conservation rankings. This means that such factors as population size, life history, dependence on sensitive habitat and interacting non-climatic stressors are excluded from the index, problematic for a stand-alone assessment. CCSI includes a more complete suite of factors to assess sensitivity. It includes some factors that could be considered as affecting adaptive capacity (e.g., life history and dispersal ability), but does not include exposure. CCVI requires considerably more detailed information, including spatial data, than does CCSI.

Rankings produced by the two indices do not match well (and neither do those produced by a third index[34]). In a test of species ranked by both systems in the US, 96% of species were ranked as vulnerable by one of the indices, but only 27% by both[35]. In addition, the rankings were not significantly correlated, and the authors were unable to determine explanatory patterns for the discrepancies (species were examined in different geographical regions, but an assessment of several species from the same area also showed a disappointing lack of congruence). These findings pose challenges for meaningful assessment and suggest that caution is required in interpreting vulnerability values. Lankford et al. (2014) suggest that any assessment should be carefully designed to address the questions of particular interest for each case.

Our examination of CCSI ratings for Myotid bats suggests that inter-observer differences may outweigh species differences. For example, Myotid bats scores ranged from low to high sensitivity. The clearest example comes from *M. lucifugus*, where three people rated sensitivity for populations in different locations (Olympics, Washington and Idaho). One gave the bat 6/7 on a scale from generalist to specialist, while two gave it 2/7; one person scored it as completely insensitive to natural disturbances (1/7), while two scored it as moderately sensitive (4-5/7). Even assessments of reproductive capacity differed by two points. These features are unlikely to shift so far across regions; instead they likely represent the implicit mental model of each assessor.

3.3.2 Proposed BC Climate Change Vulnerability Framework and Assessment

We propose a relatively simple framework designed to try to maximise transparency (Figure 1).

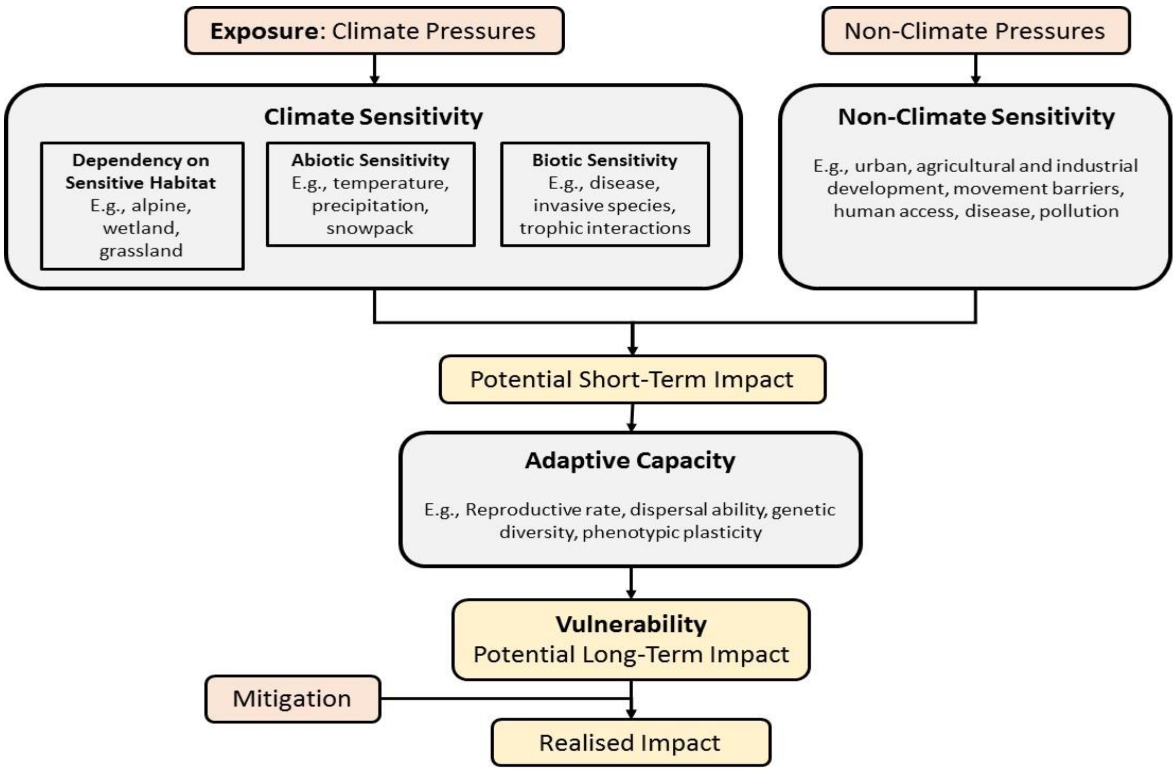

Figure 1. Proposed framework for assessing climate change vulnerability of BC's fish and wildlife.

3.3.2.1 Exposure

Climate change models have improved over the past decade, and downscaled models are available for regional use[36]. It is possible to overlay species range maps with climate maps and to project exposure spatially. The NatureServe vulnerability index (CCVI) uses such a data-intensive approach. This process, however, is time-consuming, lacking in transparency, and may not add value: in an Alberta test, the CCVI was relatively insensitive to exposure[37]. As a first approximation, this project addresses exposure at a very coarse level, using potential change in area of habitat as measured broadly by biogeoclimatic zone envelope. At a finer scale, some ecosystems will be more sensitive to extreme weather events (e.g., small wetlands may dry due to drought), and species depending on these habitats will be exposed to greater change. The proposed framework includes dependency on specific fine-scale ecosystems under sensitivity. Future refinement could increase precision of exposure estimates.

3.3.2.2 Sensitivity

Intrinsic features of a species' biology can indicate potential sensitivity to climate change. The proposed framework includes four factors: dependence on habitats that are sensitive to climate change; sensitivity to climate-relevant abiotic factors; sensitivity to climate-relevant biotic factors; and sensitivity to potentially interacting non-climate pressures (Table 2). Each factor is rated and a rationale provided in the database. The ratings capture both severity and probability. Because of high uncertainty, ratings are not finely divided; for example a rating of 2 includes both moderate sensitivity and possibly high sensitivity, because confidence in all but likely high severity sensitivities will be low. The intent is that anything with a rating of 3 or 4 is a red flag for management attention and that a rating of 2 is a yellow flag, requiring further investigation.

Table 2. Description of factors used to assess sensitivity to climate change.

Factor	*Description*	*Rating*
Habitat	• Dependence on habitats sensitive to climate changes (e.g., wetlands, seasonal streams, alpine, coastal fringe) • Captures complex interactions among abiotic and biotic factors that result in emergent patterns on the landscape, including natural disturbance regime • Includes specialists defined with a climate-change lens • Dependence on sensitive habitats will also affect adaptive capacity • Specialist species will likely be vulnerable, even with large populations, because heritable variation for traits that lead to specialisation is likely low, limiting the potential for evolution[38].	1. Broad generalist[39] 2. Generalist, but some sensitive habitats are important 3. Depends on sensitive habitats that are not rare 4. Depends on sensitive habitats that are rare
Abiotic factors	• Sensitivity to climate-relevant abiotic factors (e.g., temperature, desiccation, snowpack, dissolved oxygen, pH) • This factor addresses physiological tolerances	1. Not sensitive 2. Somewhat sensitive or possibly very sensitive 3. Likely very sensitive 4. Known very sensitive
Biotic factors	• Sensitivity to climate-relevant biotic factors • Species with particular ecological relationships may be more sensitive if these relationships are altered by climate change (e.g., predator-prey relationships, phenology, disease)	1. Not sensitive 2. Somewhat sensitive or possibly very sensitive 3. Likely very sensitive 4. Known very sensitive
Non-climate	• Sensitivity to non-climate pressures that may interact with climate factors (e.g., habitat loss, invasive species, pollution) • Sensitivity to climate change may be affected by the extent to which other factors pose threats	1. No pressures 2. Moderate pressures or possibly major pressures 3. Likely major pressures 4. Known major pressures

The Pacific Northwest CCSI uses 9 factors to assess sensitivity, with 7 ratings possible for each factor[40]. This framework places two of their factors under adaptive capacity, and combines others to achieve what seems to be a minimum set.

Unlike other indices, this proposed framework does not combine factors into a single value through a formula. Combining ratings can reduce transparency and could, for example, dilute a critical sensitivity to temperature by a low rating for biotic factors and vice versa. Instead, within this summary report, **species have colour-coded flags showing the highest rating among the three climate-change factors (habitat, abiotic and biotic factors), and all factors are listed within the database**. This process allows focus on each element separately, a focus that is facilitated by the low number of factors included.

3.3.2.3 Adaptive Capacity Factors

Adaptive capacity addresses long term resilience to climate change, and is related to life history strategy, dispersal ability, genetic diversity and physiological or behavioural plasticity (Table 3). Organisms that mature early and produce many offspring can colonise newly disturbed areas and repopulate quickly; those with few young who invest deeply in parental care are well-adapted to stable environments, but generally less flexible in changing situations. Actual reproductive rate will vary with individual body condition and ecological context (e.g., food availability, population density). Dispersal ability defines the spread of individuals over a landscape; good dispersers will be more likely to be able to follow shifting ecosystems in the absence of barriers. Over the long term, high genetic diversity likely provides a better base for climate-based selection provided that the diversity exists in climate-relevant traits. Plasticity allows individuals to respond physiologically or behaviourally to change over the short term (within a generation), by such mechanisms as the time or location of an activity, and using microhabitat refugia[41]. Data on genetic diversity and phenotypic plasticity are sparse; hence these factors are not rated, but noted as comments within the database.

Table 3. Description of factors used to assess adaptive capacity.

