Taking Nature's Pulse

The Status of Biodiversity in British Columbia

2008

BioDiversity BC
CONSERVING THE VARIETY OF LIFE

Taking Nature's Pulse

THE STATUS OF BIODIVERSITY IN BRITISH COLUMBIA

2008

Biodiversity BC

CONSERVING THE VARIETY OF LIFE

Library and Archives Canada Cataloguing in Publication Data

Main entry under title:
Taking nature's pulse: the status of biodiversity in British Columbia

Editors: M.A. Austin, et al. Cf. P.
Includes bibliographical references: p.
ISBN 978-0-0909745-0-8

1. Biodiversity – British Columbia. 2. Endangered species – British Columbia.
3. Biodiversity conservation – British Columbia. I. Austin, Matt, 1969–
II. Biodiversity BC.

QH106.2.B7T34 2008 333.9509711 C2008-960108-4

Suggested citation: Austin, M.A., D.A. Buffett, D.J. Nicolson, G.G.E. Scudder and V. Stevens (eds.). 2008. Taking Nature's Pulse: The Status of Biodiversity in British Columbia. Biodiversity BC, Victoria, BC. 268 pp. Available at: www.biodiversitybc.org.

Cover photos: Jared Hobbs (owl); Laure Neish (bee on yellow flower); Dušan Zidar (orange peel fungus); Ian McAllister (kermode); Robert Koopmans (salmon); Karen Wipond (landscape); Jennifer Heron (checkerspot); Arifin Graham (footprints in sand).

Banner photos: Frank Leung (p. v); Vera Bogaerts (p. 1); Karoline Cullen (p. 5); Jared Hobbs (p. 23); Robert Koopmans (p. 155); Jennifer Heron (p. 213).

Design and Production: Alaris Design

Table of Contents

List of Text Boxes

List of Tables

List of Maps

List of Figures

Executive Summary

British Columbia is a spectacular place, known worldwide for its natural beauty and diversity. The province's ecosystems provide habitat for a vast array of plants and animals and have sustained human populations for at least 10,000 years. Although we continue to derive huge benefits from these natural systems, their true value and significance is not fully understood. Nor do we fully understand the potential threats to the environment caused by our expanding human footprint.

This report, *Taking Nature's Pulse: The Status of Biodiversity in British Columbia*, is a comprehensive, science-based assessment of the province's natural environment. Its purpose is to assist British Columbians in making informed choices regarding biodiversity. The scope of the report is B.C.'s terrestrial and freshwater realms, including their overlap with the marine realm.

Taking Nature's Pulse was developed by Biodiversity BC, a partnership of government and non-government organizations with a mandate to produce a biodiversity strategy for British Columbia. Scientists – both provincial and international – played a key role in shaping and building the report through the preparation of technical background reports and peer reviews of the report as it was being drafted.

The report has four main sections. Section 1 provides background on biodiversity, including its attributes, importance and history in B.C. Section 2 describes the current status of B.C.'s ecosystems, species and genetic diversity, and key and special elements. Section 3 outlines the threats to biodiversity. Section 4 presents the major findings of the assessment.

Taking Nature's Pulse does not assess existing conservation programs and policies in B.C. or compare approaches taken in B.C. with those in other jurisdictions. Nevertheless, there is a wide range of conservation tools that have been employed by governments, industry, conservation organizations and the public in British Columbia. Examples include protected areas, covering more than 14% of the province; conservation areas, including Wildlife Management Areas, Wildlife Habitat Areas and Old Growth Management Areas; land management guidelines and regulations; private land conservation; and strategic land use plans with land use designations and resource management objectives designed to address biodiversity concerns.

What is Biodiversity?

Biodiversity is short for biological diversity – the variety of life in all its forms. It includes genes, species and ecosystems, and the processes that link them, an ensemble that many people think of simply as Nature.

Biodiversity provides important ecosystem services to all living things, such as regulating climate and the flow of water. It also fulfills basic human needs, providing us with essentials like food and clean water, supplies the natural capital upon which our economy depends and satisfies a wide range of recreational, spiritual and cultural needs.

British Columbia's glacial history, mountainous terrain, proximity to the Pacific Ocean and widely varied local climates have shaped its biodiversity. For at least 10,000 years, the First Peoples in British Columbia have relied on biodiversity, building a wealth of specialized knowledge about its uses and inner workings. Since the arrival of Europeans, biodiversity has continued to play a vital role in the province's development.

Ecosystem Diversity

An ecosystem is a community of organisms and their physical environment. Ecosystems are complex, dynamic and adaptive systems that are continuously evolving. When they become simplified through the loss of component parts or processes, they lose their ecological resilience – the ability to withstand and adapt to natural or human-caused disturbances.

Ecosystems can be defined and assessed at a range of scales from the very small – for example the organisms and processes occurring in a small pond – to the very large such as the coastal temperate rainforest, extending along the Pacific coast from northern California to Alaska. The primary scale used in this report for terrestrial ecosystems is biogeoclimatic zones, which are broad geographic areas sharing similar climate and vegetation. Within B.C. there are 16 biogeoclimatic zones: 12 forested, three alpine and one grassland. The finest scale used in the report is ecological communities. To date, 611 ecological communities have been described in the province.

Major Drainage Areas were used as the basis for broad-scale analysis focusing on freshwater ecosystems. Water from the entire province runs into nine Major Drainage Areas, feeding large rivers like the Fraser, Skeena, Taku and Peace, and ultimately flowing into either the Pacific Ocean or the Arctic Ocean. The Fraser River alone drains roughly one-quarter of the province. Freshwater and terrestrial ecosystems overlap with the marine realm in estuaries and intertidal zones. Both of these overlap areas are naturally rare, but are highly productive and important for biodiversity in all three realms.

PHOTO: KAREN WIPOND.

MAJOR FINDINGS:

1. **At the broad scale, four biogeoclimatic zones [Coastal Douglas-fir, Interior Douglas-fir, Ponderosa Pine, and Bunchgrass], representing approximately 5% of British Columbia's land base, are of provincial conservation concern.**
2. **At the fine scale, more than half of the ecological communities described in British Columbia are of provincial conservation concern.**
3. **British Columbia has a majority of the global range for six of the 16 biogeoclimatic zones that occur in the province [Coastal Douglas-fir, Interior Cedar–Hemlock, Montane Spruce, Mountain Hemlock, Sub-boreal Pine–Spruce, and Sub-boreal Spruce].**
4. **The Coastal Douglas-fir biogeoclimatic zone is the rarest biogeoclimatic zone in British Columbia and is of great conservation concern.**
5. **Low-elevation grassland communities are the rarest land cover type in British Columbia and are concentrated in the biogeoclimatic zones of conservation concern [see Major Finding 1].**
6. **Significant areas of wetlands in British Columbia have been converted or degraded, particularly in the two Major Drainage Areas of greatest conservation concern [those of the Columbia River and Fraser River].**
7. **Estuaries are of concern in British Columbia because of their rarity and the level of human impacts to them.**

Species Diversity

Species are genetically distinct groups of organisms that are capable of successfully interbreeding. Each species is a unique part of nature. Of all the Canadian provinces and territories, B.C. is home to the richest diversity of vascular plants, mosses, mammals, butterflies and breeding birds, and the largest number of species of reptiles, tiger beetles and amphibians found only in one province or territory. More than 50,000 different species (not including single-celled organisms) exist in B.C., but only about 3,800 of these have been assessed for their conservation status. Some parts of the province (primarily unroaded and unsettled areas) have not been surveyed and some taxonomic groups remain largely unstudied.

MAJOR FINDINGS:

8. **Of the species assessed to date in British Columbia, 43% are of provincial conservation concern and these are concentrated in the four biogeoclimatic zones of conservation concern [see Major Finding 1].**
9. **British Columbia is known to have a majority of the global range for 99 species.**

PHOTO: ISTOCK.

Genetic Diversity

Genetic diversity is the foundation of biodiversity. Genes are the functional units of heredity and genetic variation that permit species to adapt to changing environments.

B.C. has a disproportionately high level of genetic diversity relative to its species diversity. The province's glacial history, complex topography and varied climate have contributed to the evolution of a wide variety of adaptations to different environments. As a result, many species occur in the province as geographically distinct subspecies, which differ from each other in appearance, environmental tolerances and/or behaviour, which reflect differences in genetic make-up. For example, there are more than 400 genetically distinct populations among five species of Pacific salmon in B.C. This variability has allowed salmon to use all available stream systems in the province, adding to their ability to adapt to changing conditions.

Due to B.C.'s large size and biophysical variability, the province is home to many species that are at the edge of their range. Such populations are often genetically distinct from populations at the core of the species range.

B.C. also has a high density of hybrid zones that contribute to genetic diversity in both terrestrial and freshwater ecosystems. In these zones, landscape change and historic expansion and contraction of species ranges have created conditions where individuals from genetically different populations or species interbreed, producing new genetic combinations.

MAJOR FINDING:

10. **British Columbia has a high level of genetic diversity within species, which is critical for adaptation and resilience.**

Key and Special Elements of Biodiversity

Key elements are the species and ecosystem components, and the processes performed by them, that have a fundamental or disproportionate influence on how ecosystems function. *Taking Nature's Pulse* highlights a sample of the key elements that are important for biodiversity in B.C.

An important example of a key element is pollination, which is the transfer of pollen between plants by animals or by non-biological forces such as wind. The majority of animal pollination is carried out by insects such as bees, beetles, wasps, flies, butterflies and moths. One-third of the food consumed by people is a result of pollination by animals.

Special elements are components of biodiversity that are uncommon and, in some cases, found nowhere else in B.C. Examples include: seasonal concentrations of species, such as rookeries where Steller sea lions gather to breed; special communities, such as temperate rainforests and intact large mammal predator-prey systems; and noteworthy features, including karst cave systems, hot springs, saline lakes and fishless lakes, all of which are inhabited by rare and specialized species. As with the key elements, the list presented in this report is not all-inclusive.

MAJOR FINDINGS:

11. **The flow of water in lakes, streams, wetlands and groundwater systems is being seriously impacted in British Columbia by dams, water diversions, logging, stream crossings and climate change.**
12. **The natural disturbance processes that shape British Columbia's forests [e.g., wild fire, insects] are being disrupted by human activities.**
13. **British Columbia's mainland coast features a number of interconnected key and special elements of biodiversity: intact temperate rainforest, an intact large mammal predator-prey system, glacially influenced streams and salmon-driven nutrient cycling.**
14. **The majority of British Columbia has intact or relatively intact predator-prey systems, but a major threat to them is motorized access and associated human activities.**
15. **British Columbia has many significant seasonal concentrations of species [e.g., migratory birds, spawning salmon] that are vulnerable to human impacts.**

Threats to Biodiversity

Biodiversity is under threat around the world. According to the 2005 Millennium Ecosystem Assessment more than half of the earth's grasslands, forests, rivers and lakes have been degraded, along with their ability to perform essential ecosystem functions and support life. Similarly the World Conservation Union (IUCN) has ranked 40% of the 40,000 species it has evaluated as being threatened with extinction. With each species that is lost, so too is its potential to contribute to the production of food, fuel, building materials, pollination, decomposition, filtration and other services needed to maintain life on the planet.

While British Columbia faces many of the same threats that are occurring globally, its biodiversity is in relatively better shape due to the shorter history of large-scale human development and the province's mountainous terrain. However, current trends indicate that threats to B.C. species and ecosystems are increasing.

In British Columbia there are six major stresses that threaten biodiversity:

- ecosystem conversion (the direct and complete conversion of natural ecosystems to landscapes for human uses);
- ecosystem degradation (change to the structure of a natural system from activities such as forest harvesting or water diversion);
- alien species (species that occur outside their native range due to human introduction);
- environmental contamination (the release of contaminants into natural systems);
- species disturbance (the alteration of the behaviour of species due to human activities);
- species mortality (the direct killing of individual organisms).

Ecosystem conversion, ecosystem degradation and alien species are the most significant stresses on biodiversity in B.C. and globally.

The human activities that contribute most significantly to the stresses on biodiversity in B.C. are associated with climate change, agriculture, recreation, urban and rural development, forestry, transportation and utility corridors, oil and gas development and water development. Other activities that have important impacts on biodiversity are grazing, industrial development, mining and aquaculture. Within B.C., human activities are generally concentrated in areas of high biodiversity, particularly along rivers, in estuaries and in fertile valleys.

While it is logical to look at the impacts of these activities individually, losses to biodiversity generally result from a combination of stresses. These cumulative impacts can affect biodiversity at a magnitude that is greater than the sum of the individual impacts.

The impacts of climate change on biodiversity are already being felt and it is expected to be the greatest overriding threat to biodiversity in the future, especially in areas of the province where biodiversity is already affected by ecosystem conversion, ecosystem degradation, alien species and other stresses. Precisely how ecosystems and species will respond to climate change remains unknown. The speed with which species adapt to, or move in response to, changes in conditions will likely determine whether they thrive or disappear, and will in turn influence ecosystems. Where ecosystems are already degraded or fragmented by activities such as construction of roads and associated stream crossings, habitat connectivity may be lost, preventing many species from shifting their ranges in response to the changing climate.

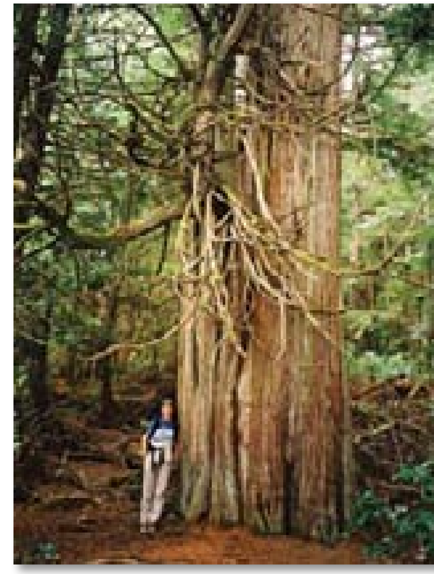


PHOTO: JANE DRENGSON.

MAJOR FINDINGS:

16. **Ecosystem conversion from urban/rural development and agriculture has seriously impacted British Columbia's biodiversity, especially in the three rarest biogeoclimatic zones [Coastal Douglas-fir, Bunchgrass and Ponderosa Pine].**
17. **Ecosystem degradation from forestry, oil and gas development, and transportation and utility corridors has seriously impacted British Columbia's biodiversity.**
18. **Alien species are seriously impacting British Columbia's biodiversity, especially on islands and in lakes.**
19. **Climate change is already seriously impacting British Columbia and is the foremost threat to biodiversity.**
20. **The cumulative impacts of human activities in British Columbia are increasing and are resulting in the loss of ecosystem resilience.**
21. **Connectivity of ecosystems in British Columbia is being lost and, among other impacts, this will limit the ability of species to shift their distributions in response to climate change.**

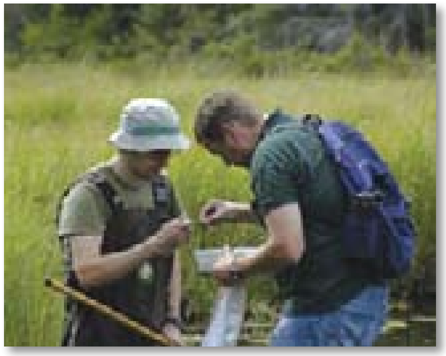


PHOTO: CHRIS DARLING.

Capacity and Knowledge

There is a substantial and ever-growing body of knowledge about biodiversity in British Columbia, which includes scientific publications, species checklists, computer databases and individual expertise. However, there is also much that is not known. Capacity refers to the ability to fill the many knowledge gaps and integrate new and existing information.

Thousands, if not tens of thousands, of species in B.C. have not been scientifically described or are not documented as being present in the province. Species groups for which such information is particularly lacking include most of the invertebrates and non-vascular plants. This taxonomic knowledge gap is currently being exacerbated by an 'extinction of experience' as the scientists with the knowledge, skills and inclination to do the work required to fill the gaps are retiring and often are not being replaced.

The majority of species in B.C. have not been assessed for their conservation status and the global ranks for many species that have been assessed are out of date. The ecology of most species and the distributions of all but a very few are poorly understood. Coarse-scale ecosystem classifications are complete in B.C., but information at a finer ecosystem scale is incomplete, as is ecosystem information from neighbouring jurisdictions. Trend monitoring is extremely limited and data on distribution and population size are lacking for many species. Information about impacts on biodiversity is generally incomplete or out of date.