Factor	***Description***	***Rating***
Reproductive capacity	• Describes life history strategy (along the continuum between r and K selection[42]) • Reproductive capacity ratings are based on averages provided in sources; actual reproductive rate will depend on condition and context • Survival to maturity varies widely among species and years, even in species with few young; however data on juvenile survival are too sparse to provide reliable information for many species.	1. Fast generation time, many offspring 2. Fast generation time, few offspring 3. Long generation time, many offspring 4. Long generation time, few offspring
Dispersal capacity	• Dispersal distances are taken from maxima noted in sources. For many species, these are extrapolated from species of similar size, a reasonable assumption[43]. • Distances do not necessarily reflect effective dispersal; e.g., fishers have been recorded to travel well over 100km, but have not to disperse successfully beyond 20km. • Barriers to dispersal limit adaptive capacity; barriers are noted and included in adaptive capacity rating.	1. > 100km 2. 10 – 100km 3. 1 – 10km 4. < 1km
Genetic diversity	• Data sparse for almost all species, although becoming more common for large mammals	Noted in text
Phenotypic plasticity	• Generalists have higher plasticity. Data are sparse.	Noted in text

The proposed framework rates overall adaptive capacity as the mean ratings for reproductive capacity and dispersal ability, modified by genetic diversity or plasticity if known: >3.5 = very poor; 3 = poor; 2.5 = moderate-poor; 2 = moderate; 1.5 = moderate-good; 1 = good. Often, species with high reproductive potential will have low dispersal ability (e.g., voles) and those with low reproductive potential have high dispersal ability (e.g., grizzly bears).

3.3.2.4 Sources of Information

This high-level, preliminary assessment relies on existing knowledge compilations rather than primary literature. Information varies among species. **COSEWIC reports** (accounts, updates, recovery strategies, management plans) provide excellent reviews of current knowledge. For a small number of species, recent COSEWIC reports (since 2010) include explicit consideration of threats posed by climate change. **BC Conservation Status reports**, available for some species, include information useful for assessing climate change, including assessments of intrinsic vulnerability and environmental specificity. The **CCSI database for the Pacific Northwest** also provides rationales for ratings. Compiled information is rather sparse for other species, limited to **BC Species Summaries** and **Species Accounts**.

All information is contained within a database for reference and verification. The database also notes sources of information and quality of information. The intent is that, over time, ratings can be refined based on expert input and literature review. Regular updates could capture new knowledge—particularly important in the rapidly-developing field of climate change.

3.3.2.5 Vulnerability to Climate Change Pressures

Exposure, sensitivity and adaptive capacity combine to determine vulnerability of a species or ecosystem to climate change. However, integrating these elements in a robust manner is challenging[44]. Existing indices attempt combination to derive a single value, but results across indices are inconsistent, suggesting that the challenges of integration have not yet been met[45]. This project does not combine factors due to high uncertainty associated with many factors as well as the strong likelihood of unpredictable feedbacks and cascading impacts. This provides transparency and allows managers to assess where to focus mitigation. Summaries provide coloured flags for sensitivity and adaptive capacity suggesting appropriate actions (Table 4).

Table 4. Colour flags for factors and interpretation.

Sensitivity to climate-change pressures	***Sensitivity to non-climate-change pressures***	***Adaptive capacity***	***Interpretation***
Likely not sensitive	Likely not sensitive	Moderate-good to good	Monitor
Somewhat sensitive/possibly very sensitive	Somewhat sensitive/possibly very sensitive	Moderate	Decrease uncertainty by increasing knowledge
Likely very sensitive	Likely very sensitive	Moderate-poor	Mitigate impacts
Known very sensitive	Known very sensitive	Poor to very poor	Mitigate impacts

In theory, some aspects of exposure and severity can be combined quantitatively; however, better data are necessary.

3.4 Grouping Species for Mitigation

The proposed framework combines species into climate-relevant groups that might benefit from similar mitigation strategies. Grouping species increases efficiencies and makes it easier to handle large numbers of species.

4 Results

Sixty-three species have been assessed for this initial project, including 15 amphibians, 33 mammals, 5 birds and 10 fish. Priorities for assessment included amphibians, due to their high sensitivity to climate change, and mammals, due to their ecological role and importance to people.

An excel workbook with detailed comments and vulnerability ratings accompanies this report. Please refer to the spreadsheet for further information. A “table of contents” sheet within the workbook describes meta-data. Individual pages list vulnerability ratings from other sources as well as ratings completed for this project. Ratings and information describe climate-change sensitivity in relation to habitat, abiotic factors and biotic factors, sensitivity to non-climate factors, and adaptive capacity as a function of reproductive rate and dispersal potential. The spreadsheet also lists potential mitigation actions and sources of information.

4.1 Climate Change Pressures

Climate pressure on wildlife species include abiotic factors (e.g., changes to temperature, precipitation, snowpack), biotic factors (i.e., changed interactions with other species), and the complex system of interactions among factors that result in emergent patterns of habitat on the landscape. Pressures will vary across the province (Table 5). For example, southern regions will experience the biggest increase in summer temperature and biggest decrease in summer precipitation, resulting in higher drought pressure and risk of fire relative to central and northern regions.

Table 5. Summary statistics for projected changes in temperature, precipitation and disturbances. Coloured cells represent regions with large increases in temperature, decreases in precipitation and increases in disturbance. Information taken from BC Provincial Vulnerability Assessment and regional Climate Change Extension Notes[46].

Region	Temp summer	Temp winter	Ppt summer	Ppt winter	Snow winter	Snow spring	Fire	Wind	Beetles
Coast	1.5*	1.3	-16	6	-28	-52	↑	↑	↑
Thompson Okanagan	2.1	1.5	-9	7	-11	-55	↑		
Kootenay	2.0	1.7	-6	8	-5	-48	↑		
Cariboo	1.6	1.8	-7	7	-8	-54			
Omineca	1.5	1.9	1	9	2	-54			
Northeast	1.4	2.2	4	11	7	-57			↑
Skeena	1.5	1.9	2	9	-6	-56		↑	↑

* Projected percentage change from baseline (1961 – 1990) to 2050s (2040 – 2069) for regions in BC. Projected changes continue to increase past 2050.

4.1.1 Abiotic Factors:

Temperature will increase: BC has become warmer over the last century, with winter warming most. By the end of this century, mean annual temperature in BC could be at least 1.7 to 4.6°C warmer than it was in the last few decades[47]. Northern and southern regions of BC are expected to warm more than coastal BC and parts of central BC. Increased temperature will increase evaporation, decreasing available moisture and increasing the rate of fire disturbance.

Variability in temperature will increase: Temperature will swing unpredictably within seasons; one result will be increased winter freeze/thaw events.

Extreme warm temperatures will increase.

Precipitation patterns will change: Projected patterns of precipitation are less clear and will vary considerably across regions. Winter precipitation is expected to increase in all regions, but summer precipitation is expected to increase in northern BC and decrease in southern and coastal BC. Even for regions with projected increased in precipitation, climate moisture deficit will increase in summer due to increased temperatures.

Droughts will increase: Precipitation will likely be clustered temporally, with longer periods of drought, particularly in southern BC.

Storms will increase: More frequent and intense storms will batter some regions, particularly on the coast, leading to increased windthrow, flooding and slope failure.

Water temperature will increase: Increased air temperature and lower summer flows will lead to warmer water in stream and wetland systems in some regions.

Snowpacks will change: Snowpacks have decreased over much of BC over the past century. Warmer temperatures mean that more late winter precipitation will fall as rain rather than snow, resulting in lower snowpacks, and earlier and more rapid snowmelt over most of the province, although some coastal areas may see increased snow depth. Snowpacks will also likely change condition due to increased freeze/thaw events.

Glaciers will continue to melt. Melting glaciers will provide cool sources of water to glacier-fed streams for several decades, but will lead to increased temperatures once glaciers disappear.

Abiotic disturbance dynamics will change: Fire frequency and size, and fire season length, will increase, particularly in southern BC. Windthrow and landslides will increase following storms. Flooding will increase in some regions.

Hydrological regimes will shift: Increased evaporation, altered vegetation communities, increased storm frequency and magnitude, decreased snow accumulations, seasonal changes to precipitation, and accelerated ice melt followed by diminished glacier extent will change regimes. Peak flows will change timing and magnitude. Summer low flows will be longer and lower.

4.1.2 Biotic Factors

Growing season will lengthen.

Biotic disturbance dynamics will change: Warming conditions, and wetter springs in some regions, will likely lead to more frequent and extensive tree mortality due to insects and diseases across BC (as already seen with mountain pine beetle, spruce beetle and *Dothistroma*), although some fungal diseases may decrease with drier conditions. In general, insects and disease organisms have high adaptive capacity and can respond to changed conditions faster than their hosts.

Invasive species will increase: Generalist species from warmer ecosystems will likely colonise disturbed habitats and spread rapidly. For example, cheatgrass will likely continue to outcompete native grasses and warm water fish (e.g., yellow perch, small and large-mouth bass) may outcompete or prey upon cold-water native species.

Disease prevalence will increase: Distribution of insects and disease that infect animals will change with climatic conditions. Individual organisms stressed by other factors (e.g., temperature, changed food availability) will be more susceptible to disease.

Ecological relationships will decouple: Trophic mismatches will result from changed phenology. For example, birds may migrate based on day-length, and miss peak prey abundance. Similarly, changed green-up time might impact ungulate reproductive success.

4.1.3 Habitat

Ecosystems will likely undergo both predictable and unpredictable ecological shifts: Climate envelopes (the climate associated with an ecosystem today) will shift. Models project that BC's biogeoclimatic ecosystem climate envelopes will move up to 300m higher in elevation and 170km farther north by 2050[48]. In response, ecological communities will disassemble and reassemble—sometimes into novel combinations—as populations decline, move or adapt. Many species, including trees, will not be able to migrate quickly enough to keep pace with shifting climate. During this transition, ecosystems will be strongly influenced by disturbances and invasive plants.

Alpine and subalpine ecosystems will shrink: High-elevation ecosystems are vulnerable to encroachment by lower-elevation ecosystems and cannot migrate.

Grasslands, shrub-steppe and dry forested ecosystems are expected to expand. Some currently forested ecosystems may undergo a shift to a new state following a combination of increased fire disturbance and decreased available moisture.

Freshwater wetlands will shrink: As physiographically limited systems, wetlands are unable to migrate, and hence are vulnerable to changed hydrology. Summer water availability will decrease, likely leading to loss of small, shallow wetlands, possibly in conjunction with growth of vegetation.

Stream ecosystems will change: Flooding, low flows and warmer temperature will affect aquatic habitat. Changes to hydrological regime will affect stream persistence and morphology. Flows may become more variable, and, in some regions, the spring recession—a long period of stable flows—may become less predictable. Storms may destroy refugia.

Marine-terrestrial interface ecosystems will change: BC has a long coast line, including extensive island archipelago systems. Sea-level rise will change tidal ecosystems, estuaries and coastal wetlands. Storms will affect coastal fringe ecosystems. Ocean acidification will affect marine species and ecosystems.

4.2 Exposure: Ecosystem Shifts

Climate modeling projects the geographic location of "climate envelopes" or ecosystem niches that are associated with particular ecosystems (Figure 2). These maps can be used to project potential habitat envelopes for individual species.

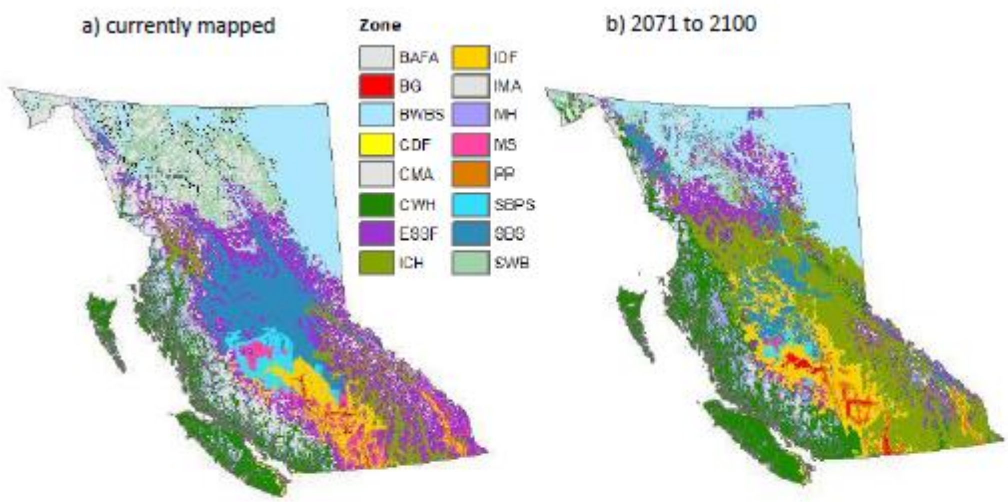

Figure 2. Geographic distributions of climate envelopes associated with BEC zones for currently mapped (a) and predicted for 2080s (b), based on consensus predictions with the best-model agreement among 20 selected climate change scenarios. From Wang et al. 2012[49].

As an initial approximation, we analysed the projected area of change in BEC zone climate envelope for each of the nearly 400 species in the BC Species and Ecosystem Explorer database with defined BEC zones, by comparing combined zones currently used and projected into 2080 (spatial analyses used SELES). Because most species use a variety of BEC zones, the estimated area of "suitable BEC zone habitat" did not change greatly, with about 60% of species retaining 95% of their suitable habitat. Even with this coarse assessment, some species showed high losses of habitat, with about 12% losing more than a third of their habitat. The northern bog lemming was projected to lose 65% of its BEC climate envelope by 2080, and southern red-backed voles, thinhorn sheep and mountain beavers to lose more than a third of their climate envelope within BC.

This approach is limited by the coarse nature of the analysis (BEC zone rather than subzone). A significant limitation applies to species that use a variety of zones, but require sensitive ecosystems at certain times. Wolverines, for example, use most BEC zones, but require alpine habitat for breeding. Because wolverines are documented as using all BEC zones, this analysis is inappropriate for determining their exposure; instead, analysis should focus on elements that are most sensitive to climate change. Similarly, exposure for species that depend on finer-grained ecosystems (e.g., small wetlands) that are scattered throughout many zones, will not be captured adequately by assessment of biogeoclimatic ecosystems, but will require assessment of the features of interest. Finally, an assessment of biogeoclimatic climate envelopes cannot consider pressures on stream systems (e.g., comparing glacier-headed versus lake-headed streams). A water-focused assessment will be necessary to capture this exposure.

Further refinement will be necessary before integrating this spatial exposure rating with measures of sensitivity and adaptive capacity.

5 Amphibians

Fourteen amphibian species have high conservation priority in BC (Conservation Framework Priority 1 or 2 in any category)[50]. These species can be divided into four groups based on traits that are relevant to climate change: steep stream-dwelling species, small-wetland breeding species, large-wetland breeding species, and terrestrial salamanders (Table 6). Some species that have not yet been assessed could be incorporated into the groups listed (e.g., long-toed salamanders in the small wetland breeding group, and western red-backed salamanders in the terrestrial salamander group).

Table 6. Climate change sensitivity of amphibian species rated as Priority 1 or 2 by the BC Conservation Framework.

Assessed Species	*Climate Change Sensitivity*[1]	*Non-Climate Stressors*	*Adaptive Capacity*[2]
Steep stream dwelling			
Rocky Mountain Tailed Frog	M-H	H	V Poor
Coastal Tailed Frog	M-H	H	V Poor
Coastal Giant Salamander	M-H	M-H	V Poor
Small wetland breeding			
Western Toad	M-H	H	Poor
Northern Leopard Frog	M-H	H	Mod-poor
Wood Frog	M-H	M	Poor
Northern Red-legged Frog	M-H	M-H	Mod-poor
Great Basin Spadefoot	H	M-H	Mod-poor
Blotched Tiger Salamander	M-H	H	V Poor
Northwestern Salamander	M-H	M	NA
Large wetland frogs			
Columbia Spotted Frog	M	M-H	Mod-poor
Oregon Spotted Frog	M	H	Poor
Terrestrial salamanders			
Wandering Salamander	M-H	M-H	V Poor
Ensatina	M	M	NA
Coeur d'Alene Salamander	H	H	V Poor

1. The highest value for sensitivity based on habitat, abiotic and biotic factors
2. Based on reproductive and dispersal capacity.

As a class, amphibians share climate-relevant traits. Species have adapted to ecosystems ranging from montane to lowland, from rainforest to desert, but all depend on water—or at least on moist microclimates—for survival and reproduction. In a warmer climate, with drier summers, wetlands, small streams and moist microclimates will become vulnerable; many amphibians depend on habitats that are very sensitive to climate change. Amphibians are sensitive to abiotic climate factors; in particular, they have low tolerance for desiccation, and must find moist refuges. They seem less sensitive to biotic factors that are related to climate: as residents, their foraging does not depend on close phenological match with prey species, and the relationship between climate change and disease prevalence is uncertain. Many amphibian populations and species face considerable non-climate threats, including the disease chytridiomycosis[c] that has devastated some species (although recent research suggests that chytridiomycosis could be linked to climate change[51]), introduced fish and invasive bullfrogs that prey on amphibians in formerly safe habitats, and habitat loss, degradation and fragmentation due to a variety of anthropogenic activities. Amphibian species share a very low capacity for dispersal. Some migrate short distances between seasons, but many, particularly salamanders, move metres rather than kilometres. Some species have long generation times (up to 10 or more years), further limiting adaptive capacity.

5.1 Existing Assessments

Species assessed using the Climate Change Sensitivity Index developed in the PNW (five frogs and the western toad) were all classified as highly sensitive. The Alberta study, using the CCVI, rates amphibians as more sensitive than other classes of vertebrates. It rates the northern leopard frog, great basin spadefoot and Columbia spotted frog as highly vulnerable, but, unlike the PNW CCSI, rates the western toad and wood frog as only moderately vulnerable. The IUCN threat calculator rates climate change threats primarily as low (except high-low for the coastal tailed frog and moderate-low for the wandering salamander). This threat is determined over a 10-year period, however; several reports note the inappropriateness of such a short time frame in considering climate change impacts.

5.2 Results by Grouping

The text below describes the climate-change sensitivity, non-climate stressors and adaptive capacity of species within each group, providing a narrative to explain the ratings in Table 6.

5.2.1 Steep-stream-dwelling Amphibians

Tailed frogs and the coastal giant salamander live in cold, clear, steep, fast-flowing streams. Climate change pressures likely include altered magnitude and timing of peak flows, decreased summer flows, increased sedimentation due to peaks or storm events, warmer water, and changed stream morphology and potentially flow persistence. These changes pose potential threats to species with a multi-year aquatic larval phase, low tolerance for sedimentation and narrow temperature tolerance. These three species also face high non-climate threats, including sedimentation from roads and development activities, changed seral stage, and introduced predatory fish at lower elevations. These species have not yet been impacted by chytrid disease, perhaps because of water temperature or perhaps because

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[c] caused to date by *Batrachochytrium dendrobatidis;* another species *B. salamandrivorans* has not yet reached North America

they use fast-flowing streams. They have very poor adaptive capacity, with long generation times (about 10 years) and very low dispersal ability.