MAJOR FINDINGS:

22. **Gaps in our knowledge of biodiversity in British Columbia create major challenges for effective conservation action.**
23. **The capacity to address some of the gaps in our knowledge of biodiversity in British Columbia is being impacted by the loss of already limited taxonomic expertise.**

Conclusion

All life is part of biodiversity and each living thing depends on a multitude of species, ecosystems and ecological processes for its existence. Throughout the province there is compelling scientific evidence that biodiversity is being significantly altered by individual and cumulative stresses resulting from human activities. Climate change is an overriding impact that is already taking a toll on B.C.'s biodiversity and is expected to become an increasingly significant threat.

Trend data for B.C. show that declines in biodiversity are occurring at the genetic, species and ecosystem levels, critical ecosystem processes are being impacted and key and special elements of biodiversity are being lost. Meanwhile, major gaps in our knowledge of the province's biodiversity hinder our ability to understand and respond to this situation.

British Columbia's biodiversity is globally significant because of its variety and integrity, but without immediate action, it is vulnerable to rapid deterioration, especially in light of climate change.

Acknowledgements

Assessing the status of 'life in all its forms' for an entire province is no simple task. It was made possible only by the enormous contributions of time, expertise and hard work by the dozens of people who participated as scientific experts, reviewers, consultants and committee members. Biodiversity BC would like to thank the following people for their assistance in making *Taking Nature's Pulse: The Status of Biodiversity in British Columbia* a reality and ensuring that it is as accurate and comprehensive as possible.

The Biodiversity BC secretariat supports the work of the Steering Committee and the Technical Subcommittee and provides ongoing strategic advice. The secretariat consists of Stuart Gale, executive director, and Janet Fontaine, coordinator.

Taking Nature's Pulse was prepared by Biodiversity BC's Technical Subcommittee, with writing and editing support from Ann Eriksson, Alison Leslie, David Greer and Frances Backhouse. The Technical Subcommittee consists of:

- Matt Austin, B.C. Ministry of Environment;
- Dan Buffett, Ducks Unlimited Canada;
- Dave Nicolson, Nature Conservancy of Canada;
- Geoff Scudder, The Nature Trust of British Columbia; and
- Victoria (Tory) Stevens, B.C. Ministry of Environment.

The Biodiversity BC Steering Committee provided direction and support to the Technical Subcommittee for the development of *Taking Nature's Pulse*. Steering Committee members reviewed the component reports that contributed to the development of the status report and reviewed all drafts of the status report. Since 2005, members of the Biodiversity BC Steering Committee have included:

- Marian Adair, Daryll Hebert, Geoff Scudder, Jim Walker (The Nature Trust of British Columbia);
- Pia Archibald, Matt Austin, Tory Stevens (B.C. Ministry of Environment);
- Tamsin Baker, Bob Peart (The Land Conservancy of British Columbia);
- Dan Buffett, Bruce Harrison (Ducks Unlimited Canada);
- Kristy Ciruna, Andrew Harcombe, Pierre Iachetti, Dave Nicolson (Nature Conservancy of Canada);
- Dianna Colnett, Heather Wornell (Metro Vancouver representing The Union of B.C. Municipalities);

- Alan Kenney, Jim Shinkewski (Pacific Salmon Foundation);
- Jan Kirkby, Kathleen Moore (Environment Canada);
- Kaaren Lewis (World Wildlife Fund Canada, representing public land environmental groups);[a]
- Eva Riccius (Canadian Parks and Wilderness Society, representing public land environmental groups);
- Liz Stanlake (Habitat Conservation Trust Foundation); and
- Liz Williams (B.C. Ministry of Agriculture and Lands).

Our appreciation goes to the authors of the following reports:

- *An Assessment of Climate Change Impacts on Biodiversity Management in BC*: Dan Ohlson;
- *Applying the Concept of Stewardship Responsibility in British Columbia*: Fred Bunnell, Laurie Kremsater and Isabelle Houde;
- *Background on Biodiversity, Ecosystem Processes*: Fred Bunnell;
- *Biodiversity: Geological History in British Columbia*: Richard Hebda;
- *Biodiversity Safety Net Gap Analysis*: Graham Long;
- *Draft S Ranks and Surrogate G Ranks for BEC Zones and Draft S Ranks for Ecoprovinces and Major Drainage Areas of BC: Preliminary Rankings*: Laurie Kremsater;
- *Ecological Concepts, Principles and Applications to Conservation*: Terje Vold;
- *Global and Provincial Status of Species in British Columbia*: Marilyn Anions;
- *Importance of Biodiversity for First Peoples of British Columbia*: Nancy Turner;
- *Key Elements of Biodiversity in British Columbia: Some Examples From the Terrestrial and Freshwater Aquatic Realm*: Rachel Holt and Todd Hatfield;
- *Major Impacts to Biodiversity in British Columbia (Excluding Climate Change)*: Don Gayton;
- *Overlap: Investigation and Review*: Dan Ohlson;
- *Preliminary Analysis of BC Climate Trends for Biodiversity*: Trevor Murdock, Arelia Werner and David Bronaugh;
- *Special Elements of Biodiversity in BC*: Rachel Holt;
- *Species Richness and Summed Irreplaceability in BC*: Leanna Warman and Geoff Scudder; and
- *The Status of Genetic Biodiversity in British Columbia:* Amy Wilson, Peter Arcese and Fred Bunnell.

And to those who made special contributions:

- Spatial analysis: Anne Downton, Emily Gouge, Kevin Neufeld and Paul Ramsey;
- Map production: Ann Blyth and Ian Laing;
- Design, production and printing: Arifin Graham, Michael Love and Eric Hughes;
- First Nations consultant: Frank Brown.

[a] Commitee membership was in 2006-2007 only. Representation of public land environmental groups was then assumed by Eva Riccius (CPAWS).

In addition to the members of the TSC, the following people participated in science workshops and/or reviewed background reports and drafts of *Taking Nature's Pulse*:[a]

October 2005 Conceptual Framework Workshop: Jacky Booth (Consultant), Fred Bunnell (UBC, Emeritus), Michael Dunn (EC), John Harper (Coastal and Ocean Resources Inc.), Dave Huggard (Consultant), Glen Jamieson (DFO), Ken Lertzman (SFU), Eric Parkinson (MoE), Ian Perry (DFO), Tony Pitcher (UBC), Jason Smith (SFU), Art Tautz (MoE), Amanda Vincent (UBC), Bill Wareham (DSF). Reed Noss (University of Central Florida) was unable to attend, but provided a review.

October 2005 Terrestrial Workshop: Carmen Cadrin (MoE), Brian Klinkenberg (UBC), Ken Lertzman (SFU), Andy MacKinnon (MoFR), Del Meidinger (MoFR), Marlow Pellatt (PC), Jim Walker (TNT).

November 2005 Freshwater Workshop: Doug Biffard (MoE), Ted Down (MoE), Malcolm Gray (ILMB), Richard Hebda (UVic/RBCM), Blair Holtby (DFO), Craig Mount (MoE), Eric Parkinson (MoE), Sue Pollard (MoE), Art Tautz (MoE), Dave Tredger (MoE).

November 2005 Marine Workshop: Jackie Alder (UBC), Jamie Alley (MoE), Kimberly Anthony (EC), Jeff Ardron (Consultant/ Pacific Marine Analysis and Research Association), Natalie Ban (UBC), Jacky Booth (Consultant), Cathryn Clarke (DFO), Chris Close (UBC), Ken Cripps (Coastal First Nations – Turning Point Initiative), Steve Diggon (DFO), Melody Farrell (DFO), Larry Greba (Coastal First Nations – Turning Point Initiative), Edward Gregr (UBC), Joy Hillier (DFO), Doug Hrynyk (PC), Sabine Jessen (CPAWS), Greg Kapala (LOS), Greg Kehm (Ecotrust Canada), Jamie Kenyon (EC), Jennifer Lash (LOS), Greg MacMillan (PC), Murray Manson (DFO), Jack Mathias (DFO), Krista Munro (LOS), Joe Truscott (MoE), Tony Turner (NRCAN), Scott Wallace (Consultant), Bruce Ward (MoE), Bill Wareham (DSF), Louisa Wood (UBC), Mark Zacharias (ILMB).

February 2006 Science Workshop: Peter Arcese (UBC), Fred Bunnell (UBC, Emeritus), Don Eastman (UVic, Retired), Jim Irvine (DFO), Phil Lee (PC), Del Meidinger (MoFR), Eric Parkinson (MoE), Ian Perry (DFO), Art Tautz (MoE).

April 2007 Ecosystem Status Workshop: Carmen Cadrin (MoE), Dave Clark (MoE), Dennis Demarchi (Consultant), Andrew Harcombe (NCC), Will MacKenzie (MoFR), Eric Parkinson (MoE), Art Tautz (MoE), Adrian Walton (MoFR).

[a] Affiliations: CPAWS=Canadian Parks and Wilderness Society; DFO=Fisheries and Oceans Canada; DSF=David Suzuki Foundation; EC=Environment Canada; FPB=Forest Practices Board; HCTF=Habitat Conservation Trust Foundation; ILMB=Integrated Land Management Bureau (B.C. Ministry of Agriculture and Lands); LOS=Living Oceans Society; MoE=B.C. Ministry of Environment; MoFR=B.C. Ministry of Forests and Range; NCC=Nature Conservancy of Canada; NRCAN=Natural Resources Canada; OGC=Oil and Gas Commission; PC=Parks Canada; PCIC= Pacific Climate Impacts Consortium; PSF=Pacific Salmon Foundation; RBCM=Royal British Columbia Museum; SFU=Simon Fraser University; TLC=The Land Conservancy of British Columbia; TNT=The Nature Trust of British Columbia; UBC=University of British Columbia; UVic=University of Victoria; WCWC= Western Canada Wilderness Committee.

June 5, 2007 Science Workshop: Martin Carver (MoE), Shane Ford (MoE), Gerry Fox (OGC), Bruce Fraser (FPB), Laura Friis (MoE), Linda Gilkeson (MoE), Stewart Guy (MoE), Ted Lea (MoE), Kaaren Lewis (MoE), Eric Lofroth (MoE), Remi Odense (MoE), Sue Pollard (MoE), James Quayle (MoE), David Tesch (MoE), Richard Thompson (MoE), Mark Zacharias (ILMB). Carmen Cadrin (MoE) was unable to attend, but provided a review.

June 12, 2007 Science Workshop: Peter Arcese (UBC), Doug Biffard (MoE), Fred Bunnell (UBC, Emeritus), Ted Down (MoE), Don Eastman (UVic, Retired), Andrew Harcombe (NCC), Trish Hayes (EC), Richard Hebda (UVic/RBCM), Kim Hyatt (DFO), Phil Lee (PC), Kathy Martin (UBC), Don McPhail (UBC, Emeritus), Eric Parkinson (MoE), John Richardson (UBC), Risa Smith (EC), Art Tautz (MoE), Eric Taylor (UBC).

August 2007 Aquatic Essential Ecosystem Characteristics Workshop: Doug Biffard (MoE), Tom Johnston (MoE), Richard Hebda (UVic/RBCM), Kim Hyatt (DFO).

August 2007 Terrestrial Essential Ecosystem Characteristics Workshop: Peter Arcese (UBC), Richard Hebda (UVic/RBCM).

December 2007 Major Findings Science Workshop: Peter Arcese (UBC), Don Eastman (UVic, Retired), Andrew Harcombe (NCC), Richard Hebda (UVic/RBCM), Kim Hyatt (DFO), Andy MacKinnon (MoFR), Don McPhail (UBC, Emeritus), James Quayle (MoE), Eric Taylor (UBC).

January 2008 Major Findings and Objectives Science Workshop: Rachel Holt (Consultant), Susan Pinkus (Ecojustice), John Reynolds (SFU), Risa Smith (EC), Eric Taylor (UBC).

February 2008 Major Findings and Objectives Science Workshop: Doug Biffard (MoE), Carmen Cadrin (MoE), Martin Carver (MoE), Don Eastman (UVic, Retired), Gerry Fox (OGC), Andrew Harcombe (NCC), Richard Hebda (UVic/RBCM), Kim Hyatt (DFO), Don McPhail (UBC, Emeritus), Trevor Murdock (PCIC), James Quayle (MoE), David Tesch (MoE).

Safety Net Gap Analysis Survey (February 2007): Marian Adair (TNT), Peter Arcese (UBC), Doug Biffard (MoE), Ken Brock (EC), Carmen Cadrin (MoE), Ted Down (MoE), Dave Fraser (MoE), Laura Friis (MoE), Andrew Harcombe (NCC), Richard Hebda (UVic/RBCM), Glen Jamieson (DFO), Chris Johnson (University of Northern British Columbia), Alan Kenny (PSF), Jan Kirkby (EC), Ted Lea (MoE), Don McPhail (UBC, Emeritus), Eric Parkinson (MoE), Marlow Pellatt (PC), Chris Ritchie (MoE), Val Schaefer (UVic), Risa Smith (EC), Liz Stanlake (HCTF). Participating TSC members: Dan Buffett, Matt Austin, Tory Stevens.

Peer Reviewers – Component Reports: Doug Biffard (MoE), Carmen Cadrin (MoE), Glyn Fox (MoE), Jenny Fraser (MoE), Richard Hebda (UVic/RBCM), Crawford S. Hollings (University of Florida), Angela Kingerlee (MoE),

Ted Lea (MoE), Ken Lertzman (SFU), Andy MacKinnon (MoFR), Don McPhail (UBC, Emeritus), Dave Nagorsen (Consultant), Gordon Orians (University of Washington, Emeritus), Ian Perry (DFO), John Reynolds (SFU), John Richardson (UBC).

Peer Reviewers[a] – October 2007 Draft Status of Biodiversity Report: Marilyn Anions (NatureServe Canada), Peter Arcese (UBC), Doug Biffard (MoE), Andre Breault (EC), Fred Bunnell (UBC, Emeritus), Rob Butler (EC), Carmen Cadrin (MoE), Martin Carver (MoE), Orville Dyer (MoE), Don Eastman (UVic, Retired), Wendy Easton (EC), Bob Elner (EC), Laura Friis (MoE), Stewart Guy (MoE), Andrew Harcombe (NCC), Trish Hayes (EC), Richard Hebda (UVic/RBCM), Ole Hendrickson (EC), Rachel Holt (Consultant), Jim Irvine (DFO), Tom Johnston (MoE), Elsie Krebs (EC), Ted Lea (MoE), Ken Lertzman (SFU), Eric Lofroth (MoE), Don McPhail (UBC, Emeritus), Trevor Murdock (PCIC), Reed Noss (University of Central Florida), Ian Perry (DFO), Susan Pinkus (Ecojustice and on behalf of DSF, ForestEthics, Sierra Club of Canada [BC Chapter] and WCWC), Sue Pollard (MoE), Hugh Possingham (University of Queensland), James Quayle (MoE), John Reynolds (SFU), Carmen Revenga (The Nature Conservancy – Worldwide Office), Art Tautz (MoE), Eric Taylor (UBC), Richard Thompson (MoE), Ken Vance Borland (Conservation Planning Institute), Jim Walker (TNT), Leanna Warman (UBC).

Peer Reviewers[b] – February 2008 Final Draft Status of Biodiversity Report: Candace Batycki (ForestEthics), Shannon Berch (MoFR), Fred Bunnell (UBC, Emeritus), Don Eastman (UVic, Retired), Deepa Filatow (MoE), Dave Fraser (MoE), Andrew Harcombe (NCC), Richard Hebda (UVic/RBCM), Don McPhail (UBC, Emeritus), Susan Pinkus (Ecojustice and on behalf of DSF, ForestEthics, Sierra Club of Canada [BC Chapter] and WCWC), Jim Pojar (Consultant), Eric Taylor (UBC).

We thank you all.

Biodiversity BC Steering Committee, Technical Subcommittee.