5.2.2 Shallow-wetland-breeding amphibians

Many amphibians breed in small and/or shallow wetlands to avoid predation by fish. The main climate change pressure is drying of small wetlands due to lower snowpack and warmer summers[52]. Water temperature will increase, but there is no information to suggest that these species are sensitive to warmer water. The Great Basin spadefoot toad and tiger salamander depend on these wetlands in the already-warm Southern Interior Ecoprovince. Other species within this category also depend on shallow wetlands, but are not limited to the warmest ecoprovince (although the northern leopard frog is limited to a single managed marsh in Creston); hence risk is somewhat lower. These species face significant non-climate stressors including chytrid fungus (particularly Northern Leopard Frog and Western Toad; other species seem less affected), and competition and predation by introduced and invasive species including stocked fish and bullfrogs. The Great Basin spadefoot and Tiger Salamander face decreased water table due to irrigation, trampling of riparian areas by cattle, and pollution. The red-legged frog is challenged by intense forest harvesting. All species have moderately-poor or poor adaptive capacity, with short dispersal distances.

5.2.3 Large wetland frogs

The Columbia and Oregon spotted frogs breed in larger wetlands with shallow edges and emergent vegetation surrounded by forest. Columbia frogs overwinter in deep wetlands and lakes, and are aquatic generalists. These larger wetlands are likely less sensitive to climate change than the smaller wetlands used by other species. Both species lay eggs communally. If water levels fluctuate, entire populations of embryos may be susceptible to desiccation. Both species face non-climate threats from habitat loss and degradation, introduced species (bullfrog, fish, reed canary grass infilling wetlands) and disease (ranavirus). The Oregon spotted frog has a very limited distribution in BC. The two frogs have moderately poor to poor adaptive capacity.

5.2.4 Terrestrial salamanders

Lungless salamanders need moist microhabitats to breathe. These microhabitats will likely decline with increased drying, particularly in summer. The coastal wandering salamander stays moist under the bark of large downed wood. Populations in the CDF are likely more vulnerable than those in the CWH based on projected climate envelopes. Tsunamis may impact populations on the coast, potentially destroying two island populations. The Coeur d'Alene salamander uses waterfall spray zones, steep creeks and moist rock fissures to stay moist in a dry landscape. Drier conditions in the Columbia basin will likely decrease movement and increase fragmentation. The cold-adapted, montane salamander may also experience heat stress. Ensatina are generalists, and likely less sensitive than the other two species in this grouping. Salamanders have not yet experienced mortality due to chytrid fungus, but a new species of the fungus—lethal to salamanders—has recently spread from Asia to Europe and may pose a serious health risk in the future. Non-climate threats include forest harvesting that decreases the amount of large downed wood for the wandering salamander and road building for several locations of the Coeur d'Alene salamander. Salamanders are strongly philopatric and have very poor adaptive capacity.

5.3 Mitigation Opportunities

Simple, robust management opportunities exist to mitigate climate change pressure for many amphibian species (Table 7). Primary mitigation activities include hydrological and thermal buffering by leaving sufficient riparian cover and not drawing down water during dry periods. For sensitive species, higher levels of retention than status quo management may be necessary; for example, small wetlands and feeder drainages hosting sensitive species need sufficient retention to both maintain full shade and remain windfirm. Strategies designed to reduce non-climate threats (e.g., not stocking breeding habitat with fish, reducing habitat loss and degradation) would reduce potential cumulative effects. Any strategies that reduce habitat loss and maintain connectivity will also increase resilience to climate change impacts.

Table 7. Potential mitigation activities for assessed amphibians

Mitigation
Steep stream dwelling: Rocky Mountain tailed frog, coastal tailed frog, coastal giant salamander
• buffer small, steep streams (e.g., 30m buffers have been designated as WHAs for Rocky Mountain tailed frogs; these buffers could be monitored for effectiveness) • provide well-located corridors between streams and upland for dispersal • follow strategies designed to mitigate other threats
Small wetland breeding: western toad, northern leopard frog, wood frog, northern red-legged frog, Great Basin spadefoot, northwestern salamander, blotched tiger salamander
• buffer wetlands of all sizes • buffer small non-fish-bearing streams (particularly for northwestern salamander) • conserve water levels in small wetlands (don't draw down during dry periods) • provide well-located corridors between breeding sites and upland habitat • follow strategies designed to mitigate other threats
Large wetland species: Columbia spotted frog, Oregon spotted frog
• buffer wetlands • follow strategies designed to mitigate other threats
Terrestrial salamanders: wandering salamander, ensatina, Coeur d'Alene salamander
• leave sufficient large live trees and downed wood for habitat and to allow dispersal (for wandering salamander) • buffer small non-fish-bearing streams (for Coeur d'Alene salamander movement) • maintain cover at known sites (for Coeur d'Alene salamander)

6 Mammals

Thirty-four mammal species have high conservation priority in BC (Conservation Framework Priority 1 or 2 in any category)[53]. Other species are important for the key role they play in ecosystems or as part of functioning predator-prey systems. For example, beavers are ecosystem engineers that might become more important wetland creators as the climate changes. Some large species have particular cultural or subsistence significance to people (e.g., moose, grizzly bear). Assessed mammals include 15 representatives from the high conservation priority list plus 18 other key species (total 33 species). These species can be divided into five groups based on habitat-use traits that are relevant to climate change: habitat generalists, alpine specialists, grassland specialists, old forest specialist, and riparian specialists. Bats form a sixth group (Table 8). Any classification system can have fuzzy borders; these mammal groupings are particularly so: grizzly bears are habitat generalists, but salmon specialists; southern red-backed voles are oldgrowth indicators in some regions but not others; riparian specialists vary widely from fishers who need massive cottonwoods to water shrews who need moist microclimate near aquatic ecosystems. Groupings include species of varying size; these will have different adaptive capacities (e.g., large mammals generally have higher dispersal potential). Some species that have not yet been assessed could be incorporated into the groups listed, though variation within each group remains higher than for amphibians.

Table 8. Climate change sensitivity of 33 mammal species.

Assessed Species	*Climate Change Sensitivity[1]*	*Non-Climate Stressors*	*Adaptive Capacity[2]*
Generalist			
Coyote	L	L	Mod-good
Grey Wolf	L	M	Mod-good
North American Porcupine	L	L	Mod
Snowshoe Hare	L	M	Mod-good
White-tailed Deer	M	M	Mod-good
Mule Deer	M	M	Mod-good
American Black Bear	L	M	Mod
Canada Lynx	M	M	Mod-good
Elk	M	M	Mod-good
Grizzly Bear	M-H	H	Mod-poor
Alpine specialists			
Hoary Marmot	H	L	Mod-poor
Mountain Goat	H	M-H	Mod-poor
Northern Bog Lemming	H	NA	Mod-poor
Wolverine	H	M_H	Mod-poor
American Pika	H	L	Mod-poor
Grassland specialists			
Wood and Plains Bison	M	H	Poor
Bighorn Sheep	M	M-H	Moderate

Assessed Species	*Climate Change Sensitivity*[1]	*Non-Climate Stressors*	*Adaptive Capacity*[2]
Thinhorn Sheep	M	M	Moderate
American Badger	M	H	Moderate
Old forest specialists			
Southern Red-backed Vole	M	M	Moderate
Caribou[54]	M-H	H	Moderate
Riparian specialists			
American Beaver	M	M	Moderate
American Water Shrew	M	M	Mod-poor
Pacific Water Shrew	M	H	Mod-poor
Fisher	M	H	Moderate
North American Water Vole	M-H	M	Moderate
Moose	M-H	M-H	Mod-good
Mountain Beaver	M-H	H	Poor
Bats			
Hoary Bat	M	M	Mod-good
Pallid Bat	M	M-H	Moderate
Townsend's Big-eared Bat	M	M-H	Moderate
Little Brown Myotis	M	H	Moderate
Northern Myotis	M	H	Moderate

1. The highest value for sensitivity based on habitat, abiotic and biotic factors
2. Based on reproductive and dispersal capacity.

As a class, mammals have adapted to a vast range of ecosystems. Many species are generalists, with plasticity (ecological or behavioural) that allows them to survive and thrive in a variety of habitats. Many carnivores, with parental care and high ability to learn, demonstrate this flexibility that makes them resilient to change. Other species depend on particular habitats, some of which are sensitive to climate change: for example, interior alpine ecosystems are projected to shrink by 80% by 2080. Most mammals are fairly insensitive to abiotic climate factors; exceptions include thermally sensitive moose and pikas. Many species are sensitive to changes to snowpack: decreased snowpack reduces thermal buffering for small subniveal mammals; increased crust following freeze/thaw events poses movement and energetic stresses, and increases predation probability, for heavy mammals, particularly ungulates. There remains high uncertainty about many biotic climate factors. Exceptions include grizzly bears in western populations that are known to be sensitive to declines in salmon and increased stress to caribou posed by shifting distribution of alternative prey species (in response to a mix of climate and development factors) that increase predation rate and, potentially, disease transmission to caribou. For most species (except for migrating bats), foraging does not depend on close phenological match with prey species, although changed green-up timing may cause a mismatch with ungulate calving. Change in disease prevalence is likely, but difficult to predict. Many mammals face considerable non-climate threats, primarily due to habitat loss and degradation due to anthropogenic development (urbanisation, roads, forestry, hydroelectric flooding, other industry, agriculture). Domestic livestock transmit disease to some species of ungulates. Colonial cave-dwelling bat species will likely be extirpated due to white-nose fungus that is travelling west across Canada with mortality rates well over 90%. Mammal species vary considerably in their reproductive rate and capacity to disperse. Dispersal potential is related to body size and diet type (large mammals disperse further; carnivores disperse further than herbivores and omnivores)[55]. In general, small species have high reproductive rates but low dispersal, while large species have lower reproductive rates and longer dispersal potential.

6.1 Existing Assessments

The Climate Change Sensitivity Index developed in the PNW classes alpine, riparian and old forest specialists, as well as bats, as having medium or high sensitivity, and classes generalist species as low or medium sensitivity (with the exception of the lynx). The Alberta study, using the CCVI, rates alpine specialists and caribou as highly vulnerable, riparian specialists and bison as moderately vulnerable and a single bat, and generalist species (except for the snowshoe hare) as not vulnerable. Of species assessed by both processes, the two indices are particularly inconsistent in rating the little brown myotis (highly sensitive in the CCSI, but low-moderate in the CCVI), and moose and fisher (highly sensitive in the CCSI, but moderate in the CCVI). Section 3.3.1 describes some of the challenges involved with using these assessments. The IUCN threat calculator rates climate change threats over 10 years primarily as negligible to low (except high for bison

6.2 Results by Grouping

The text below describes the climate-change sensitivity, non-climate stressors and adaptive capacity of species within each group, providing a narrative to explain the ratings in Table 8.

6.2.1 Generalists

Generalists are most resilient to climate change, already surviving in a variety of habitats and conditions. Coyotes, wolves and bears are capable learners, with extreme behavioural plasticity. Snowshoe hare camouflage will increase its mismatch with snow. Grizzly bears face the biggest challenge as habitat generalists, but salmon specialists. The projected decline in salmon with climate change poses a significant threat. Most generalist species also face relatively low threat from non-climate factors, again with the exception of grizzly bears that face considerable threat due to human access to their habitat. Generalists have the potential to disperse long distances. Most have relatively short generation time (except for bears), but produce few young (except for snowshoe hares). Overall adaptive capacity is moderate to good except for grizzly bears.

6.2.2 Alpine Specialists

Alpine specialists face known threats as high elevation alpine and subalpine islands shrink with warmer temperatures. Other climate pressures include changes to snow cover: wolverines den in areas with persistent spring snow; pikas depend on snow to buffer cold. Changed time of green-up could impact mountain goat breeding. Non-climate stressors are limited to human access and recreational activities for most species; mountain goats are particularly sensitive to disturbance. All species have moderately-poor adaptive capacity, either due to small dispersal distances (particularly challenging in moving to surviving pockets of alpine ecosystems) or long generation time.

6.2.3 Grassland Specialists

Grassland habitats are projected to expand with warmer temperatures and increased fires, potentially benefitting grassland specialists. Climate change pressures include changes to snowpack (particularly challenging for bison with their high loading) and biotic shifts, including potential expansion of winter tick range to higher elevation, increased disease (in part due to expansion of white-tailed deer), and a decrease in nutritious forage if invasive species (e.g., cheatgrass, knapweed) outcompete native species. Non-climate pressures are high for bison, due to population control and containment, and for badgers, due to road-kill. Disease transmission from domestic livestock and loss of habitat pose a threat to sheep and bison. The grassland species assessed (none are very small) can travel long distances; additional work is needed to address small grassland mammals. Wood bison have poor adaptive capacity due to low genetic diversity.

6.2.4 Old-Forest Specialists

Although many mammals use old forest, fewer require it. The two species assessed within this group represent opposite extremes in sensitivity. The southern red-backed vole is an old-growth indicator in some regions, but uses a variety of habitats elsewhere. Voles depend on mycorrhizal fungi; abundance may shift with changes in precipitation. Otherwise, projected climate pressures are low to moderate. Caribou depend on arboreal as well as terrestrial lichens, and depend on old forest for part of the year. Increased disturbances (fire and insects) will change forest succession; the mountain pine beetle has already changed available lichen forage. Abiotic climate change pressures for caribou include increased snow crust that makes terrestrial lichen harder to access, decreased snow patches leading to physiological stress in summer, and changed snow depth that may limit spring dispersal and/or increase neonatal predation. Climate-related changes are projected to favour deer and other alternative prey species, increasing predator populations and subsequent mortality probability for caribou, and facilitating disease. Winter ticks will likely increase their impact, and longer growing seasons could increase harassment by summer insects. Changed timing of spring green-up may lead to a mismatch of high quality forage and calving. Non-climate pressures on caribou are high, including habitat loss, degradation and fragmentation due to industrial development, increased young seral habitat, increased predation due to habitat alteration, and increased human access leading to disturbance, mortality and increased predator efficiency. In terms of adaptive capacity, voles have a high reproductive rate, but low dispersal capability; caribou have a low reproductive rate (calf mortality is high) but high dispersal capability, although poor habitat presents a barrier due to high mortality.

6.2.5 Riparian Specialists

Riparian specialists include some of the largest and smallest mammals. Moose enjoy wetland vegetation and the cooling water; fisher use massive cottonwoods for denning; water shrews eat aquatic invertebrates and need moist riparian microclimates. Hydroriparian habitats, particularly small streams and wetlands, will change. Mountain beavers live in areas with cool and humid microclimates, denning near small streams and foraging in wet meadows; these habitats could decrease, particularly affecting the east Cascades sub-population. Current populations are limited by aridity and high summer temperatures. Water voles live close to water in subalpine and alpine meadows as well as seasonal streams and marshes—all vulnerable ecosystems in a changing climate. Moose are very sensitive to heat in all seasons. They are well adapted to cold climates and deep snow, but will be challenged by increased freeze/thaw events. Increased winter tick infestations are likely linked to climate change. Beavers use a variety of water sources. Their engineering abilities reduce their sensitivity, although increased variability in water depth could pose challenges. Beavers may be increasingly important as ecosystem engineers with climate change, potentially creating new wetlands to replace those lost to a warmer climate. Non-climate pressures include habitat loss and degradation (critical for populations of mountain beaver and Pacific water shrew living in the lower mainland), impacts of winter recreation on the subniveal environment and trapping (beaver and fisher, the latter mostly incidental). The riparian specialists assessed all reproduce relatively rapidly (the shrews and vole very rapidly), but vary considerably in dispersal potential.

6.2.6 Bats

The ability to fly, nocturnal foraging and use of climate-buffered hibernacula by some species separates bats from other mammals. Many species are generalists, with populations limited by their particular hibernacula and roosting requirements. Cave-dwelling bats, although sensitive to small changes in microclimate, may be less sensitive to climate change than many mammal species. Climate change may alter the peak of insect abundance, affecting foraging success and reproduction, especially for migrating species such as the hoary bat, although warmer temperatures could also lead to hibernating species, including Townsend's big-eared bat and Myotis species, becoming metabolically active when prey abundance is low. White nose fungus poses the largest threat to colonial cave-dwelling bats, including the little brown bat and northern bat. This fungus is travelling west at a rate of 200-250 km/year, resulting in mass mortality and extirpation of some populations. White nose fungus was introduced from Europe a decade ago. Its spread does not seem related to climate change, but to lack of immunity in North American bats. Other non-climate pressures include loss of roost sites (particularly those in buildings) and human disturbance of hibernating bats in caves. Bats' adaptive capacity is moderate: they have high dispersal capacity, but several species have long generation times and most have a single offspring per year.

6.3 Mitigation Opportunities

Climate-change mitigation options exist for some, but not all climate change pressures (Table 9). For example, mitigating changes to snowpack resulting from increased freeze/thaw regimes will be daunting. Similarly, reducing risks associated with changed patterns of disease and parasites will be challenging due to unpredictability in relation to epidemic triggers and potential for rapid evolution in disease organisms. Measures to reduce non-climate threats could decrease potential cumulative effects and reduce the stress associated with these changes; essentially, species will be more resilient to changed conditions if they have near-natural populations and sufficient connected suitable habitat to allow movement. Examples of strategies to reduce cumulative effects include deactivation of roads to minimise disturbance in forested areas, and maintaining forested buffers between roads and open cut-blocks.

Table 9. Potential mitigation activities for assessed mammals

Mitigation
Generalists: porcupine, snowshoe hare, white-tailed deer, mule deer, elk, coyote, grey wolf, lynx, black bear, grizzly bear
• none needed for most species • for salmon-dependent grizzly bears, maintain salmon populations (e.g., maintain fully-functioning riparian buffers, maintain water quality, ensure fish passage, prevent over-harvest) • maintain low-snow areas (e.g., by maintaining forest cover or conserving south-facing slopes and wind-blown areas) • follow strategies designed to mitigate non-climate threats
Alpine Specialists: American pika, hoary marmot, northern bog lemming, mountain goat, wolverine
• as alpine areas shrink, regulate human activities to avoid impacts associated with increased overlap with alpine species (e.g., changes to snowpack, disturbance) • follow strategies designed to mitigate non-climate threats
Grassland Specialists: bison, bighorn sheep, thinhorn sheep, American badger
• as grasslands expand, particularly in southern regions, maintain native grass and minimise invasive plant species • follow strategies designed to mitigate non-climate threats
Old Forest Specialists: southern red-backed vole, caribou
• maintain sufficient old forest habitat to buffer changes in temperature and moisture and allow for dispersal (for vole) • maintain sufficient old forest for caribou as disturbance rate increases • follow strategies designed to mitigate non-climate threats; because caribou are particularly vulnerable to cumulative effects, avoid human activities in caribou habitat
Riparian Specialists: North American water vole, beaver, moose, American water shrew, Pacific water shrew, mountain beaver, fisher
• buffer wetlands of all sizes and small streams to maintain moist, cool microclimate • buffer wet seeps and other riparian habitat in mountain beaver range • maintain connectivity of forest cover for dispersal, along riparian zones and to upland • conserve water levels in small wetlands (don't draw down when dry) • follow strategies designed to mitigate non-climate threats
Bats: little brown myotis, northern myotis, Townsends' big-eared bat, pallid bat, hoary bat
• ensure protection of hibernacula with the ability to maintain necessary microclimatic conditions • follow strategies designed to mitigate non-climate threats

7 Birds

One hundred and fifty-two bird species have high conservation priority in BC (Conservation Framework Priority 1 or 2 in any category)[56]. Other species are important for the key role they play in ecosystems (e.g., pileated woodpeckers).