BIODIVERSITY BC PARTNER GROUPS: The Nature Trust of British Columbia, B.C. Ministry of Environment, B.C. Ministry of Agriculture and Lands, Ducks Unlimited Canada, Nature Conservancy of Canada, Environment Canada, Habitat Conservation Trust Foundation, Metro Vancouver (representing the Union of British Columbia Municipalities), The Land Conservancy of British Columbia, Pacific Salmon Foundation, Canadian Parks and Wilderness Society (representing environmental non-governmental organizations).

[a,b] Science experts outside of the Biodiversity Steering Committee.

About This Report

Creation of the Status Report

In 2005, Biodiversity BC (a partnership of governments and non-government conservation organizations) was given the mandate to develop and facilitate the implementation of a science-based biodiversity strategy for British Columbia. A number of reports have been developed to support this process (see below). This report, *Taking Nature's Pulse: The Status of Biodiversity in British Columbia*, summarizes the current scientific knowledge about the state of biodiversity and threats to biodiversity in British Columbia, derived from the best available scientific data and expert opinion.

Taking Nature's Pulse is the result of two years of consultation by Biodiversity BC with more than 100 scientists and other experts. Between fall 2005 and spring 2006, a series of expert workshops was held to gather input on approaches to developing a biodiversity strategy, including the preparation of a science-based status report. In February 2006, the Technical Subcommittee (TSC) of Biodiversity BC was formed to coordinate the development of a status report. Members of the TSC include scientists and technical practitioners from partner organizations, including the B.C. Ministry of Environment, Ducks Unlimited Canada, Nature Conservancy of Canada and The Nature Trust of British Columbia.

A related document – *Ecological Concepts, Principles and Applications to Conservation* – was commissioned by Biodiversity BC in 2006 to provide the broad context for the development of the status report. Other supporting scientific and technical reports were commissioned from experts in the field (see Acknowledgements) and have been reviewed by members of Biodiversity BC, as well as external peer reviewers. These reports cover:

- First Nations and Biodiversity
- Geologic History
- Ecosystem Status
- Species Status

The range of the Pacific chorus frog (*Pseudacris regilla*) extends from southern B.C. to Mexico.
PHOTO: NEIL K. DAWE.

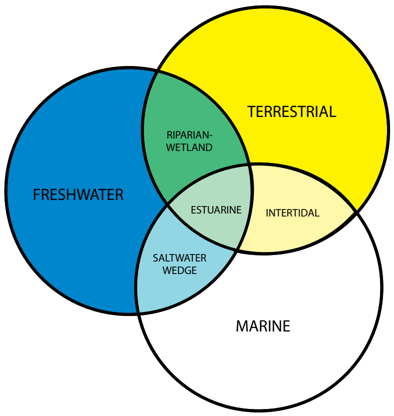


FIGURE 1: Spatial overlap of the terrestrial, freshwater and marine realms. Shading indicates the scope of this report.
SOURCES: Fraser, D.F., A. Banner and A. Harcombe. 1995. A Framework for Ecological Classification in British Columbia. Resource Inventory Committee, Victoria, BC. Unpublished report. 27pp.; and Mackenzie, W.H. and J.R. Moran. 2004. Wetlands of B.C.: A Guide to Identification. Land Management Handbook 5. B.C. Ministry of Forests, Research Branch, Victoria, BC. 297pp. Available at: www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/Lmh52.htm

- Species Richness
- Stewardship Responsibility
- Jurisdictional and Marine Realm Overlap
- Genetic Diversity
- Key and Special Elements
- Major Impacts
- Safety Net Gap Analysis
- Climate Change

Based on scientific information, *Taking Nature's Pulse* is intended to guide government and non-government organizations and citizens in taking action to conserve biodiversity. It provides a synthesis and overview of the findings contained in a wide variety of reports on the status of biodiversity in British Columbia and elsewhere. Detailed methods and data supporting the development of the status report are provided in the background reports. For those wishing more in-depth information, these reports are available on the Biodiversity BC website (www.biodiversitybc.org). Also available on the website is *The Biodiversity Atlas of British Columbia* (the Atlas), a companion document to *Taking Nature's Pulse*. The Atlas was developed to provide a map-based, province-wide overview of a range of biodiversity components, as well as threats affecting biodiversity at the ecosystem and species level.[a]

Taking Nature's Pulse considers threats to biodiversity due to human impacts following European contact. It addresses the status of the full range of terrestrial and freshwater biodiversity in the province, as well as the overlap between the marine realm and both the freshwater and terrestrial realms, as shown in Figure 1. The full range of marine biodiversity is not addressed in this report, as the assessment of the marine realm was identified to be within the mandate of Fisheries and Oceans Canada.[b] Species that are solely marine, such as whales and marine phytoplankton, are not included.

Although there are currently a wide variety of conservation tools and measures in place to conserve biodiversity in B.C., *Taking Nature's Pulse* does not attempt to provide an assessment of these. Its purpose is to describe the current condition of biodiversity and related threats from human activity. An assessment of the extent to which management tools have proven to be effective in maintaining biodiversity is something that can better be done in the context of determining future priorities and actions for biodiversity conservation.

[a] In collaboration with many partners, Biodiversity BC has led the development of Hectares BC (www.hectaresbc.org), a web application that allows users to access, and do analyses on, map-based information relevant to biodiversity conservation.
[b] See Pacific Ocean status reports at: www.pac.dfo-mpo.gc.ca/SCI/psarc/OSRs/Ocean_SSR_e.htm.

Examples of current conservation tools in British Columbia include protected areas, which cover more than 14% of the province; conservation areas, including Wildlife Management Areas, Wildlife Habitat Areas and Old Growth Management Areas; land management guidelines and regulations; private land conservation; and strategic land use plans, which include land use designations and resource management objectives. Governments, industry, conservation organizations and the public all participate in implementing these measures.

How to Read the Status Report

The Status Report is organized into four sections:

- **Section 1: *A Primer on Biodiversity* provides definitions and context for the discussion of biodiversity in British Columbia.** It addresses three key questions: What is biodiversity? Why is biodiversity important? What are the elements that characterize B.C.'s biodiversity?
- **Section 2: *British Columbia's Natural Legacy* is the core of the report, summarizing the current status of ecosystems, species and genetic diversity and key and special elements.** It identifies areas of overlap with the marine environment and with other jurisdictions.
- **Section 3: *Threats to Biodiversity in British Columbia* examines the factors that are currently driving the loss of biodiversity in British Columbia.**
- **Section 4: *Major Findings* represents a synthesis of the assessment presented in Sections 2 and 3 and serves as the foundation for the development and implementation of priorities and actions.**

References are cited by number (e.g., [3]) and provided in order at the end of the document. Footnotes are indicated by letter (e.g., [a]) and provided at the bottom of the relevant page. All glossary terms are highlighted in **green** when first used in the body of the text and defined in the glossary, which begins after Section 4. Scientific names are given only with the first mention of a species within the body of the text.

There are two types of maps in this report: full-page provincial maps taken from the Atlas, and smaller maps from a variety of sources. The smaller maps are considered figures and are numbered sequentially as part of the list of figures in the table of contents. The full-page Atlas maps are listed separately in the table of contents.

For the Atlas maps that illustrate analyses, the analysis units are the result of an overlay of biogeoclimatic zones/subzones/variants, ecosections and third-order watersheds. There are 72,335 analysis units in the province, ranging in size from 1 to 1,530 ha.

Tchaikazan River in southwestern B.C.
PHOTO: MOIRA LEMON.

One of two varieties of satin flower (*Olsynium douglasii*) that occur in B.C.
PHOTO: LIZ WILLIAMS.

UNDERSTANDING THE STATUS REPORT MAPS

Most of the full-page maps consist of a main map and a smaller, inset map, which present the same data in two different ways.

The main map uses ten percentile classes, each of which generally incorporates the same number of analysis units.[a] In effect, one-tenth of the analysis units are in each percentile class no matter what range of values that represents. For example, if an analysis unit has a road density that is greater than or equal to 60% of the other analysis units, it is in the 60th percentile.

The inset maps mostly use an equal-interval approach, in which the data are divided into 10 equally spaced classes, where each class may contain a different number of analysis units. For example, the road density values range from 0 to 22.1 km/km^2, so the first class contains all analysis units with a value between 0 and 2.21 km/km^2, the second class contains all analysis units with a value between 2.22 and 4.42 km/km^2, etc.

These two cartographic approaches for presenting data were used to meet three sometimes conflicting goals: following consistent mapping methods; allowing for comparisons between maps; and accurately representing the distribution of data values, while showing spatial variation within B.C.

[a] The exception to each percentile class having the same number of analysis units occurs when there is a tie between the values for a particular measure in two or more analysis units; for example, when a large number of units have a value of 0 for a given measure.

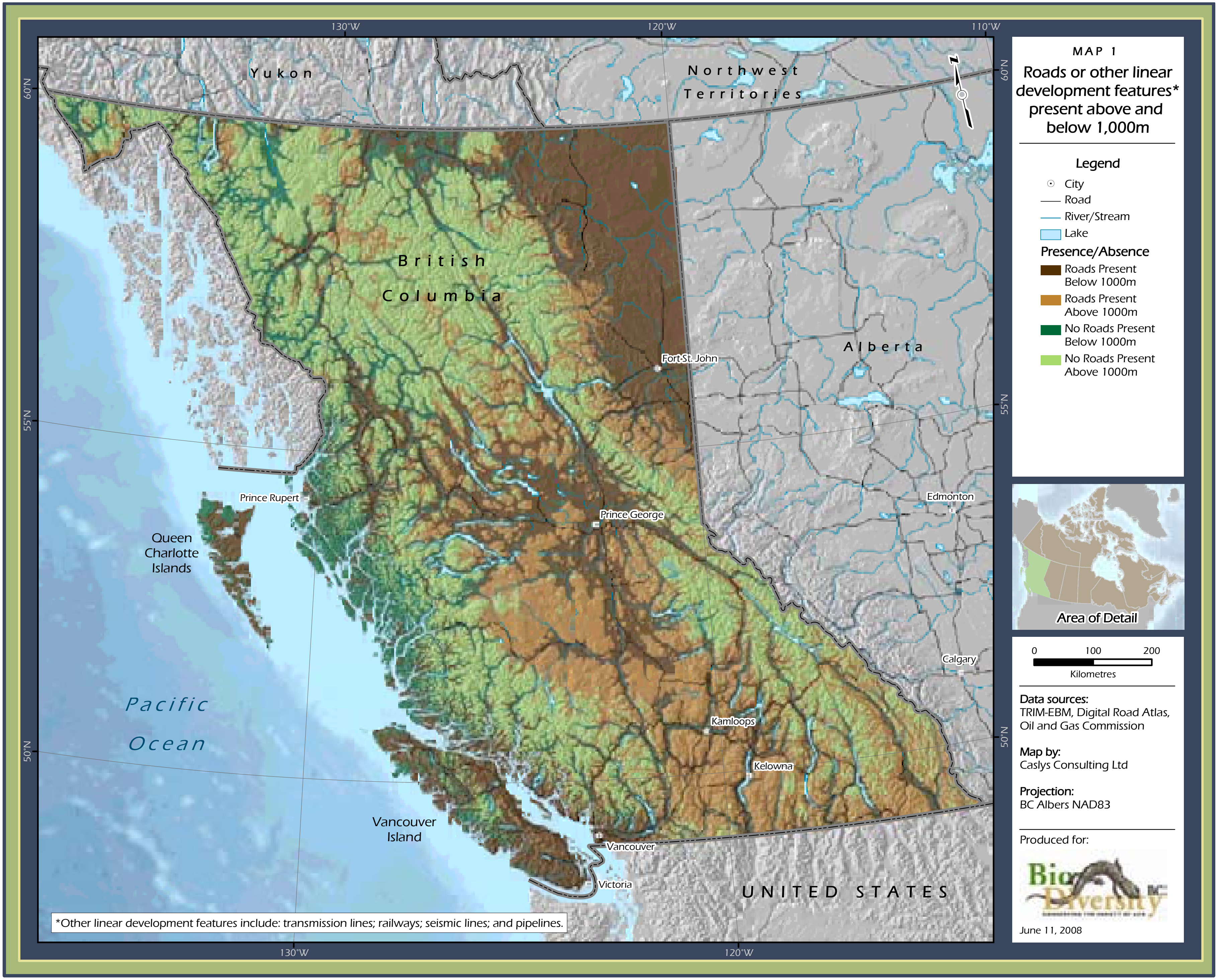
Introduction

Arrowleaf balsamroot (*Balsamorhiza sagittata*) near Gun Creek in the southern Chilcotin region.
PHOTO: MOIRA LEMON.

British Columbia is an exceptional place, known worldwide for its spectacular landscapes and remarkable wildlife. The province's mountainous **topography**, glacial history and ocean-influenced climate have fostered a wide diversity of **ecosystems** and an incredible abundance of life. Of all the Canadian provinces and territories, B.C. is home to the richest diversity of **vascular plants**, mosses, mammals, butterflies and breeding birds, and the largest number of **species** of reptiles, tiger beetles (*Cicindela* spp.) and amphibians found only in one province or territory.[1] Some species – such as the Vancouver Island marmot (*Marmota vancouverensis*), Macoun's meadowfoam (*Limnanthes macounii*) and at least eight south Okanagan insect species – live nowhere else in the world. Others, like the mountain goat (*Oreamnos americanus*)[2] and mountain caribou (*Rangifer tarandus caribou* mountain **ecotype**),[3] have a majority of their **population** in B.C. Several sticklebacks (*Gasterosteus* spp.) that are found only in a few small B.C. lakes are considered scientific treasures because of the genetic insights they offer.[4] Examples of important biological diversity or **biodiversity** also abound at the ecosystem level. For instance, the province shares the world's only inland temperate rainforest with Idaho, Montana and Washington,[a] and, along with Alaska, is home to most of the remaining intact coastal temperate rainforest.

Human activities are altering the landscape of B.C. in ways that compromise components of the province's biodiversity. An increasingly large proportion of the province is roaded (Map 1) and the human population has grown to over four million, with 80% concentrated in urban centres in the lower mainland, on Vancouver Island and in the interior near Kamloops and Kelowna; by 2031, B.C.'s population is expected to reach close to six million (see Sec. 3.3.4, p. 196). Urbanization has replaced large areas of low-elevation natural ecosystems with **impervious surfaces** such as concrete and pavement, and agriculture has converted biologically diverse forests, wetlands

[a] Depending on how the inland temperate rainforest is defined, the entire global range of this ecosystem may be contained within B.C. (see Section 2.5.2.2-A, p. 141).


MAP 1
Roads or other linear development features* present above and below 1,000m
Legend
City
Road
River/Stream
Lake
Presence/Absence
Roads Present Below 1000m
Roads Present Above 1000m
No Roads Present Below 1000m
No Roads Present Above 1000m
Area of Detail
0
100
200
Kilometres
Data sources:
TRIM-EBM, Digital Road Atlas, Oil and Gas Commission
Map by:
Caslys Consulting Ltd
Projection:
BC Albers NAD83
Produced for:
June 11, 2008
130°W
120°W
110°W
60°N
55°N
50°N
Yukon
Northwest Territories
British Columbia
Alberta
Fort St. John
Edmonton
Prince Rupert
Prince George
Queen Charlotte Islands
Calgary
Kamloops
Kelowna
Pacific Ocean
Vancouver Island
Vancouver
Victoria
UNITED STATES
*Other linear development features include: transmission lines; railways; seismic lines; and pipelines.

and grasslands to pasture and crops. Resource extraction places a variety of pressures on biodiversity, particularly through **ecosystem conversion** and **ecosystem degradation**, **environmental contamination** and **species disturbance**, while other human activities impact biodiversity through direct **species mortality** and introduction of **alien species**. Recently, changes in climate as the result of human activities have begun to affect biodiversity in the province in unprecedented and often unpredictable ways.

Nevertheless, British Columbia still has wild places and is considered to be globally important to the conservation of many species and ecosystems. Its rugged terrain and short industrial history, which began with the arrival of European explorers 200 years ago, have limited human activity in much of the province. As a result, sensitive species and ecosystems that have been lost elsewhere are still found in B.C.

Biodiversity, however, is more than just the sum of its parts.[5] Species and ecosystems are connected through numerous natural **processes**. All elements of biodiversity, regardless of whether we understand their roles or know their status, play a role in maintaining functioning, evolving, resilient ecosystems. Maintaining the integrity, evolutionary potential and resilience of our natural systems will facilitate their ability to adapt, particularly in the face of rapid **climate change**.