Birds differ from other wildlife groups in the quantity of monitoring data available through breeding bird surveys and other programs. Environment Canada's 2012 report on the State of Canada's Birds[57] provides an excellent high-level overview of population trends for groups of birds across regions of Canada and includes some discussion of climate-change impacts where they are known or suspected. For most species, BC Conservation Status reports include insufficient data for use in the proposed framework, and even COSEWIC reports, except for the most recent, do not include the most recent information on trends and potential threats. For example, several reports note "no threat" for species that have subsequently declined drastically (e.g., northern goshawk).

Relevant existing groupings of birds[58] to assess potential impacts of climate change include aerial insectivores, forest birds, marine birds, waterfowl, other water birds, raptors, grassland birds, shorebirds and alpine birds (only a small selection have been assessed to date; Table 10).

Table 10. Climate change sensitivity of 5 bird species.

Assessed Species	*Climate Change Sensitivity[1]*	*Non-Climate Stressors*	*Adaptive Capacity[2]*
Aerial insectivores			
Barn swallow	M-H	M	Mod-good
Forest birds			
Northern goshawk	H	H	Moderate
Marine birds			
Marbled murrelet	M-H	H	Mod-poor
Waterfowl			
Barrow's goldeneye	M	M-H	Mod-good
Other water birds			
American bittern	M	M-H	NA

1. The highest value for sensitivity based on habitat, abiotic and biotic factors
2. Based on reproductive and dispersal capacity.

Many groups of birds are declining in BC and elsewhere, often from unknown causes. Aerial insectivores have decreased the most dramatically since the 1980s, with long-distance migrants declining most[59]. Climate change poses several challenges to birds, and is at least partially responsible for declines. Phenological match between prey sources (particularly insects) and migration and/or nesting is crucial for survival and reproduction. Many bird species rely on abundant insect populations to feed fast-growing nestlings. If nesting period becomes uncoupled from food availability, more nestlings will die[60]. In a contrasting example of decoupling, nesting during peak blackfly abundance can increase nestling mortality due to blood loss and parasite transmission[61]. Declining insect populations is the most likely explanation for the decline in aerial insectivores; this decline in food during migration could be related to large-scale timing or magnitude changes in temperature and rainfall as well as to pesticide use[62]. Altricial nestlings are more exposed to the elements than most juvenile mammals, and are particularly sensitive to temperature extremes (cold and warm) and storms. In some species, nesting time has decoupled from optimum weather patterns: warmer temperatures have led to earlier nesting times, but cold snaps in early spring have increased mortality.

Most birds have good dispersal capacity and should be able to follow ecosystems and climate as it changes. Although some species are expanding their range, however, recent work suggests that North American passerine species are shifting the equatorial edge of their range northward, likely due to heat stress to nestlings, but are not expanding their range northward although climatic conditions should be becoming suitable[63]. Likely climate is not the limiting factor at the northern extent. Hence, ranges are shrinking into narrower bands.

7.1 Existing Assessments

The Climate Change Sensitivity Index developed in the PNW classes very few species as having low sensitivity (American crow, red-tailed hawk, barred owl). Aerial insectivores, alpine species, many marine species and some water species are classed as high sensitivity. The Alberta study, using the CCVI, rates many species as low vulnerability, surprisingly including some aerial insectivores. The two indices are inconsistent for many species, with the PNW ratings higher than the CCVI ratings. The IUCN threat calculator rates climate change threats over 10 years primarily as negligible for goshawk (at odds with a recent precipitous population decline that may be related to changed phenology leading to an unpredicted increase in blackfly loads on nestlings[64]) and moderate for marbled murrelet.

7.2 Results by Grouping

7.2.1 Aerial insectivores

Aerial insectivores have decreased globally, and BC is no exception. Climate change, combined with pesticide use, has likely decreased insect populations along migration routes and increased mortality[65]. Storms can cause mass mortality; if they increase in frequency, more birds will die en route.

7.2.2 Forest Birds

BC's forest birds have declined, with species associated with mature forest decreasing most steeply (e.g., pine siskin, red crossbill). These species are vulnerable to habitat loss through forestry and increased climate-driven disturbance including the mountain pine beetle. Forest birds are likely impacted by a combination of habitat loss and mismatched phenology. The northern goshawk provides an example: breeding goshawks have declined precipitously by 96% in central BC (only 2 of 72 known nesting areas were occupied). Reasons for the decline remain uncertain, but nestling mortality due to blackfly attack and habitat loss seem likely candidates.

7.2.3 Marine birds

Pacific seabirds have declined for a variety of reasons. Climate-related pressures include, for example, toxins from dinoflagellate blooms and loss of sand lance and other favoured prey due to warmer ocean temperatures. Phenology mismatches are also an issue as plankton populations peak earlier in the season, and are less available for foraging. Non-climate pressures include, for example, introduced rats and raccoons that eliminate nesting colonies, particularly damaging to ancient murrelet populations, fishing bycatch and oil spills.

7.2.4 Waterfowl

As a group, waterfowl have increased in BC, with Canada geese, hooded mergansers and ring-necked ducks more than doubling in BC since 1970. Some species (e.g., common loon) are able to access forage in deeper lakes that have previously been limited by ice. Some species, including the great blue heron, have decreased. Small wetlands are most productive for waterfowl; these wetlands are also most sensitive to drought[66]. Species nesting in emergent vegetation are also sensitive to changes as habitat could decline rapidly in shallow wetlands as water levels drop.

7.2.5 Shorebirds

Migratory shorebirds depend on wetland and upland habitats along their journey. Their decline may be linked to habitat loss and degradation rather than to climate change. Rising sea levels will flood coastal stopover habitats and change estuary dynamics.

7.2.6 Alpine Specialists

Alpine specialists face known threats as high elevation alpine and subalpine islands shrink with warmer temperatures. Few birds are alpine specialists: ptarmigan are likely the most sensitive.

7.2.7 Grassland Specialists

Grassland specialists are declining in BC, most likely due to habitat loss rather than climate change. It is unknown how much an increase in invasive species will impact these species. Whether projected increases in grassland will be beneficial to birds is unknown.

7.3 Mitigation Opportunities

Climate-change mitigation options are limited for birds. Buffering changes to wetlands and avoiding drawing down water levels could be useful for some waterfowl, but addressing phenological mismatches is only amenable to mitigation through reducing carbon released. Measures to reduce non-climate threats could decrease potential cumulative effects and reduce stress. Maintaining sufficient habitat (e.g., large forested areas for goshawks, riparian reserves with large trees for cavity-nesting waterfowl) can increase resilience to climate change impacts.

8 Freshwater Fish

Thirty-nine fish species have a high conservation priority in BC (Conservation Framework Priority 1 or 2 in any category). Other species play keystone roles in ecosystems. Anadromous species, including BC's iconic salmon, transport a vast biomass of marine-derived nutrients upstream, feeding a complex terrestrial food chain and fertilizing riparian areas. BC holds global responsibility for maintaining salmon. Bull trout are apex predators requiring large areas of connected, intact habitat, and requiring the coldest water of any Pacific salmonid.

Considerable literature assesses climate change risks to salmon and species at risk; much less exists for other species. Assessed fish include several salmonids with different habitat requirements and a small set of other species. Freshwater fish can be grouped by habitat requirements that relate to types of sensitivity: anadromous species, cool steep stream species, warm gentle stream species and lake species (Table 11). Most fish use several habitats, and many species include populations that use different suites of habitats (e.g., some coastal cutthroat trout are resident in small streams while others travel to the ocean).

Table 11. Climate change sensitivity of 10 fish species.

Assessed Species	*Climate Change Sensitivity*[1]	*Non-Climate Stressors*	*Adaptive Capacity*[2]
Anadromous			
Coho salmon	H	M-H	Mod-good
Chinook salmon	H	M-H	Mod-good
Sockeye salmon	H	M-H	Mod-good
Eulachon	H	M-H	Mod-good
Cooler, steeper streams			
Bull trout	H	M-H	Moderate
Columbia sculpin	M-H	M-H	Mod-poor
Arctic grayling	M-H	M-H	Moderate
Warmer, gentler streams and rivers			
Coastal cutthroat trout	H	H	Mod-poor
Sturgeon	M-H	H	Mod-poor
Lake and/or stream residents			
Threespine stickleback	M	M	Mod-good

1. The highest value for sensitivity based on habitat, abiotic and biotic factors
2. Based on reproductive and dispersal capacity.

Fish live within a mostly linear habitat that conducts heat and transports sediment, inorganic chemicals and organic matter downstream. As a class, fish are very sensitive to changes in water quality, including temperature, chemical composition and sediment load. Climate change is expected to impact BC's fish distributions via altered stream flow and water temperature. Stream-dwelling species are sensitive to changes in their habitat caused by changed hydrology, including flooding, low-flows and changed seasonal patterns. Rising temperatures in lakes and streams may exceed preference ranges or tolerance for some species, while warm-water fish may expand their ranges. Increased water temperature can alter development, change timing of migration and spawning, increase disease frequency, provide migration barriers and alter species abundance[67].

8.1 Existing Assessments

The Climate Change Sensitivity Index developed in the PNW rates chinook salmon as high sensitivity. No other fish species have been assessed using this index and fish were excluded from the Alberta study.

8.2 Results by Grouping

The text below describes the climate-change sensitivity, non-climate stressors and adaptive capacity of species within each group, providing a narrative to explain the ratings in Table 11.

Note that many species belong in more than one grouping.

8.2.1 Anadromous Fish

Most research has focused on salmon. Anadromous fish habitat includes the ocean and estuary environments, the migration route and the freshwater environment. Estuaries and associated wetlands provide vital nursery areas. Freshwater streams provide important habitat for reproduction and growth in most salmon species. High mortality of fish in the early life stages results from predation, siltation, high water temperatures, low oxygen concentration, loss of stream cover and in-stream structure, and reductions in river flow.