Biodiversity supplies a host of benefits and services that are essential to the well-being of humans and non-humans alike. This natural capital, which depends on maintaining **native species** and ecosystems and the **functions** they perform, supports the high quality of life British Columbians have come to enjoy.

◀ **The mountainous terrain of B.C. has limited human habitation and development – indicated in Map 1 by the presence of roads and other linear development features such as power lines – in much of the province. Roads or other linear features are present in 79% of the analysis units below 1,000 m in elevation and in 43% of the analysis units above 1,000 m.**[a]

[a] See "About This Report" (p. XXVII) for an explanation of analysis units. For details of methods, see *The Biodiversity Atlas of British Columbia*, available at: www.biodiversitybc.org.

1 A Primer on Biodiversity: Its Importance and History in British Columbia

1.1 What Is Biodiversity?

In the 1980s, the eminent biologist Edward O. Wilson coined the term 'biodiversity' as a shorthand for biological diversity.[a] Biodiversity describes the diversity of all living creatures and their interactions. It is this complex web that sustains life on this planet. From among many possible definitions, Biodiversity BC uses that of the Canadian Biodiversity Strategy: *the variety of species and ecosystems on earth and the ecological processes of which they are a part – including ecosystem, species and genetic diversity components.*[6,7]

The interaction of species, ecosystems and processes is dynamic and links multiple scales (from centimetres and days to hundreds of kilometres and millennia) that collectively shape biodiversity.[8] In a forest, for example, interactions across the range of scales include: physiological processes that affect the life cycle of leaves; competition between neighbouring plant species that affects populations; disturbance and predation processes; and climatic processes that influence the physical and biological character of landscapes and regions.

Ecosystems are complex, dynamic and adaptive systems that are rarely at equilibrium. However, the more an ecosystem maintains its integrity, the more resilient it is and the better it can withstand shocks and rebuild itself without changing to a different state. As ecological functions are impaired and systems simplified, resilience is reduced, making such ecosystems more vulnerable to biophysical or human-caused events that they would otherwise tolerate.[9] Maintaining ecological processes promotes ecological resilience and helps ensure the continued functioning of dynamic, natural ecosystems.[10]

[a] The first published use of 'biodiversity' was in 1988, in the title of the proceedings of the first U.S. national conference on the subject, edited by Wilson (*Biodiversity*, National Academy Press, 1988).

1.1.1 GENETIC, SPECIES AND ECOSYSTEM DIVERSITY

Complex concepts such as biodiversity are often easier to grasp if reduced to their component pieces. While this approach does not give a complete picture of how these pieces interact and combine to create biodiversity, it helps us understand different aspects of biodiversity. The various levels of organization within biodiversity (e.g., **genes**, species and ecosystems) express different features of the complexity and value of biodiversity and interact with each other through ecological processes. Genes make up species, and species (linked by ecological processes) inhabit ecosystems (Figure 2), with smaller ecosystems nested within larger ones. Ecosystems vary enormously in size.[11] They may be as tiny as a drop of pond water or a glacial rivulet, or as vast as the Stikine River watershed, the northwest Pacific coast or the whole planet.

GENES

Genes are the working units of heredity; each gene is a segment of the **DNA** molecule that encodes a single **enzyme** or structural protein unit. Genetic diversity is the foundation of all biodiversity.. Genetic variation permits populations to adapt to changing environments and continue to participate in life's processes. Study of **subspecies** and populations can reveal how organisms respond to their environment, which may not be evident when looking only at the species level. Genetic diversity is continuously changing from generation to generation as a result of **natural selection** and random effects such as **mutation**.

In the long history of life on earth, genetic variants of many species have evolved, and are still evolving, in response to changing local environmental conditions. For example, the current, highly productive runs in the Bristol Bay sockeye salmon (*Oncohynchus nerka*) fishery in Alaska originated from low-producing runs that responded to mid 1990s climate changes.[12] Figure 3 illustrates how genetic variations influence the fur colour of the American black bear (*Ursus americanus*), which occurs as different colour morphs (see also Section 2.4.1.2, p. 75).

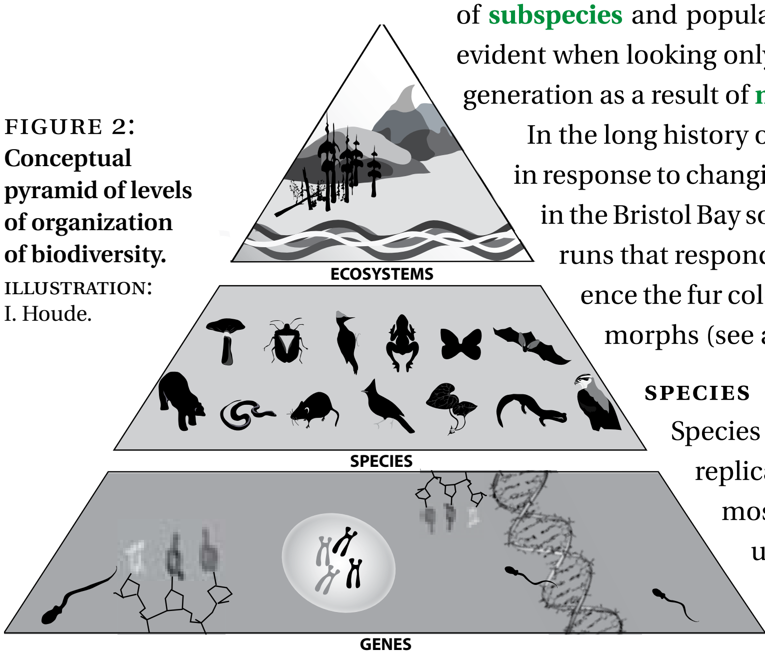


FIGURE 2: Conceptual pyramid of levels of organization of biodiversity.
ILLUSTRATION: I. Houde.

SPECIES

Species (and their subspecies and populations) are generally considered to be the only self-replicating units of genetic diversity that can function as independent units. In the case of most living organisms, each species generally represents a complete, self-generating, unique ensemble of genetic variation, capable of interbreeding and producing fertile offspring. Some animals[13] and many plants[14] can also exchange genes through **hybridization**, which sometimes results in new species (see Section 2.4.1.4, p. 82).

Ian McAllister / Frank Leung / David Huchinson

FIGURE 3: **Colour morphs of the American black bear (*Ursus americanus*). Sustaining a species over its entire range helps to maintain its genetic variation. Within black bears, part of that variability is evident in different colour morphs, such as the rare white coastal morph (known as the Kermode or spirit bear), the more inland cinnamon morph, and the common, widespread black morph. There also is a bluish morph, known as the glacier bear, in the extreme northwest of the province.**

In addition to the millions of species that biologists have already documented worldwide (ranging from microscopic viruses and bacteria to large mammals), many millions more have yet to be identified and categorized. When species become **extinct**, diversity is lost at both the species and genetic levels and cannot be recovered. Species, like genes, do not exist in isolation. They interact with other organisms in groupings called communities. Retaining all member species helps maintain **community** resilience.

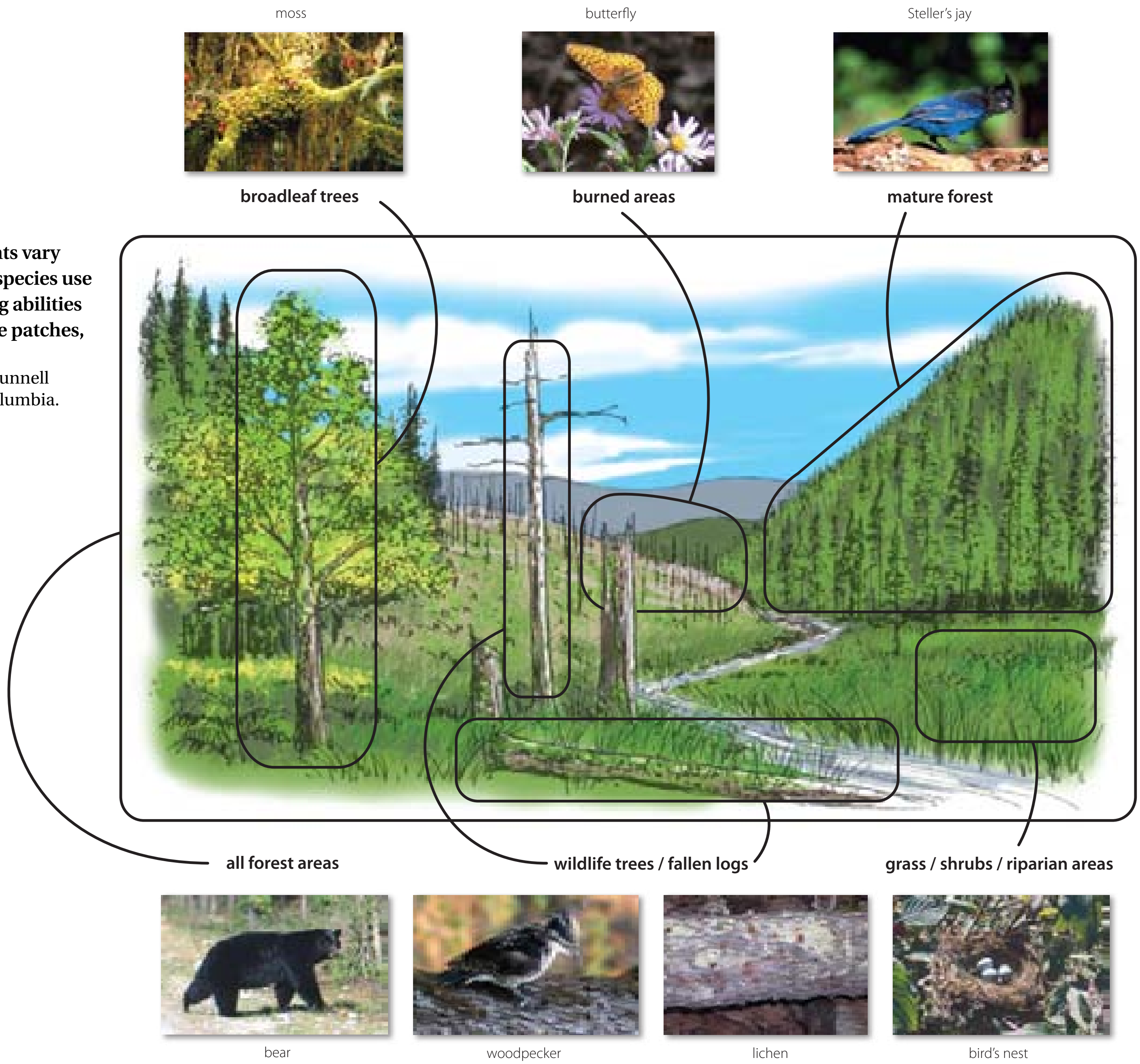
ECOSYSTEMS

An ecosystem is a dynamic complex of plant, animal and microorganism communities and non-living (**abiotic**) elements, all interacting as a functional unit. An ecosystem's character changes as community members and physical contexts change, sometimes crossing a threshold of tolerance within the system that results in its inability to return to its previous form. For example, severe winter temperatures regulate the survival of mountain pine beetle (*Dendroctonus ponderosae*) larvae.[15] Without this controlling mechanism, the increase in larval survival over a period of years can result in a major shift in the character of interior pine forest ecosystems. Text box 16 (p. 105) describes the impact of the current mountain pine beetle epidemic on B.C. forest ecosystems.

1.1.2 COMPOSITION, STRUCTURE AND FUNCTION

Besides being examined at the various levels of organization, biodiversity can also be described in terms of attributes such as **composition**, **structure** and function.

FIGURE 4: Patch size requirements vary by species. Members of different species use space differently and have varying abilities to traverse compatible and hostile patches, and to avoid isolation.
SOURCE: Adapted from original by F. Bunnell and I. Houde, University of British Columbia.
ILLUSTRATION: Soren Henrich.



Composition is the identity and variety of an ecological system. Descriptors of *composition* are typically lists of the species resident in an area or an ecosystem. Measures of composition, such as **species richness** and diversity of species, can help demonstrate how biodiversity in an area is faring.

Structure is the physical organization or pattern of a system; for example, the size and spacing of trees in a landscape. Measures of *structure,* which often describe the **habitat** of species, reveal arrangements and patterns in both living and non-living components of the environment. These necessarily span a wide range of scales and **patch** sizes to encompass the natural range of life forms and the ways they respond to the environment (Figure 4) and include the mosaic pattern of communities across landscapes.

Function refers to the result of ecological and evolutionary processes. Examples of function include **gene flow** (resulting from processes such as **dispersal** and reproduction) and **nutrient cycling** (resulting from processes such as **photosynthesis** and **decomposition**). Measures of a *function* must be designed specifically for that function, and perhaps for each of its component processes. For some of the most critical functions, including water purification, nutrient cycling and **pollination**, scientists know only a fraction of the species and processes involved – and not necessarily the most important ones.

These three biodiversity attributes are inseparable. Composition changes as structure changes; functions and processes change as composition changes. Changes in structure can influence processes such as herbivory and predation, and these processes can change species composition. Changes in composition, such as relative abundance of certain species, can alter structure, leading to further changes in composition. For example, when large predators are lost, populations of large browsers and grazers may increase to the point that certain vegetation elements are eradicated, thereby eliminating other species dependent on that vegetation. The loss of wolves (*Canis* spp.) and cougars (*Puma concolor*) in the eastern United States and the subsequent increase in deer (*Odocoileus* spp.) populations have locally eliminated many ground- and shrub-nesting birds and could lead to the demise of local hardwoods (e.g., oak [*Quercus* spp.] and American beech [*Fagus grandifolia*]).[16,17,18] On Haida Gwaii/Queen Charlotte Islands, where cougars and wolves do not naturally occur, high numbers of introduced Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) have had a severe impact on western redcedar (*Thuja plicata*), have browsed Sitka spruce seedlings (*Picea sitchensis*) to the point that moss sometimes grows faster than the seedlings and have kept at least one plant species, western oxypolis (*Oxypolis occidentalis*), from flowering.[19]

Emily Carr, one of B.C.'s best-known artists, drew inspiration from the natural world for many of her paintings. Emily Carr, *Cedar*, 1942, oil on canvas, 112.0 x 69.0 cm, collection of the Vancouver Art Gallery, Emily Carr Trust, VAG 42.3.28.
PHOTO: TREVOR MILLS, VANCOUVER ART GALLERY.

1.2 Why Is Biodiversity Important?

Biodiversity provides a long list of services critical to supporting life on earth (Figure 5).[20] Such ecosystem services directly and indirectly contribute economic value. Ten years ago, the global economic value of 17 ecosystem services for 16 **biomes** was estimated to be in the range of $US16–54 trillion per year, with an average value of US$33 trillion per year.[a,21]

Biodiversity also provides diverse cultural services, such as opportunities for spiritual and religious experiences, education, recreation and an aesthetic connection with nature that is exemplified in many art forms.[22,23] These cultural values have remained important even with increasing urbanization and are perhaps most obvious among Aboriginal peoples whose connections to nature are well maintained. For example, western redcedar and yellow-cedar (*Chamaecyparis nootkatensis*) are culturally important to coastal First Nations (see Text box 2, p. 13).[24] Both species are also under increasing threat due to climate change.[25,26]

Many people believe that humans have a moral obligation to protect all life forms for their own sake, as well as for their value to future generations. A world without the services provided by species and ecosystems is unimaginable. For example, if major groups of decomposer organisms were to fail, organic debris would simply accumulate, and nutrient cycling, plant growth and food production would come to a halt. Pollination of food plants by insects accounts for about one of every three mouthfuls of food eaten by humans.[27] While some species could disappear with little measurable impact, many of the species responsible for the critical ecosystem services required for life and human well-being are unknown. Conserving biodiversity maintains options for future generations.

ECOSYSTEM SERVICES

PROVISIONING SERVICES (GOODS)	**CULTURAL SERVICES**	**REGULATING SERVICES**	**SUPPORTING SERVICES**
Food, fibre & fuel	Spiritual values	Invasion resistance	Primary production
Genetic resources	Knowledge systems	Pollination	Provision of habitat
Biochemicals	Education & inspiration	Seed dispersal	Nutrient cycling
Fresh water	Recreation & aesthetic values	Climate regulation	Soil formation/retention
Habitat		Pest & disease regulation	Production of atmospheric oxygen
		Natural hazard protection	Water cycling
		Erosion regulation	
		Water purification	

FIGURE 5: **Services derived from biodiversity that support human well-being.**
SOURCE: Secretariat of the Convention on Biological Diversity. 2006. Global Biodiversity Outlook 2. Montreal, PQ. 81pp. Available at: www.biodiv.org/gbo2/default.shtml.

[a] To put this in context, the global gross national product was around US$18 trillion per year.

TEXT BOX 1. THE EARTH SUMMIT AND THE CANADIAN BIODIVERSITY STRATEGY

In 1992, the United Nations Conference on Environment and Development[28] (UNCED '92, commonly known as the Earth Summit) was convened in response to growing public concern about the loss of biodiversity. The summit led to several international agreements and treaties, including the Convention on Biological Diversity (CBD). The objectives of the CBD are:

- conservation of biodiversity;
- sustainable use of biological resources; and
- fair and equitable sharing of benefits arising from the use of genetic resources.

The Canadian Biodiversity Strategy is Canada's response to the CBD. In 1996, federal, provincial and territorial governments agreed to use the Canadian strategy as a guide to their actions and to implement it according to their own priorities and fiscal circumstances.[29] A number of provinces and territories have developed biodiversity strategies and action plans, and others are in the process of developing them.

1.3 Importance of Biodiversity for First Peoples of British Columbia

First Nations in B.C. have relied on, and helped to sustain, biodiversity in their home territories for at least 10,000 years. More than 30 linguistically distinct indigenous groups have resided here, often in dense populations, especially along the coast and the major river systems. Many of these peoples still live in communities within their traditional territories. Although they have distinctive languages (Figure 6) and cultural traits, they also share many similarities in their cultural practices.

1.3.1 TRADITIONAL USES OF BIODIVERSITY

Biodiversity is important to traditional First Nations food systems, technology and medicine (Text box 2). Diets based on a combination of animal and plant foods (including salmon, other finfish, shellfish, marine and land mammals, game birds, birds' eggs, berries and other fruits, green and root vegetables, mushrooms and the inner bark of trees) have nourished and sustained people for countless generations.[30,31,32,33] Plants and animals have also provided a wide range of important material resources: wood for fuel, construction, canoes and implements; sheets of bark and fibrous materials for canoes, cordage, mats, basketry and clothing; pitch for waterproofing

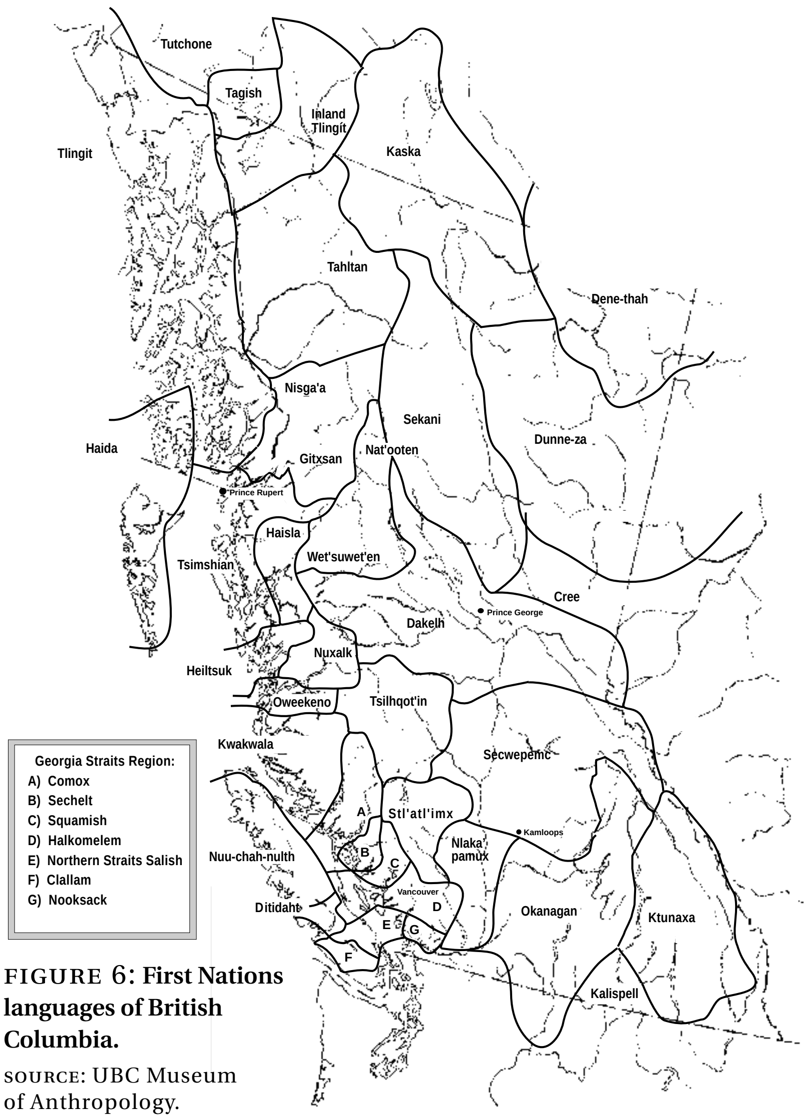


FIGURE 6: **First Nations languages of British Columbia.**

SOURCE: UBC Museum of Anthropology.

NOTES: This map is regularly revised. Latest revision October 15, 1996. No reproduction without permission.
Boundaries on this map mark out areas within which district languages are spoken. The areas are approximate and subject to revision. Names used here are those which are preferred by First Nations and have come into general acceptance for the languages concerned. They are also subject to revision.

and glue; kelp for fishing line and containers; shells, bone and antler for knives, chisels and points; and a host of other substances for dyes, stains, waterproofing, cleansing and protective scents.[34] A host of medicines for maintaining health and treating injuries and ailments of many kinds have been derived from plants, as well as some animals and **fungi**.[35, 36, 37]

Plants, animals and fungi are also prominent in First Nations' belief systems, art, songs and ceremonies.[38,39] Ceremonial species and those featured in art and narrative are often the same ones that have practical applications.[40] The richness of Northwest Coast First Peoples' connections with biodiversity is reflected perhaps most famously in their world-renowned art forms, which represent animals, birds, fish and other beings in totem poles, masks, dishes, jewellery, sculptures and paintings.[41,42,43] These designs represent key figures in the histories of families, clans and individuals. Their immense power and compelling form symbolize the depth of human reliance on biodiversity.

Food species alone include at least 100 animal species and 150 plant species across the different nations and regions of the province. Species used for material or technology number at least 100, and medicinal species probably 300 or more. Altogether, about 400 to 500 species (some used for more than one purpose) are named and used or have specific cultural importance for B.C.'s First Peoples. Many others – including many attractive wildflowers that might not be named individually, but are nonetheless recognized and distinguished – have general importance. First Nations' knowledge systems encompass immense expertise about the ecological and **morphological** characteristics of plants and animals. Many species serve as indicators of traditional seasonal rounds, with the flowering of certain plants, the songs of certain birds or the appearance of certain types of butterflies or other insects marking seasonal changes or signalling the time for important harvest events.[44]

Some plants and animals are so important and well known that First Peoples recognized and named different varieties and strains. For example, the Gitga'at of Hartley Bay have names for at least six different varieties of Pacific crab apple

TEXT BOX 2. CULTURALLY SIGNIFICANT SPECIES

Culturally significant species shape the cultural identity of a people in a major way. Their importance is reflected in the fundamental roles they play in diet, materials, medicine and/or spiritual practices.[45]

Species that are culturally significant for First Peoples in British Columbia include:

- Pacific salmon: Five species of Pacific salmon – chinook (*Oncorhynchus tshawytscha*), chum (*O. keta*), coho (*O. kisutch*), pink (*O. gorbuscha*) and sockeye – as well as steelhead (*O. mykiss*), are a key economic, nutritional and cultural resource for First Nations in both coastal and interior B.C. Fresh, dried or smoked salmon, as well as salmon eggs and salmon oil, have been widely traded by First Peoples since pre-European times. More recently, salmon has formed the basis of a major commercial fishery and cannery industry that has supported many First Nations communities. First Peoples have been important stewards of salmon populations and their habitats.
- Eulachon (*Thaleichthys pacificus*): A small smelt also known as oolichan, oulachen or ooligan, spawns in early spring along the shores of rivers from the Fraser River to the Nass River. It has been a major source of a nutritious oil (commonly called 'grease'), rendered from the fish caught after spawning. Smoked and dried eulachon are also consumed. These products are still important in trade, although some eulachon runs have declined drastically in recent years.[46]
- Western redcedar: Known as a sacred tree, western redcedar is the cornerstone of Northwest Coast Aboriginal culture. It is prized for its important and varied uses in material technology and ceremonial purposes.
- Edible red laver seaweed (*Porphyra abbottiae*): This marine alga is an important food source for Aboriginal people in coastal areas. It is valued not only for its nutritional properties, but also as a gift or trade item and for its medicinal uses.
- Wapato (*Sagittaria latifolia* var. *latifolia*): Also known as the Indian swamp potato by the Katzie and other Sto:lo peoples of B.C., wapato was a traditional staple root vegetable and valued as a trade item. The maintenance of wapato patches by particular families was an important part of First Peoples' community structure, which was disrupted as wetlands in the Fraser River valley were converted to intensive agriculture, decreasing the amount of habitat suitable for growing wapato.
- Bitterroot (*Lewisia rediviva*): The thick, fleshy taproot of bitterroot is an important food of the Thompson people from Lytton to Ashcroft and eastwards. Bitterroot was an important trade item and so valuable it was usually served only on special occasions.[47]

First Peoples of B.C. have many uses for western redcedar (*Thuja plicata*), from clothing to longhouses. Pictured here is Nani Florence collecting cedar bark.

PHOTO: ROBERT D. TURNER.

Coastal strawberries (*Fragaria chiloensis*), one of several wild strawberry varieties found in B.C.
PHOTO: NANCY TURNER.

TEXT BOX 3. FIRST PEOPLES' STEWARDSHIP OF BIODIVERSITY

In many cases, First Peoples have maintained and enhanced plant and animal populations and productivity and increased habitat diversity through resource management strategies that yield a greater variety and abundance of foods and materials than would be naturally available.[48] Early Europeans arriving in various parts of B.C. were impressed by the tremendous richness of the fisheries, game populations, berries and other traditional resources that were under First Nations stewardship. For example, when James Douglas arrived on southern Vancouver Island at the site near where he would build Fort Victoria, he was struck by the majestic, park-like appearance of the landscape, with its oak groves and extensive fields of lush clover (*Trifolium* spp.), common camas (*Camassia quamash*) and other flowering plants.[49,50]

While caring for and maintaining biodiversity was essential for First Peoples' survival, they also saw it as part of their cultural responsibility. Fish, trees and other animals and plants were all regarded in traditional world views as generous relatives, willing to give themselves to humans within a reciprocal system that demanded proper care and respect in return. Children were raised in traditional indigenous society with the understanding that animals and plants had their own societies and possessed powers given to them by the Creator to influence human lives in positive or negative ways, depending on whether the humans were worthy and behaved properly toward them.[51,52,53,54]

(*Malus fusca*) and the Nlaka'pmx (Thompson) and Stl'atl'imx (Lillooet) of the southern interior name and use five or more varieties of Saskatoon (*Amelanchier alnifolia*).[55,56]

Biodiversity at the broader scale of community or ecosystem variation is also critically important to First Nations. People routinely moved between ecosystems, from the ocean and valley bottoms to the high mountaintops, to gain access to a range of resources. Generally residing in permanent winter villages on the coast or along rivers and lakeshores, they would, and still do, travel to different sites throughout their territories following the availability of various seasonal resources. They were also able to obtain resources from beyond their own homelands through trade and intermarriage with other groups.[57,58]

1.3.2 IMPACTS OF BIODIVERSITY DEGRADATION ON FIRST PEOPLES

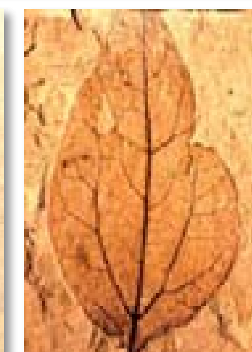
Erosion of biodiversity in various parts of the province has severely impacted First Peoples and their traditional food systems. Declines and losses of traditional resources, from salmon and abalone to berries and root vegetables, are of great concern. Major changes to traditional food systems have occurred partly as a result of environmental deterioration, and this in turn has resulted in health problems and cultural loss in many communities. First Peoples' lifeways have been directly and consistently impacted by declining populations of game, salmon and other fish, loss of forest cover and loss of access to their traditional land base. It is difficult to assess the extent of their loss in quantitative terms. Only a handful of the 400 to 500 species that were used directly have been assessed as being of provincial **conservation concern**. Nevertheless, according to the testimony of many elders who have witnessed tremendous change in B.C. landscapes over their lifetimes, most of these species are not as productive or as common as they once were.[59]

1.4 Biodiversity and Geological History

Geologic history and landscape age play key roles in shaping the biodiversity of a region. In general, old, stable landscapes support more species than young ones because there has been more time for variation to evolve. As well, geologically old regions often have had numerous geographic connections with sources of new life forms from other regions. Landscapes with complex geological histories also tend to have more habitats because the land surface is diverse.

Exceptional events such as glaciation and harsh climates reduce biodiversity and eliminate ecosystems, yet also create isolated pockets of life in which new evolutionary directions are explored.[60] British Columbia has experienced widespread glaciation and harsh climates in the past 15,000 years, a short duration in geologic time.[61,62]



These fossil plants from the Eocene Epoch (about 50 million years ago) – elm (*Ulmus* spp.), ginkgo (*Ginkgo* spp.), dawn redwood (*Metasequoia* spp.) and sassafras (*Sassafras* spp.) – represent a wide-ranging flora that extended around the northern hemisphere in all continents. These species grew as part of warm-temperate to temperate forests of evergreen, deciduous and coniferous species under a climate many degrees Celsius warmer than today. Remnants of that biome now occur mainly in the southeastern United States and in Southeast Asia. Elements such as dawn redwood, though once extremely widespread, especially in B.C., persist today in only a few small populations. Ginkgo, once common, has never been collected in the wild, but survived in an Asian monastery garden. PHOTOS: KEN O'NEILL.

Global geological processes during the past 100 million years have variously connected and separated B.C. from regions to the east, northwest and south, bringing infusions from a wide range of ecosystems and species and fostering local evolution. For much of the Cenozoic Era (the period of geological history that spans the past 65 million years), the B.C. region was part of a warm, temperate, broadleaf forest biome, which provided the raw materials for modern terrestrial biodiversity[63] and extended across the northern hemisphere.

As terrestrial ecosystems developed in the Cenozoic Era, marine biodiversity was largely being shaped by **migrations** north and south along the Pacific Coast as global temperatures fluctuated. Coastal marine ecosystems developed a north-south pattern of zones. During this period, the oldest fossil member of the **salmonid** family, *Eosalmo driftwoodensis*, inhabited lakes and rivers that drained into the Pacific Ocean.[64] Shoreline ecosystems of 25 million years ago were broadly similar to those of today and many constituent species of that time have modern relatives.

Temperatures declined during the last 10 million years of the Cenozoic, producing the cool and cold climates of the **Pleistocene** Epoch. During this period of cooling, western North America evolved distinctive temperate and northern floras, faunas and biomes, as well as dry, inter-mountain ecosystems. During this time, the warm, temperate, broadleaf forest biome was slowly replaced by a broad zone of coniferous and deciduous forest.[65]

1.4.1 THE PLEISTOCENE (ICE AGE) EPOCH

Beginning 1.8 million years ago, a major Pleistocene Epoch cooling trend initiated northern hemispheric migrations and progressive development of boreal and **tundra** biomes.[66] B.C. experienced several widespread glaciations, which reset biodiversity patterns with each advance and retreat.[67]

Taiga (a moist, subarctic forest dominated by conifers, which begins where the tundra ends), tundra and cold, dry **steppe** ecosystems spread widely across the continent including B.C., alternating in time with coniferous forest ecosystems similar to those of today. A distinctive Pleistocene-adapted, mammal **megafauna** ranged widely, and cold-adapted species, such as the muskox (*Ovibos moschatus*), extended into southern B.C. during cold intervals.[68]

1.4.2 BEFORE THE LAST GLACIAL MAXIMUM: 50,000 TO 17,000 YEARS AGO

The most important interval for the origin and development of B.C.'s current biodiversity is the past 50,000 years, which includes the last major ice advances. North America, like the rest of the world, was generally cooler, with glacial ice probably covering most of northeastern North America and possibly some B.C. mountain ranges.