A quarter of the world's sockeye populations, including 10 BC runs, are at risk of extinction due to cumulative effects of climate and non-climate pressures[68]. Non-climate pressures include overfishing (due to mixed stock fisheries that take high proportions of smaller stocks), negative effects of hatcheries and habitat degradation (spawning, rearing and migration habitat) associated with forestry, urbanisation and hydropower development. Climate effects include changed ocean conditions that lead to poor marine survival, warmer streams and lakes leading to increased disease prevalence and mortality, and changed peak and low flows that impact stream habitat. High temperatures are lethal to sockeye salmon. Fraser River sockeye populations have decreased during warm years. Over time, sockeye may be unable to migrate along the Fraser due to water temperature[69]. Eulachon only spawn in streams with high snowpacks or glaciers, and hence are sensitive to glacial loss and decreased snow.

Fish distributions will change as water warms and streamflow changes. Migration timing and food availability are related to temperature and flow; warmer temperatures delay upstream migration in some populations, but hasten migration in others. Increased variability in water flows could affect spawning habitat through erosion, sedimentation, and exposure during low flows. In systems transforming from snow to rain-driven, the long, stable spring recession period will be lost.

Other than ocean-going species, aquatic organisms can only migrate within the stream/lake system, limiting adaptive capacity. Cold water refugia within a population's range may provide some thermal buffering. Salmon populations have evolved a diversity of strategies in response to variable freshwater system conditions. This "portfolio effect" has increased resilience to changed climate conditions over the past century, as some populations thrive while others shrink. Maintaining a diversity of stocks and stream habitats increases salmon resilience[70]; conversely, loss of genetic variability will decrease adaptive capacity.

8.2.2 Cooler, Steeper Stream Residents

Small, cold, steep streams make up a large portion of BC's stream systems. Fish living in cool steep streams are sensitive to changes to temperature, stream flow and channel morphology. Many species, including bull trout and Arctic grayling, are cold-adapted, and very sensitive to increased temperatures. Bull trout are apex predators requiring large areas of connected, intact habitat. They require the coldest water of any Pacific salmonid. Modelling in the US Pacific Northwest suggests that bull trout will lose 95% of their largest contiguous pieces of range and most of the smaller areas[71]. This fragmented range will be more vulnerable to increased extreme disturbances related to fire. Mountainous regions may provide cold water refugia, at least for several decades. Although Columbia sculpin live in a warmer region of BC, they use water cooled by snowmelt or groundwater. Changes to peak flow timing and intensity can alter stream habitat considerably in small streams.

Non-climate change pressures include fragmentation due to stream crossings (these small streams are often crossed by roads), loss of riparian habitat, and overfishing for some species (e.g., grayling and bull trout).

Adaptive capacity varies with dispersal capability, although even those species with the ability to travel long distances are frequently limited by dispersal barriers. Bull trout living in areas vulnerable to change have the least genetic diversity and may be subject to inbreeding, reducing adaptive capacity.[72]

8.2.3 Warmer, Gentler Stream and River Residents

Habitat in low-gradient streams and rivers is threatened by low summer flows, decreasing channel size and drying side channels. Cutthroat trout spawn in spring and use high flows to ascend stream networks. They could be indicators of changes in spring flow regimes. Low gradient small streams may experience higher temperature changes than steeper, faster-flowing streams. Fish that live in low-gradient streams and rivers vary in their temperature sensitivity. For example, coastal cutthroat trout are sensitive to changes in flow that alter habitat, but less sensitive to warmer temperature. White sturgeon tolerate warm water as adults, but high temperatures decrease survival of juveniles, and particular temperature and flow regimes may signal optimal spawning conditions. Coastal cutthroat trout face non-climate pressures due to loss of riparian cover, development-related habitat fragmentation and water withdrawal. White sturgeon face non-climate pressures from dams and diversions as well as pollution (given their extreme life-span). Adaptive capacity is highly variable. Resident cutthroat trout are strongly philopatric, moving less than 100m, while sea-run trout travel many kilometres. Sturgeon have limited adaptive capacity due to their long generation time and disconnected sub-populations.

8.2.4 Lake Fish

Lakes will warm, changing thermal layering and nutrient mixing[73]. The amount of warming varies with lake location and characteristics; ice-covered lakes are warming at rates greater than air temperature[74]. Northern and southeastern BC will see the largest increases. As temperature warms, the composition of lake communities will change and trophic mismatches will increase as some species change their behaviour with temperature and others do not. As well as warming, small lakes could become smaller and shallower, reducing habitat and changing shoreline ecosystems. Coastal erosion may drain small coastal lakes, including the habitat of the unarmoured three-spine stickleback. Productivity could increase in northern latitudes where nutrients are not limiting. Non-climate pressures include introduced species and pollution. Adaptive capacity will vary with species.

8.3 Mitigation Opportunities

The principle climate-change mitigation option for fish is to provide thermal and hydrological buffering by maintaining riparian habitat[75]. Maintaining, and restoring as necessary, riparian habitat will also reduce many non-climate pressures. Avoiding water withdrawals that reduce summer low flows will be important to mitigate habitat loss and temperature change, particularly to low-gradient streams. Measures to reduce non-climate threats could decrease potential cumulative effects and reduce stress; for example, preventing pollution, minimising changes to fine and coarse sediment loading due to roads and to forestry, ensuring fish passage, and reducing fishing pressure, will potentially increase resilience. Introducing fish to lakes can pose risks to resident organisms (including other fish and amphibians); hence ensuring that fish introduction programs have appropriate goals (e.g., assisting migration), consider secondary effects and include adequate monitoring will increase the probability of maintaining ecological integrity. Maintaining connectivity will be critical to allow dispersal and increase adaptive capacity.

9 Ecosystems

Climate shapes disturbance regimes, species distributions and ecological communities. As populations decline, migrate or adapt to changed conditions, communities will disassemble and reassemble. Ecosystems will likely undergo both predictable and unpredictable ecological shifts: some ecosystems may remain relatively intact, with species moving in parallel upslope; others may change gently, retaining similar functional capacity; yet others will undergo regime shifts to new disturbance regimes, successional pathways and dominant species[76]. Many species, including trees, will not be able to migrate quickly enough to keep pace with shifting climate. The biggest shifts will be associated with intense disturbances, particularly when invasive species colonise and block historical successional pathways.

Climate envelopes (the climate associated with an ecosystem today) represent one way of integrating climate pressures to demonstrate potential ecosystem change, although it is critically important to recognise that “ecosystems do not migrate, species do”[77]. Models project that BC’s biogeoclimatic ecosystem climate envelopes will move up to 300m higher in elevation and 170km farther north by 2050[78]. Alpine, subalpine and sub-boreal ecosystems (BAFA, IMA, MS, SWB, SBPS, SBS) are projected to lose over 80% of their current range by 2080 (Table 12). Climate envelope models also predict that some ecosystem niches will expand. Envelopes for dry ecosystems (BG, PP, IDF) as well as the diverse moist conifer forests of the ICH are projected to more than double by 2080. Coastal ecosystems are projected to undergo the smallest change.

Table 12. Predicted change in the area of each biogeoclimatic zone over time (current range - % lost from current range + % gained from outside the current range). Shading shows change classes (> 60% loss; 59 – 20% loss; 20% loss to 20% gain; 20 – 100% gain; > 100% gain). Modified from Wang et al. 2012[79].

BEC Zone	Area (x 1,000 ha)	Change in climate habitat (% loss or gain)		
		2020s	2050s	2080s
MS	2,800	-44	-75	-88
SBPS	2,300	-45	-71	-85
BAFA	7,600	-47	-64	-81
IMA	1,200	-52	-74	-81
CMA	4,400	-16	-26	-45
SBS	10,300	11	-15	-44
SWB	8,000	-13	-49	-44
ESSF	17,200	-19	-21	-33
MH	3,600	-4	-7	-12
BWBS	15,700	13	12	11
CDF	200	-1	-3	19
CWH	10,800	22	40	69
IDF	4,500	42	78	91
BG	300	19	71	128
PP	400	61	115	211
ICH	5,600	76	200	325

Models predict that the climate favouring the grassland, shrubland and dry forest ecosystem types common to southern BC will move north and upslope, that climates suitable for moist forests will move upslope to replace subalpine forests, and that climates suitable for boreal spruce forests and alpine ecosystems will decrease substantially[80].

Determining the magnitude of ecological vulnerability requires comparing current and projected conditions for a particular area. Shifts to climate envelopes associated with similar plant communities suggest lower ecological stress. Smaller geographic distances between current and predicted ecological communities indicate a higher likelihood of migration and ecological recovery—that is, higher adaptive capacity. Analyses for ecosystems within the Nadina Forest District in Central BC (SBSdk, SBSmc2, ESSFmc) suggest that, at the site scale, the wettest and driest ecosystems may experience highest stress: while mesic site series share about half species between current and projected communities, wet and dry site series share fewer than a third of species[81]. It would be possible to complete similar analyses for the communities listed in the BC Species and Ecosystem Explorer.

9.1 Vulnerable Ecosystems[82]

9.1.1 Alpine ecosystems

Alpine tundra will shrink and some alpine islands will disappear as woody ecosystems (subalpine forests and shrublands) move upwards. Interior alpine ecosystems are projected to lose more than 80% of their area, while coastal alpine ecosystems are projected to lose about half.

9.1.2 Subalpine ecosystems

Subalpine ecosystems will move upwards and to shrink in area. Forested subalpine communities may become shrublands in some areas, because shrubs migrate faster than trees (a conversion that is already happening in Alaska[83]). Such a shift would change the ecological functionality and habitat value of these ecosystems.

9.1.3 Boreal and sub-boreal ecosystems

These ecosystems are projected to decline in area and to be replaced by moist interior conifer forest and/or dry interior forest depending on region and moisture regime.