Vegetation zones were displaced southward and to lower elevations (by 400–500 m). In the northwestern United States, mixed **conifer** forest alternated in time and space with open ecosystems, dominated by sagebrush (*Artemisia* spp.) and pines (*Pinus* spp.) in the interior.[69]

In B.C., extensive subalpine spruce (*Picea* spp.) and mountain hemlock (*Tsuga mertensiana*) forests and parkland prevailed between about 48,000 and 30,000 years ago.[70,71] Wetlands seem to have occurred widely and rivers and lakes may have had relatively high sediment loads.

Cold, dry glacial conditions developed across North America, from the north to the mid continent, about 30,000 years ago and intensified to about 20,000 years ago. Steppe ecosystems, including elements of the widespread megafauna, such as woolly mammoths (*Mammuthus primigenius*), seem to have prevailed.[72,73] Current high-elevation alpine species, such as Sitka valerian (*Valeriana sitchensis*) and American bistort (*Polygonum bistortoides*),[74] grew at sea level.[75] Large glaciers occupied major valleys and fed unstable stream and river systems that transported masses of sediment at their leading edges. A brief respite from these glacial conditions occurred 17,000 to 18,000 years ago when subalpine-like forest returned (at least in southwestern B.C.), before the next intense glaciation began about 15,000 year ago.[76] During that short interval, salmonids were found in unglaciated areas such as the Thompson Valley.[77]

Woolly mammoths *(Mammuthus primigenius)* roamed widely in B.C. and adjacent regions in the late Pleistocene Epoch, but went extinct with the warming climate about 10,000 years ago.
PHOTO: ANDREW NIEMANN, ROYAL BRITISH COLUMBIA MUSEUM.

1.4.3 THE GLACIAL MAXIMUM: 17,000 TO 14,000 YEARS AGO

The traditional view is that almost all of B.C. was ice-covered during this last glaciation and that B.C.'s terrestrial biodiversity originated with the subsequent migration of species from the south, east and north. From this perspective, B.C.'s biodiversity is a regional variation on evolutionary themes largely developed elsewhere. To a considerable extent this is true. However, recent research, especially DNA studies, suggest that unglaciated zones, or **refugia**, in B.C. were larger than previously thought and that elements of the province's biodiversity have a long pre-glacial history.[78]

The most widely recognized B.C. refugia are high-elevation sites and some adjacent slopes on Haida Gwaii/Queen Charlotte Islands and the Brooks Peninsula on Vancouver Island.[79,80] In these areas, alpine and probably high-elevation, cool oceanic ecosystems persisted, resulting in a unique set of plant species and subspecific lineages **endemic** to the region.

DNA studies of mountain sorrel (*Oxyria digyna*), a globally widespread alpine plant, also suggest there were ice-free zones for alpine species in northern B.C., possibly with connections to **Beringia**.[81] These studies also confirm the presence of refugia on the north coast. Although it is not known to what extent low-elevation sites were included in the refugia, the studies indicate a potentially high level of genetic diversity and globally unique biodiversity in the region.

Despite the existence of refugia, a key feature of the last glacial interval is that B.C. had no extensive conifer forests as we know them today, though scattered coniferous trees (e.g., subalpine fir [*Abies lasiocarpa*] at high elevations in the south and lodgepole pine [*Pinus contorta* var. *latifolia*] along the coast) may have persisted.[82,83,84] The province's modern forest ecosystems developed during the past 14,000 years, as ice-age climates ended.

In the nearshore marine environment, sea levels fluctuated widely for several thousand years and the present-day coastal marine zone was exposed to a depth of more than 100 m. Many now-isolated land masses, such as Haida Gwaii/Queen Charlotte Islands, were connected to the mainland, facilitating migrations.[85]

1.4.4 END OF THE ICE AGE: 14,000 TO 10,000 YEARS AGO

Landscape instability continued for at least 4,000 years as the glacial regime ended between 14,000 and 10,000 years ago. During this interval of widespread climatic and ecological adjustment, extensive migrations took place throughout the region and forest ecosystems began to re-form.[86]

Three broad migration patterns were superimposed over the unique alpine and coastal ecosystems that had survived glaciation in B.C. In the north, elements of the Beringian steppe-tundra landscape spread southward. From the south, migration occurred on two fronts: one along the coastal zone, largely involving coastal temperate rainforest species; and one east of the Coast-Cascades mountain axis, involving Great Basin cold steppe and dry forest species. In addition, continental boreal and conifer woodland species came from the southeast along the waning Laurentide ice sheet.[87]

In some respects, the ecosystems of this transition time might have looked familiar, though out of place to modern observers. For example, for several thousand years, open, dry, cold lodgepole pine forests extended along the B.C. coast to Alaska, forming a distinctive biome.[88] In the interior, cold sagebrush and grassland ecosystems likely predominated.[89] Tundra-like ecosystems spread across the north of the province. Moist, cool mixed-coniferous forests featuring mountain hemlock developed for about a thousand years (12,000 to 11,000 years ago), from the pine biome along the coast down to present-day sea level.[90] These ecosystems reflected the cooler-than-present climates of the day.

In one major respect, however, life in the late-glacial period differed from what we see today, as it included the now-extinct megafauna. Mastodons (*Mammut americanum*), giant bison (*Bison antiquus*), woolly mammoths and giant ground sloths (*Megatherium americanum*) roamed parts of B.C., including southern Vancouver Island.[91]

These animals clearly influenced the ecological processes, structure and composition of plant communities. In addition, a new species – humans – began to depend upon and influence B.C.'s evolving biological diversity.

In the freshwater realm, a degree of stability returned as the land was stabilized by vegetation. Familiar ecosystems, such as cattail (*Typha* spp.) and bulrush (e.g., *Scirpus* spp.) marshes and shallow-water communities, developed widely. Lime-rich, **marl**-depositing ecosystems occurred widely on parts of the south coast and in the southern interior. The marine zone was, however, much less stable because of sediment input from waning valley glaciers and the invasion of salt water on a glacially depressed landscape. Diverse cold-water **mollusc** faunas predominated.[92]

Between 11,000 and 10,000 years ago, a brief, but profound cooling event (called the Younger Dryas in Europe), brought cold, dry conditions for about 500 years and widely disrupted the landscape.[93] Temperatures declined over a few decades by as much as 5°C and cold-climate processes such as solifluction (the slow, downslope movement of moist or saturated, seasonally frozen, surficial material and soil) disturbed the landscape as far south as Vancouver Island.[94] There was widespread forest loss and return of cold and unstable ecosystems, creating alder (*Alnus* spp.) scrub along the coast.[95] Migration and extinction of the ice-age megafauna took place globally. As far as scientists know, none of the megafauna survived the dramatic climatic and ecological changes into the **Holocene** Epoch and non-glacial climates in B.C.,[96] as hunting by humans hastened the disappearance of these species.[97]

Skull of the now-extinct giant bison (*Bison antiquus*) from the Saanich Peninsula on Vancouver Island, about 12,000 years ago.

PHOTO: ANDREW NIEMANN, ROYAL BRITISH COLUMBIA MUSEUM.

1.4.5 WARM DRY EARLY HOLOCENE EPOCH: 10,000 TO 7,000 YEARS AGO

Around the world, rapid warming by as much as 5–8°C ushered in the warm, interglacial climates of the modern Holocene Epoch. This period of roughly 10,000 years can be broadly divided into three climatic intervals, during which B.C.'s pre-European disturbance biodiversity arose: warm, relatively dry (from 10,000 to 7,000 years ago); warm, moist (from 7,000 to 4,000 years ago); and moderate, moist (from 4,000 years ago to the present).[98]

The warm, dry early Holocene was a time of rapid immigration of species and establishment of new ecosystems in many regions under climates warmer than today. On the south coast, Douglas-fir (*Pseudotsuga menziesii*) spread widely and rapidly to dominate forests and woodlands well into the zone of today's cedar-hemlock forests.[99] In the moist climates of western Vancouver Island and the central and north coast, Sitka spruce combined with western hemlock (*Tsuga heterophylla*) to form an ecosystem that has no modern equivalent in B.C.[100]

Warm, dry grasslands and Garry oak (*Quercus garryana*) ecosystems, including many of the species associated with them today, became established and occupied areas much greater than today. Beyond the grasslands in the southern interior, dry pine-dominated forests reached well into, if not fully occupying, today's range of the Engelmann Spruce–Subalpine fir **biogeoclimatic zone**.[101] Species that are now rare in B.C., such as Oregon ash (*Fraxinus latifolia*), were much more widespread, whereas species common today, such as western redcedar, occurred infrequently.[102] Fires burned widely in the southern half of the province, regularly disturbing the landscape in the interior and even on the coast.[103]

Extensive tracts of open ecosystems related to modern non-forest communities occurred widely during the warm dry early Holocene interval. Many herbaceous and shrubby species of open terrain (e.g., sagebrush) became well established in late glacial times, especially during drier phases. To these were added species that migrated from the south following newly available warm to hot, dry valley bottoms and slopes, each according to its natural rate of dispersal. In the southern interior, valley-bottom grasslands stretched through a series of elevation zones upslope into alpine heights, forming a large area suitable for rangeland dwellers.[104,105] Extensive steppe ecosystems reached as far north as the latitude of Quesnel. Along the south coast, sea levels were at least 10 m lower than today and many coastal meadow species that are now uncommon, restricted or rare spread throughout the **Georgia Basin**.[106] Treelines were at higher elevations than today and the alpine region was less extensive in the south.

What little is known about northern ecosystems during the warm, dry interval indicates that boreal-like forests involving spruces gradually developed and pines migrated into the region. Yet even in northeastern B.C., grasslands were more widespread than today.[107]

Freshwater environments were generally warmer and shallower than today, with some smaller water bodies being **ephemeral**.[108] Water chemistry tended toward neutral or even alkaline and marl-depositing communities occurred widely in the southern interior. Marshes and swamps were dominant types of wetlands.

Little is known about conditions in the marine environment during this interval. Whereas the early Holocene was a time of migration and connection on the south coast, isolation and fragmentation took place on the north coast. Sea levels rose and separated Haida Gwaii/Queen Charlotte Islands from the continent, drowning extensive low-lying coastal ecosystems and eventually resulting in an island area much smaller than exists today.[109]

1.4.6 WARM MOIST MIDDLE HOLOCENE EPOCH: 7,000 TO 4,000 YEARS AGO

Increasing moisture and gradual cooling fostered major ecological changes between 7,000 and 4,000 years ago.[110] During this transition to modern conditions, western hemlock and Sitka spruce coastal forests persisted, while amabilis fir (*Abies amabilis*) and western redcedar became more abundant. Dry south coast regions continued to support Douglas-fir-dominated ecosystems, except on southeastern Vancouver Island, where there were extensive tracts of Garry oak woodland and meadow.[111]

Grasslands were widespread in the southern interior, but pine forests expanded to lower elevations. Engelmann spruce (*Picea engelmannii*)–subalpine fir forests began to appear in moist, cool sites, while boreal forest continued to develop in the north.[112]

Topographic basins filled with greater amounts of permanent water.[113] Ephemeral and small ponds expanded into lakes. Seasonally intermittent streams may have become permanent water courses. The wet shore zone accordingly expanded outwards and the volume of deep water grew. The marine shoreline and its ecosystems now began to stabilize, but major sea-level adjustments continued.[114]

Cross-section of a Douglas-fir (*Pseudotsuga menziesii*) from Heal Lake, southern Vancouver Island, showing a sudden change in ring thickness, about 4,000 years ago, when the modern climate arose.
PHOTO: RICHARD HEBDA.

1.4.7 MODERATE AND MOIST LATE HOLOCENE EPOCH: 4,000 YEARS AGO TO PRESENT

The latter part of the Holocene Epoch saw cooler temperatures than in the preceding 6,000 years, which, combined with relatively abundant moisture, fostered forest and wetland expansion. During this period, the modern pattern of ecosystems became well established and glaciers and ice fields expanded widely at high elevations.

On the coast, the most important event was the spread of western redcedar and the development of modern coastal temperate rainforests.[115] The range of dry ecosystems, such as the Garry oak meadow complex, became very limited, although regular burning by First Nations may have maintained them over a wider area than the climate dictated.[116] In the interior, cedar-hemlock forests arose for the first time.[117,118] At high elevations in the interior, cold, moist Engelmann spruce–subalpine fir forest became well established, largely developing from earlier, relatively dry pine forests.[119] Similarly, coastal mountain hemlock forests developed fully and spread more widely.[120,121] In the central interior, sub-boreal spruce forests spread southward into areas previously too dry to support them. As forests expanded on many fronts, grasslands shrank to their minimum range, where they largely remain today.[122]

Associated with the cooling and moistening climate of 4,000 years ago, fire activity declined notably. Nevertheless, fires were used by First Nations throughout much of the province and at all elevations for maintaining resources associated with open and successional communities.[123]

Increasing moisture on the landscape fostered widespread growth of peatlands. Bogs arose or spread widely in wet coastal forests and in moist interior areas, providing habitat for the distinct species associated with them. Other wetland and aquatic habitats also expanded. Mid- and high-elevation lakes and streams cooled as glaciers redeveloped and expanded.[124]

Relative stability on land was paralleled by stability in the marine zone as sea levels reached equilibrium following nearly 10,000 years of postglacial adjustment.[125]

2 British Columbia's Natural Legacy

To describe the beauties of this region will, on some future occasion be a very grateful task to the pen of a skilled panegyrist.[a] The serenity of the climate, the innumerable pleasing landscapes, and the abundant fertility that unassisted nature puts forth [renders] it the most lovely country that can be imagined.

– CAPTAIN GEORGE VANCOUVER, 1792.[126]

Prior to Europeans arriving at the end of the 18th century on the shores of the land we now call British Columbia, the population of First Peoples is estimated to have been between 80,000 and 250,000.[127] Clues to the abundance and diversity that existed here at that time can be found in First Nations stories and legends and in the journals of early European visitors who regarded the landscapes and wildlife as remarkable. Historical ecosystem mapping shows that Garry oak ecosystems were common along the southeast coast of Vancouver Island and extensive grasslands flourished throughout the Okanagan, Thompson and Nicola valleys.[128,129] Robert Brown, the first colonial to cross Vancouver Island on foot, describes the deer being "so thick that you only require to go behind a bush – sound [a] hunting whistle and take your pick of the fattest and best" and the lakes "merry with leaping trout and salmon."[130] More than 400 grizzly bear (*Ursus arctos*) hides were taken from the Cascade Mountains between 1846 and 1851,[b,131] and in 1918, a herd of about 2,000 mountain caribou was sighted at Isaac Lake in what is now Bowron Lake Provincial Park.[c,132] Peak runs of sockeye salmon in the Fraser River in the early 1900s are estimated to have exceeded 50 million fish.[133]

[a] A panegyrist is a person who writes laudatory speeches or tributes.
[b] Includes a portion of the Cascade Mountains in Washington State.
[c] This exceeds the current estimated provincial population of mountain caribou (see Text box 13, p. 85).

While 14 species, including the passenger pigeon (*Ectopistes migratorius*), western pond turtle (*Actinemys marmorata*) and viceroy butterfly (*Limenitis archippus*), have disappeared from the province since European contact (see Table 14, p. 58), almost all of the native species and ecosystems that were present in B.C. in 1776, when Captain Cook stepped ashore on Nootka Island, still occur here today.

Like early European explorers, a modern visitor to the province might use the word 'remarkable' to describe B.C.'s landscapes and wildlife. There are still vast forests, mountains and great rivers; **ungulates** and carnivores that have disappeared from other places continue to roam the province; and enormous flocks of migratory birds still stop to rest and feed on many lakes and **estuaries**. But over the past two centuries there have been changes in the abundance and distribution of many native species and ecosystems.

Section 2 summarizes information on the current state of B.C.'s ecosystem, species and genetic diversity relative to pre-European contact. Each of these components is examined in relation to the terrestrial and freshwater realms, as well as to the portions of those realms that overlap with the marine realm. The overlap of species and ecosystems with other jurisdictions is also considered. This section describes recent trends where available, as well as information about **key elements** of B.C.'s biodiversity that are essential to the functioning of particular ecosystems and **special elements** that are relatively unique in the world.

2.1 Approach

The assessment of biodiversity in British Columbia was based on an examination of **conservation status** and proportion of global range for ecosystems, species and genes. The current status and threats are reviewed for examples of key elements and special elements.[134]

Conservation status indicates the level of risk of **extirpation** (provincially) or extinction (globally) for an element of biodiversity (e.g., an ecosystem or a species) and was examined at both the provincial and global level.

Proportion of global range is the proportion of the global population (for species, subspecies, ecotypes, etc.)[a] or range (for ecosystems) of an element of biodiversity within B.C. This is sometimes referred to as 'global responsibility' or 'stewardship responsibility.'[135] The reason for considering the proportion of an element's global range in B.C. is that it indicates the opportunity that exists for the province to influence its global status (i.e., its risk of extinction). For example, the province has the potential to have a major influence on the global status of elements that are found exclusively or predominantly in B.C. (see Section 2.5.2, p. 137).

[a] In the majority of cases, population data were not available and range was used as a proxy.

An additional analysis of richness was applied to species and an analysis of rarity was conducted for ecosystems. Species richness is the total number of species in an area.[136] Ecosystem rarity is the proportion of an area (in this case the entire province) occupied by an ecosystem.[137]

Due to a lack of information, the assessment of genetic diversity was restricted to those subspecies, populations and varieties that have been identified by the B.C. Conservation Data Centre as being of conservation concern.

2.2 Ecosystem Diversity in British Columbia

The province of British Columbia stretches from the 48th parallel at its most southerly point on Vancouver Island to the 60th parallel in the north, and ranges in elevation from sea level along the coast to over 4,000 m at the peaks of the highest mountains – Mount Waddington in the Coast Mountains and Mount Fairweather at the south end of the St. Elias Mountains on the Alaska-B.C. border.[138] On the coast, warm, moist air from the Pacific Ocean releases its moisture as rain or snow as it rises over the mountains, producing the highest rainfall and some of the most productive forests in Canada.[139] Much of the province is covered by the Cordilleran mountain system of western North America, with the Coast Mountains to the west and the Cassiar-Omineca, Cariboo, Columbia and Rocky mountains to the east. These mountain systems give rise to British Columbia's great rivers: the Fraser, Thompson, Kootenay, Columbia, Parsnip, Finlay, Peace, Kechika, Liard, Skeena, Nass, Stikine and Taku. Two high inland plateaus – the Interior and the Stikine – sit at an average of 1,000 m above sea level. On the Interior Plateau and in the surrounding low-elevation mountains, the continental air mass creates greater extremes of temperature and precipitation. The province's driest regions occur in the valleys of the southern interior, in the rain shadow to the east of the Coast Mountains. The warm Pacific air rises once again as it travels east, creating an interior wet belt to the west of, and within parts of, the Rockies. The Peace region in the northeast, an extension of the interior plains of Alberta and one of B.C.'s few lowland areas, is characterized by flat, rolling hills and a cold northern climate.

British Columbia's large size, intricate coastline and complex topography, and the resulting climates have created a wide array of diverse ecosystems. Almost three-quarters of the province is covered by forest (Figure 7). Most of the remaining area is covered by glaciers and alpine ecosystems, with grasslands, wetlands, lakes and streams collectively occupying only about 10% of the province's total area. Almost 10% of the province is covered by rock, with the majority (almost 9%) occurring in the alpine.[140]

Because ecosystems are dynamic over space and time (see Section 1.1, p.5), it can be difficult to characterize an ecosystem as a discrete unit. Ecosystems can be examined at a wide range of scales, from a single rotting log in a forest to an entire forest type covering thousands of square kilometres. For the purposes of this report,

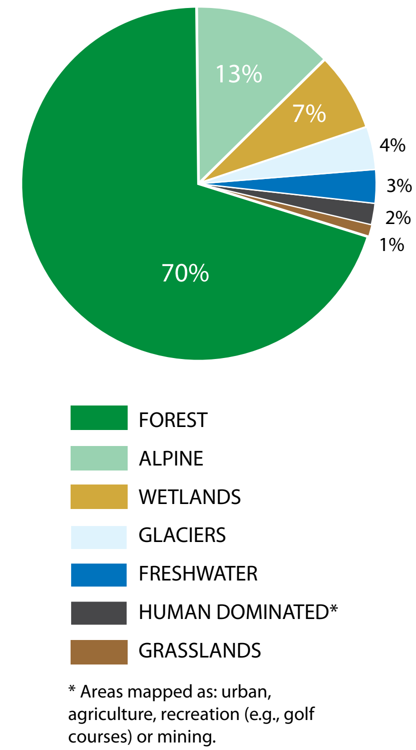


FIGURE 7: **Land cover types in B.C. as percent of total land area.**
SOURCE: Biodiversity BC, 2008. The Biodiversity Atlas of BC. Available at: www.biodiversitybc.org.

The 16 biogeoclimatic zones of B.C. fall into three categories: forest, alpine and grassland.

PHOTOS (TOP TO BOTTOM): JARED HOBBS, GAIL ROSS, JARED HOBBS.

terrestrial ecosystems were assessed at a broad provincial scale using a well-defined, higher-level ecosystem classification, the **Biogeoclimatic Ecosystem Classification** (BEC) system,[141] and freshwater ecosystems were assessed at the level of **Major Drainage Areas**. Although there was a difference in emphasis between the two analyses, both terrestrial and freshwater systems were considered in each one.

2.2.1 TERRESTRIAL ECOSYSTEMS: BIOGEOCLIMATIC ECOSYSTEM CLASSIFICATION ZONES

Biogeoclimatic Ecosystem Classification zones, commonly referred to as biogeoclimatic zones, are broad geographic areas sharing similar climate and vegetation. The BEC system was developed specifically for B.C. in the 1960s and early 1970s and continues to be revised and updated. Because biogeoclimatic zones have been well delineated, they were chosen as the broad-scale representation of ecosystems for the province. Sixteen biogeoclimatic zones are recognized for B.C. (see Map 2, p. 28). Twelve of the zones are forested, three are alpine and one is dominated by grasses (Text box 4).

TEXT BOX 4. BRITISH COLUMBIA'S BIOGEOCLIMATIC ZONES[142,143,144]

B.C.'s biogeoclimatic zones are each named after one or more dominant native plants, often with a geographic modifier (e.g., coastal, interior, alpine) or climatic modifier (e.g., boreal, montane).

FORESTED ZONES

Boreal White and Black Spruce: Covers B.C.'s northeast corner and extends into valleys west of the northern Rocky Mountains at low elevations. Consists of a mix of upland forest and muskeg ecosystems, with a wide range of tree species including white spruce (*Picea glauca*), black spruce (*P. mariana*), lodgepole pine, trembling aspen (*Populus tremuloides*), black cottonwood (*Populus balsamifera* ssp. *trichocarpa*) and tamarack (*Larix laricina*).

Coastal Douglas-fir: Limited to low-elevations covering a small part of southeastern Vancouver Island, several Gulf Islands and a narrow strip of the adjacent mainland. Douglas-fir is the dominant tree, frequently accompanied by western redcedar, grand fir (*Abies grandis*), arbutus (*Arbutus menziesii*), Garry oak or red alder (*Alnus rubra*).

Coastal Western Hemlock: Covers most low elevations west of the Coast Mountains. Western hemlock and western redcedar are both common.

Engelmann Spruce–Subalpine Fir: Occupies the uppermost forested elevations in the southern three-quarters of the interior. Includes continuous forest dominated by Engelmann spruce and subalpine fir at lower and mid elevations, and subalpine parkland (characterized by clumps of trees scattered among areas of heath, meadow and grassland) at upper elevations.

Interior Cedar–Hemlock: Occurs in two separate parts of B.C. – the southeast and the northwest. Dominated by western redcedar and western hemlock, but has the highest diversity of tree species of any zone in the province.

Interior Douglas-fir: Occurs at low to mid elevations in the south-central interior, including leeward slopes of the Coast Mountains and the southern Rocky Mountain Trench. Although Douglas-fir-dominated forests are most common, this zone features a wide array of ecosystems, including extensive grasslands in drier areas.

Montane Spruce: Occurs at mid elevations in the southern interior. Features a unique mix of species from both higher and lower zones, including hybrid spruce (*Picea engelmannii* x *glauca*; a cross between Engelmann and white spruce), subalpine fir, Douglas-fir and lodgepole pine.

Mountain Hemlock: Occupies subalpine elevations of the Coast Mountains. The most common tree species are mountain hemlock, amabilis fir and yellow-cedar, often with a dense understory of blueberries (*Vaccinium* spp.) and other shrubs.

Ponderosa Pine: Occurs at low elevations in very dry, southern interior valleys. Consists of a mosaic of forest and grassland, but is dominated by trees. Ponderosa pine (*Pinus ponderosa*) often grows in very open, park-like stands with an understory dominated by bluebunch wheatgrass (*Pseudoroegneria spicata*).

Spruce–Willow–Birch: Occupies subalpine elevations in the northern third of the interior. In forested ecosystems, the main tree species are white spruce and subalpine fir. Shrub-dominated ecosystems, characterized by scrub birch (*Betula nana*) and various willows (*Salix* spp.), are also common in this zone.

Sub-Boreal Pine–Spruce: Occurs on high plateaus in the central interior. Consists of two principal ecosystems: lodgepole pine forests and wetlands. Besides lodgepole pine, the only common tree species are white spruce and trembling aspen.

Sub-Boreal Spruce: Occupies the gently rolling terrain of the Interior Plateau and extends into mountainous areas to the north, west and east. Features dense coniferous forests dominated by hybrid spruce and subalpine fir.

ALPINE ZONES

Boreal Altai Fescue Alpine: Occurs in the northern Rocky, Skeena, Omineca and Cassiar mountains in the north and on the lee side of the Coast Mountains north of the Chilcotin. In the alpine as a whole, the primary vegetation consists of low-growing, evergreen shrubs. In this zone, the dominant species are dwarf willows, grasses (e.g., altai fescue [*Festuca altaica*]), sedges (*Carex* spp.) and **lichens**.

Coastal Mountain-heather Alpine: Occurs along the windward spine of the Coast Mountains and the mountains of Vancouver Island and Haida Gwaii/Queen Charlotte Islands. Features extensive beds of white mountain-heather (*Cassiope mertensiana* var. *mertensiana*) and pink mountain-heather (*Phyllodoce empetriformis*).

Interior Mountain-heather Alpine: Occurs in the southern third of the province in the Columbia Mountains, southern Rocky Mountains and on the lee side of the Coast and Cascade mountains. Dominant vegetation ranges from mountain-heathers in snowier areas to mountain-avens (*Dryas* spp.) on the driest sites.

GRASSLAND ZONE

Bunchgrass: Occupies narrow fingers of land at lower elevations along the major southern interior valleys. Dry sites are dominated by grasses, such as bluebunch wheatgrass and needle-and-thread grass (*Hesperostipa comata*), with a scattering of shrubs, such as big sagebrush (*Artemisia tridentata*), and an extensive **cryptogamic crust** (see Section 2.5.1.2-H, p. 111). Wetlands are also common throughout this zone.

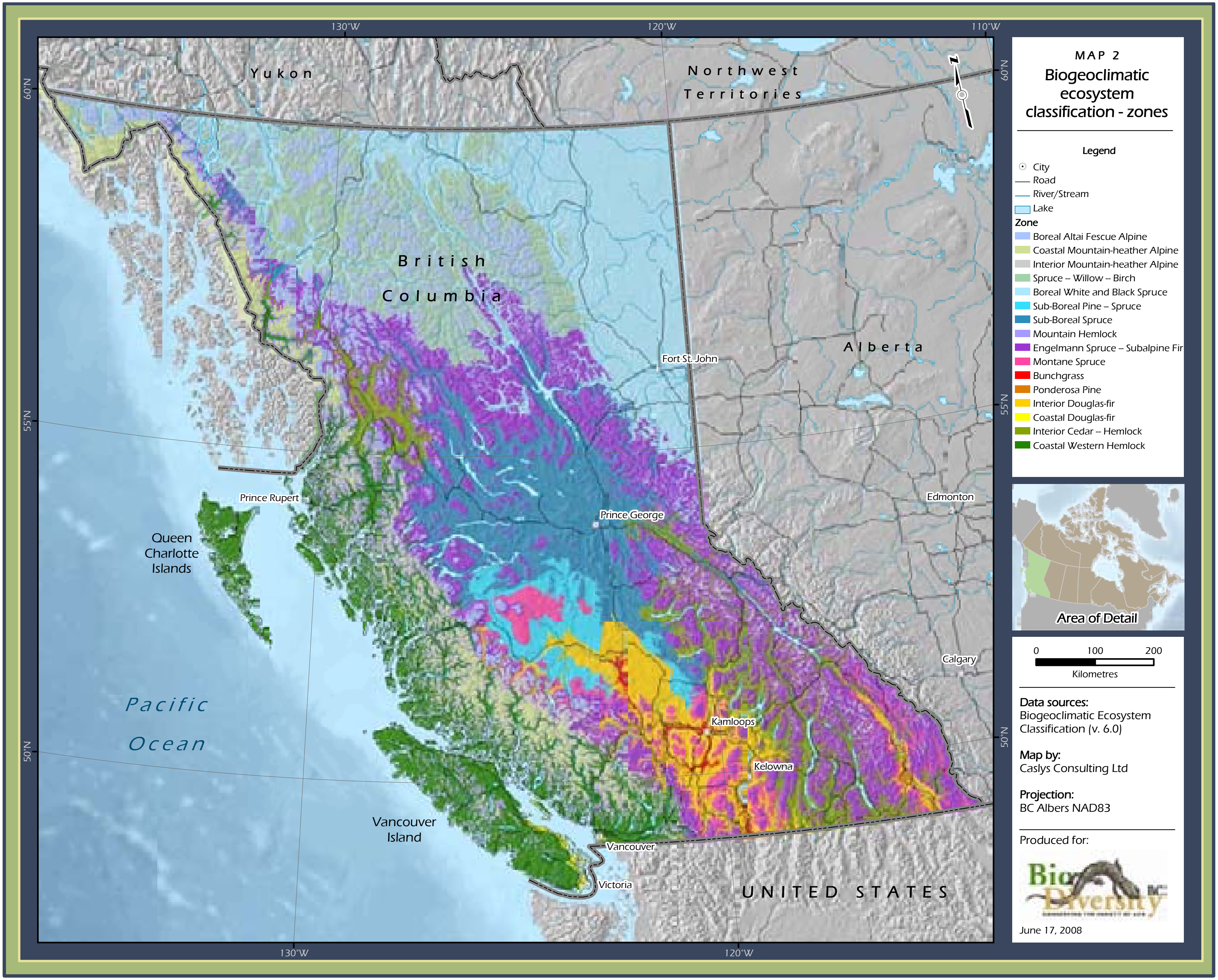

MAP 2
Biogeoclimatic ecosystem classification - zones
Legend
City
Road
River/Stream
Lake
Zone
Boreal Altai Fescue Alpine
Coastal Mountain-heather Alpine
Interior Mountain-heather Alpine
Spruce – Willow – Birch
Boreal White and Black Spruce
Sub-Boreal Pine – Spruce
Sub-Boreal Spruce
Mountain Hemlock
Engelmann Spruce – Subalpine Fir
Montane Spruce
Bunchgrass
Ponderosa Pine
Interior Douglas-fir
Coastal Douglas-fir
Interior Cedar – Hemlock
Coastal Western Hemlock
Area of Detail
0 100 200
Kilometres
Data sources:
Biogeoclimatic Ecosystem Classification (v. 6.0)
Map by:
Caslys Consulting Ltd
Projection:
BC Albers NAD83
Produced for:
June 17, 2008
130°W
120°W
110°W
60°N
55°N
50°N
Yukon
Northwest Territories
British Columbia
Alberta
Fort St. John
Prince Rupert
Prince George
Edmonton
Queen Charlotte Islands
Calgary
Kamloops
Kelowna
Pacific Ocean
Vancouver Island
Vancouver
Victoria
UNITED STATES

TABLE 1. AREAL EXTENT OF BIOGEOCLIMATIC ZONES IN B.C.