9.1.4 Grassland ecosystems

In general, grassland ecosystems are projected to expand northward and upslope. Southern grasslands will expand into currently forested ecosystems, but are vulnerable due to the potential for invasive species to simplify complex native communities. Boreal grasslands in northern BC could be vulnerable in warmer wetter climates unless the warmer temperatures overwhelm increases in precipitation. These rare grasslands are already being invaded by woody vegetation. Subalpine grasslands in high elevation valleys may be vulnerable to encroachment by shrubs if the air warms too much to maintain the cold air ponding.

9.1.5 Wetlands

Wetlands are patchy, limited by topography, and sensitive to changes in hydrology; hence they are vulnerable to changes in temperature and precipitation. Shallow interior wetlands are likely to dry due to warmer temperatures, leading to moisture deficit, decreased snowpack and loss of glaciers. Wetlands that depend on stable hydrology may also be vulnerable. Marshes and fens, with fluctuating water tables, are likely less vulnerable.

9.1.6 Freshwater aquatic ecosystems

Changed patterns of precipitation, as well as loss of glaciers, will affect streams persistence and morphology. Small streams may experience more variable flows and decreasing habitat stability, particularly during the spring recession in systems that transition from snow- to rainfall-driven. Flooding or debris torrents associated with storms may destroy refugia. Cold-water habitats are vulnerable as air and water temperatures increase and summer low-flow periods elongate. Shallow lakes and ponds are also sensitive to temperature change, with changes to stratification dynamics. Their aquatic organisms are particularly vulnerable as they cannot easily migrate.

9.1.7 Marine-terrestrial interface ecosystems

Sea-level rise will engulf intertidal ecosystems and affect estuaries and coastal wetlands. Coastal storms will affect coastal ecosystems. Ocean acidification will affect a variety of species, including keystone marine species, with severe cascading effects that are already being felt.

9.2 At-risk Ecosystems

BC has global responsibility for 6 or 16 biogeoclimatic zones (CDF, ICH, MS, MH, SBPS, SBS[84]). Several of these zones, particularly the MS, SBPS and SBS, are projected to lose considerable area with climate change. At the broadest scale, four biogeoclimatic zones (CDF, IDF, PP, BG), representing approximately 5% of BC's area, are currently at risk due to historic ecosystem conversion[85]. These are also the ecosystems with the highest numbers of species and of species at risk. The climate envelopes supporting these ecosystems are projected to expand—and hence the ecosystems have the potential to increase their area. Unfortunately, these ecosystems are fragmented and already impacted by non-native invasive plants; mitigation activities that establish connectivity and limit invasive species will be important to increase adaptive capacity and the probability of retaining integrity. At a finer scale, more than half of the ecological communities described in BC are currently of concern. Low-elevation grasslands are rare and concentrated in at-risk BEC zones; grasslands will expand, but likely will be dominated by invasive species. Many wetlands have been converted or degraded, particularly in the Columbia and Fraser watersheds. Climate change poses further threats to these ecosystems. Estuaries are of concern due to their rarity and level of human impacts; sea-level rise and storms will likely impact estuaries further.

10 Adaptation and Mitigation

Climate change will increase unpredictability in weather and resource availability. Unpredictable environments select for traits such as early maturity, high fecundity, low parental investment and phenotypic plasticity. Generalist species, and those with high genetic diversity or existing phenotypic plasticity, will be the likely winners. Coyotes, crows, bullfrogs and warm-water fish will be able to exploit new conditions. Most specialised species, however, will lose. Even species that can migrate north to newly-suitable climates will be challenged by atypical ecosystems arising from changed disturbance patterns, increased variability and invasive species. It is not possible to change an organism's sensitivity, but it is possible to reduce exposure and to maintain adaptive capacity. Adaptation options for unpredictability include buffering ecosystems from rapid change by, for example, maintaining areas of old forest that buffer microclimate and conserving riparian buffers to minimise changes to water flow and temperature. Management options that favour adaptive responses and resilience include biogeographic connectivity that allows organisms to disperse to suitable ecosystems over long time periods[86].

Many adaptation strategies are similar across BC. With the exception of assisted migration, most strategies are not novel, but are elements of ecosystem management that require broader application. Expanding strategies beyond status quo actions will be necessary to maintain the resilience of moderately and highly sensitive species. For example, buffers around streams and wetlands hosting sensitive species should be wide enough not only to maintain full shade, but also to be sufficiently wind-firm to maintain shade over time.

Strategies to reduce overall risk include

1. **promoting resilience** by
   a. maintaining or increasing ecological diversity at all scales, including maintaining the full variety of habitats and tree diversity,
   b. focus on enduring features of the landscape as the core of climate adaptation areas,
2. **combating detrimental change** by
   a. providing thermal and hydrological buffers in the form of fully functional forest and other natural ecosystems; in particular, providing sufficient forested buffers around wetlands of all sizes and streams of all sizes is a robust strategy,
   b. avoiding water withdrawals from sensitive wetlands during hot dry periods,
   c. controlling invasive plants, particularly in ecosystems undergoing ecological transformation,
   d. avoiding disease transmission from domestic livestock;
3. **guiding ecological transformation** by facilitating dispersal:
   a. Maintain landscape connectivity within and across landscapes, including latitudinal, longitudinal and altitudinal corridors within BC and across jurisdictional boundaries, noting that intact natural landscapes provide the best opportunities for dispersal.
   b. Species migrate most easily through intact ecosystems that are similar to those they have left. Movement can be constrained by ecosystem degradation, roads, urban and agricultural development. For example, the yellow badger (*Taxidea taxus*) could spread through intact grasslands, savannah and open forest, but will be hampered by roads and other development. Encroachment of invasive species can also create ecosystems that are unsuitable for migrating species.
   c. Steep terrain provides a variety of climatic regions in close proximity, compressing ecosystems into elevational bands, with high biodiversity. Conserving ecosystems in mountains provide an excellent opportunity for allowing wildlife to survive through migration or adaptation. Climbing 100m up a mountain is similar to moving 1 degree of latitude.[87]
   d. Assist migration for selected species.
4. **limiting cumulative effects** of multiple land-use activities, including for example
   a. limiting industrial, agricultural and urban development in climate adaptation areas,
   b. avoiding increases in rate of cut following disturbances (e.g., salvage harvest),
   c. limiting density of roads and linear corridors to reduce barriers to dispersal,
   d. regulating recreational activities in sensitive ecosystems (particularly wetlands and alpine),
   e. ensuring that conservation levels are maintained in wetlands, ponds and lakes before water is drawn down,
   f. avoid pesticides that kills the insect prey base and other pollution-creating activities,

g. prevent overharvest,
h. follow already-developed best management practices.

Increased planning for cumulative effects of climate change and other factors will be critical to prioritise appropriate strategies. As recommended by the 2011 Species-At-Risk taskforce, planning should **take an ecosystem-based approach to species at risk**. Climate change increases the importance of this recommendation: a species-by-species approach cannot succeed when ecosystems are changing. As in all good conservation planning, fine filter strategies can be added to the coarse filter ecosystem base as necessary. Increased **watershed assessments** will facilitate maintenance of resilient hydrological functions and identify priority actions and locations.

Increased monitoring will also be important to track and respond to unpredictable and changing conditions, including changed hydrology, natural disturbance and patterns of disease.

Building management capacity among humans will be the biggest challenge. Ultimately, success in maintaining BC's vibrant, functional, wild ecosystems will depend upon integrating conservation and climate action strategies.[88]

11 Next Steps

11.1 Review, Complete and Update Framework

Expert review has been limited, given the tight timeline for this project. Achieving consensus among large groups of experts on precise species ratings would be time-consuming and likely of limited relative benefit; however, broad review of the usefulness of the approach and of the ratings would definitely be useful. In particular, experts should note priority species to be assessed using the framework and should add new information to the database and update the assessments appropriately. Establishing a structured process for updating and editing the database will help ensure that information represents consensus knowledge. Current knowledge exists to approximately double the number of assessed species, but information is lacking for many others. Because mitigation actions for high-priority species will also benefit species with similar traits, completing assessments for all species will not be necessary.

11.2 Incorporate Spatial Habitat and Exposure Information into Assessment

Any vulnerability assessment depends on the geographic and temporal extent of the assessment. Most information used to complete this assessment was based on province-wide Conservation Reports, COSEWIC reports and the climate-change sensitivity database developed for the US Pacific Northwest. Threats for many species will likely vary regionally; hence expanding the assessment to compare regions and increasing the spatial resolution of exposure could help pinpoint regions for focus. As a first task, a list of sensitive species developed from this assessment could be assessed and prioritised for further work by regional experts. Shapefiles of publicly available occurrence records and masked secured occurrence records are available for download from the Data Distribution Service: http://www.data.gov.bc.ca/dbc/geographic/download/index.page?[89]

11.3 Increase Information on Wildlife Health

Recognition that changes to wildlife health due to climate change pose cross-jurisdiction threats to human health, agriculture and conservation is fairly recent; initial focus has been human health (e.g., Lyme disease). Projects are currently underway, gathered by the Canadian Wildlife Health Cooperative, but information is not yet summarised. CWHC has a registry of pathogens and a long-term database that has the capacity for spatial/temporal correlations and would be useful for examining trends. To date, **the impacts of climate change on wildlife health are inadequately addressed**, particularly given the cross-jurisdiction concerns. Next steps include collaboration with wildlife health experts, including the CWHC, and incorporating monitoring of their database into BC climate change vulnerability assessments.

11.4 Refine Mitigation Options in Relation to Non-Climate Strategies

This framework lists general mitigation strategies for species and classes of organisms. Strategy success will vary in relation to actions adopted to reduce risk related to non-climate impacts. Measures to reduce non-climate threats could decrease potential cumulative effects and reduce the stress associated with these changes; for example, species will be more resilient to changed conditions if they have near-natural populations and sufficient connected suitable habitat to allow movement. Identifying climate-change benefits of existing and planned actions designed to address other impacts will help prioritise those actions with the most combined potential for success.

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