BIOGEOCLIMATIC ZONE	AREA (KM²)	PERCENTAGE
Engelmann Spruce–Subalpine Fir (ESSF)	170,364	18%
Boreal White and Black Spruce (BWBS)	153,367	17%
Coastal Western Hemlock (CWH)	102,253	11%
Sub-boreal Spruce (SBS)	92,346	10%
Spruce–Willow–Birch (SWB)	80,101	9%
Boreal Altai Fescue Alpine (BAFA)	76,812	8%
Coastal Mountain-heather Alpine (CMA)	52,007	6%
Interior Cedar–Hemlock (ICH)	50,915	5%
Interior Douglas-fir (IDF)	40,418	4%
Mountain Hemlock (MH)	36,572	4%
Montane Spruce (MS)	27,795	3%
Sub-boreal Pine Spruce (SBPS)	22,359	2%
Interior Mountain-heather Alpine (IMA)	17,681	2%
Ponderosa Pine (PP)	2,896	<1%
Bunchgrass (BG)	2,048	<1%
Coastal Douglas-fir (CDF)	1,310	<1%
Total	**929,244**	**100%**

SOURCE: Prepared for this report.
NOTES: Areas of ecosystem conversion (see Map 12, p.161), as well as lakes and rivers, were removed from each zone for this analysis.

The zones are divided into subzones, based on differences in regional climate. Variants are still finer subdivisions of subzones, which reflect local variation within the subzone-level climate (e.g., areas that are slightly wetter or warmer than other areas in the subzone).

Table 1 summarizes the area of each of B.C.'s biogeoclimatic zones, listing them in order of rarity (from most common to rarest). The least common biogeoclimatic zones in B.C. are Coastal Douglas-fir, Bunchgrass and Ponderosa Pine, all dry, low-elevation or valley-bottom zones, which together make up less than 1% of the province's land area. The Coastal Douglas-fir zone occurs on the east coast of southern Vancouver Island and on the southern Gulf Islands and Sunshine Coast, while the Bunchgrass and Ponderosa Pine zones are found

One of the species of conservation concern in the Interior Douglas-fir biogeoclimatic zone is the giant helleborine (*Epipactis gigantea*), pictured here growing near Fairmont Hot Springs in the Rocky Mountains. Giant helleborines can grow to 100 cm tall.
PHOTO: VIRGINIA SKILTON.

in the southern interior. The most common zones within B.C. are the Engelmann Spruce–Subalpine Fir, Boreal White and Black Spruce and Coastal Western Hemlock, all predominantly forested ecosystems.

2.2.1.1 CONSERVATION STATUS OF BIOGEOCLIMATIC ZONES

The conservation status of each of the biogeoclimatic zones was determined using a modification of the NatureServe[a] methods. Conservation status rankings were based on criteria that included rarity, trends and the level of threat from human activity.[145] For this analysis, ecosystems ranked as Critically Imperilled (1), Imperilled (2) and Vulnerable (3) were considered to be of conservation concern in British Columbia (for rank definitions, see Table 2). Information was compiled at two scales: global (G), indicating the status of a biogeoclimatic zone in its worldwide range; and provincial or subnational (S), indicating the status of a biogeoclimatic zone within B.C.

The threat assessment completed as part of the process included the effects of:

1. Residential development (including housing and urban areas, commercial area and tourism recreation areas);
2. Agriculture and aquaculture (non-timber crops, plantations, livestock);
3. Energy production and mining (oil and gas, mining and quarrying, renewable energy);
4. Transportation and service corridors (roads and railways, utility and service lines, seismic lines, shipping lanes, flight paths);
5. Biological resource use (hunting and collecting, logging, fishing, harvesting of aquatic resources);
6. Human intrusion and disturbance (recreational and work activities);
7. Natural systems modification (fire and fire suppression, dams and water management);
8. Invasive and problem species (invasive and/or alien species, problematic native species, introduced genetic material);
9. Pollution (household, industrial, agricultural/forestry, garbage and solid waste, airborne pollution);
10. Geological events (volcanoes, earthquakes, avalanches); and
11. Climate change and severe weather (habitat shifting and alteration, droughts, temperature extremes, storms, flooding).

[a] NatureServe is an international network that includes the B.C. Conservation Data Centre. For more information, see www.natureserve.org/explorer .

TABLE 2. CONSERVATION STATUS RANKS FOR ECOSYSTEMS IN B.C.

RANK	DEFINITION	DESCRIPTION
1	**Critically Imperilled**	**At very high risk of extinction or extirpation.**
2	**Imperilled**	**At high risk of extinction due to very restricted range, steep declines, or other factors.**
3	**Vulnerable**	**At moderate risk of extinction or extirpation due to a restricted range, recent and widespread declines, or other factors.**
4	Apparently Secure	Uncommon but not rare, and usually widespread. Some cause for long-term concern.
5	Secure	Common or very common, and widespread. Not susceptible to extirpation or extinction under current conditions.
NR	Not yet Ranked	Rank is not yet assessed.
U	Unrankable	Suitable information is not available for ranking.

SOURCE: Adapted from Anions, M. 2006. Global and Provincial Status of Species in British Columbia. Biodiversity BC, Victoria, BC. 16pp. Available at: www.biodiversitybc.org.
NOTES: For analyses in this report, range ranks (given when not enough information is available to score a specific rank) are rounded to the higher rank (e.g., S2S3 is rounded to S2; S2S4 is averaged to S3). See Section 2.3.2 (p. 51) for an explanation of conservation status rankings.
Boldface indicates that ecosystems with these ranks are of conservation concern.

Specific information used in the assessments included the overlap of the present and projected biogeoclimatic zone **climate envelopes**, (see Section 3.3.1.2, p. 186),[146] the proportion of the zone with roads or other linear development features present (see Map 1, p. 2) and the proportion of the zone recently logged (see Map 19, p. 197).

Four biogeoclimatic zones are of conservation concern in the province: three in the interior (Bunchgrass, Ponderosa Pine and Interior Douglas-fir) and one on the coast (Coastal Douglas-fir) (Table 3). These zones collectively occupy less than 5% of B.C.'s area (Map 3).

TABLE 3. CONSERVATION STATUS OF BIOGEOCLIMATIC ZONES IN B.C.

BIOGEOCLIMATIC ZONE	CONSERVATION STATUS
Bunchgrass	**Imperilled (S2)**
Coastal Douglas-fir	**Imperilled (S2)**
Ponderosa Pine	**Imperilled/Vulnerable (S2/S3)**
Interior Douglas-fir	**Vulnerable (S3)**
Coastal Western Hemlock	Apparently secure (S4)
Interior Cedar–Hemlock	Apparently secure (S4)
Sub-boreal Pine–Spruce	Apparently secure (S4)
Boreal White and Black Spruce	Apparently secure (S4)
Spruce–Willow–Birch	Apparently secure (S4)
Sub-boreal Spruce	Apparently secure (S4)
Montane Spruce	Apparently secure (S4)
Mountain Hemlock	Apparently secure (S4)
Engelmann Spruce–Subalpine Fir	Secure (S5)
Coastal Mountain-heather Alpine	Secure (S5)
Boreal Altai Fescue Alpine	Secure (S5)
Interior Mountain-heather Alpine	Secure (S5)

SOURCE: Kremsater, L. 2007. Draft S Ranks and Surrogate G Ranks for BEC Zones and Draft S Ranks for Ecoprovinces and Major Drainage Areas of B.C.: Preliminary Rankings for Informing the Biodiversity Status Report and Action Plan. Biodiversity BC, Victoria, BC. 64pp. Available at: www.biodiversitybc.org.
NOTES: **Boldface** indicates biogeoclimatic zone is of conservation concern.
The global conservation status (G rank) for the biogeoclimatic zones was considered relative to the provincial conservation status (S rank) and in all cases was assumed to be similar; therefore, the G and S rankings were the same. Only the S rank is reported.

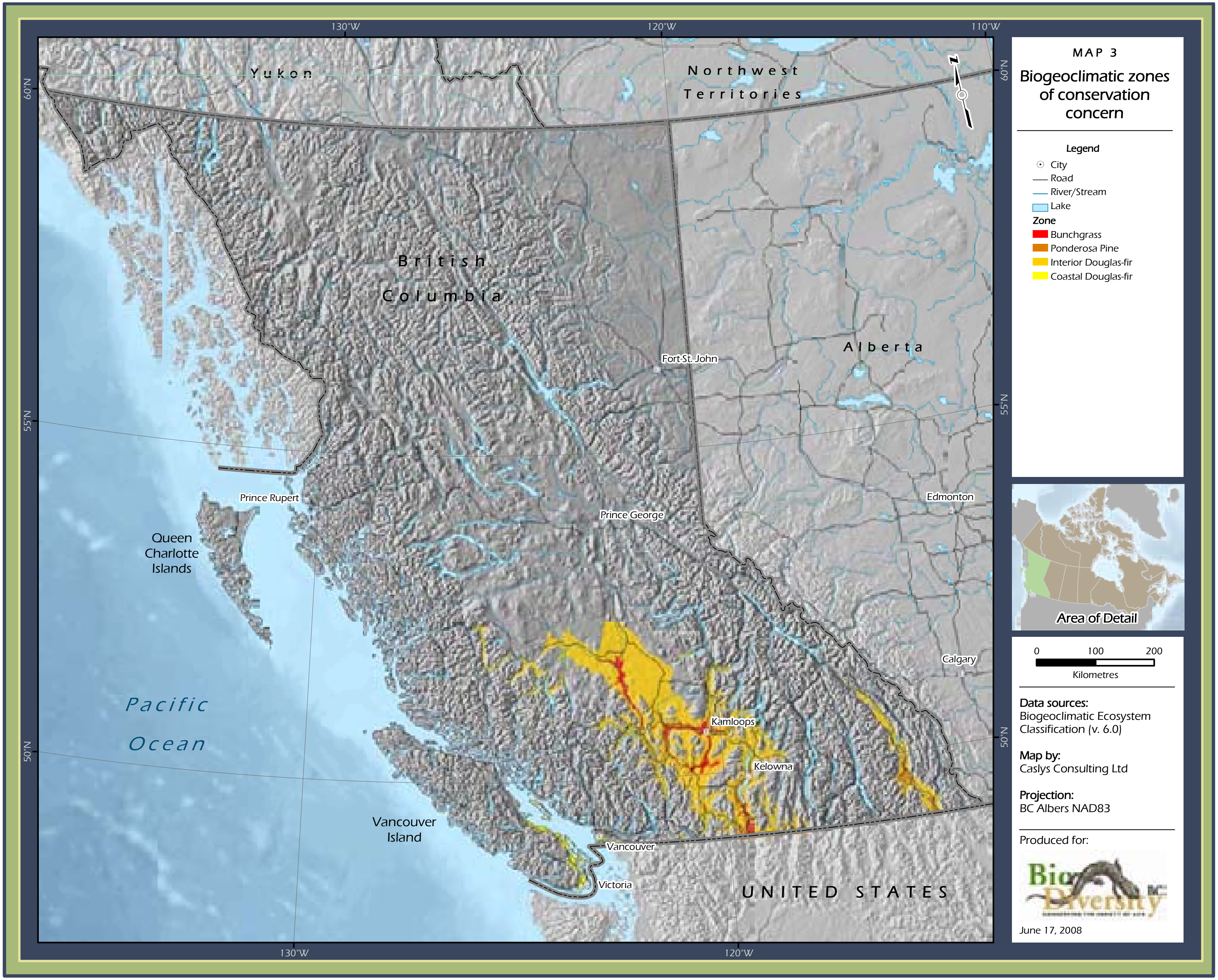

MAP 3
Biogeoclimatic zones of conservation concern
Legend
City
Road
River/Stream
Lake
Zone
Bunchgrass
Ponderosa Pine
Interior Douglas-fir
Coastal Douglas-fir
Yukon
Northwest Territories
British Columbia
Alberta
Fort St. John
Prince Rupert
Prince George
Edmonton
Queen Charlotte Islands
Calgary
Pacific Ocean
Kamloops
Kelowna
Vancouver Island
Vancouver
Victoria
UNITED STATES
130°W
120°W
110°W
60°N
55°N
50°N
Area of Detail
0
100
200
Kilometres
Data sources:
Biogeoclimatic Ecosystem Classification (v. 6.0)
Map by:
Caslys Consulting Ltd
Projection:
BC Albers NAD83
Produced for:
June 17, 2008

TABLE 4. DISTRIBUTION OF SPECIES OF CONSERVATION CONCERN IN B.C. BY BIOGEOCLIMATIC ZONE.

BIOGEOCLIMATIC ZONE	TOTAL AREA (KM²)	SPECIES OF GLOBAL CONSERVATION CONCERN		SPECIES OF PROVINCIAL CONSERVATION CONCERN	
		Number of species	Density (# of species/ 1,000 km²)	Number of species	Density (# of species/ 1,000 km²)
Coastal Douglas-fir	**1,310**	**24**	**18.3**	**170**	**129.8**
Bunchgrass	**2,048**	**10**	**4.9**	**165**	**80.6**
Ponderosa Pine	**2,896**	**10**	**3.5**	**114**	**39.4**
Interior Douglas-fir	**40,418**	**27**	**0.7**	**252**	**6.2**
Montane Spruce	27,795	12	0.4	93	3.3
Coastal Western Hemlock	102,253	40	0.4	242	2.4
Mountain Hemlock	36,572	13	0.4	45	1.2
Interior Cedar–Hemlock	50,915	17	0.3	170	3.3
Alpine Tundra	146,500	21	0.1	144	1.0
Spruce–Willow–Birch	80,101	10	0.1	68	0.8
Engelmann Spruce–Subalpine Fir	170,364	21	0.1	138	0.8
Sub-boreal Spruce	92,346	10	0.1	89	1.0
Sub-boreal Pine–Spruce	22,359	2	0.1	33	1.5
Boreal White and Black Spruce	153,367	12	0.1	140	0.9

SOURCE: Prepared for this report with data from the B.C. Conservation Data Centre.
NOTES: Data were not available for all species of conservation concern. This table is based on information for 783 out of a total of 1,169 species of conservation concern (mosses were excluded due to lack of information). A species can occur in more than one biogeoclimatic zone.
Boldface indicates biogeoclimatic zone is of conservation concern.
The Alpine Tundra zone includes the recently created Interior Mountain-heather Alpine, Coastal Mountain-heather Alpine and Boreal Altai Fescue Alpine zones.

The four biogeoclimatic zones that are of conservation concern have the highest densities of species of both global and provincial conservation concern (Table 4). One hundred and forty-six species of provincial conservation concern have been recorded only in zones of conservation concern (i.e., in one or more of these zones). It is perhaps not surprising that there are higher numbers, and therefore higher densities, of species of provincial conservation concern in these rare zones, but the numbers and densities for species of global conservation concern show the same pattern, which is consistent with the assessment that these zones are also of global conservation concern.

Of the 12 biogeoclimatic zones that are not of conservation concern within the province, five each contain more than 100 species of provincial conservation concern (Coastal Western Hemlock, Interior Cedar–Hemlock, Alpine Tundra,[a] Engelmann Spruce–Subalpine Fir and Boreal White and Black Spruce) and three each have more than 20 species of global conservation concern (Coastal Western Hemlock, Alpine Tundra and Engelmann Spruce–Subalpine Fir). As these zones occupy large areas, the densities of species of conservation concern are lower.

2.2.1.2 PROPORTION OF GLOBAL RANGE FOR BIOGEOCLIMATIC ZONES

For each biogeoclimatic zone, the proportion of its global range that occurs in B.C. was determined using maps covering a number of neighbouring jurisdictions, combined with expert knowledge where the zones were believed to extend beyond the limits of available information.[b,147] Proportion of global range is described by seven classes ranging from 1 (Endemic; 100% of global range in British Columbia) to 7 (Low and Localized; <10% of range in British Columbia and occurs over <30% of the province) (Table 5).

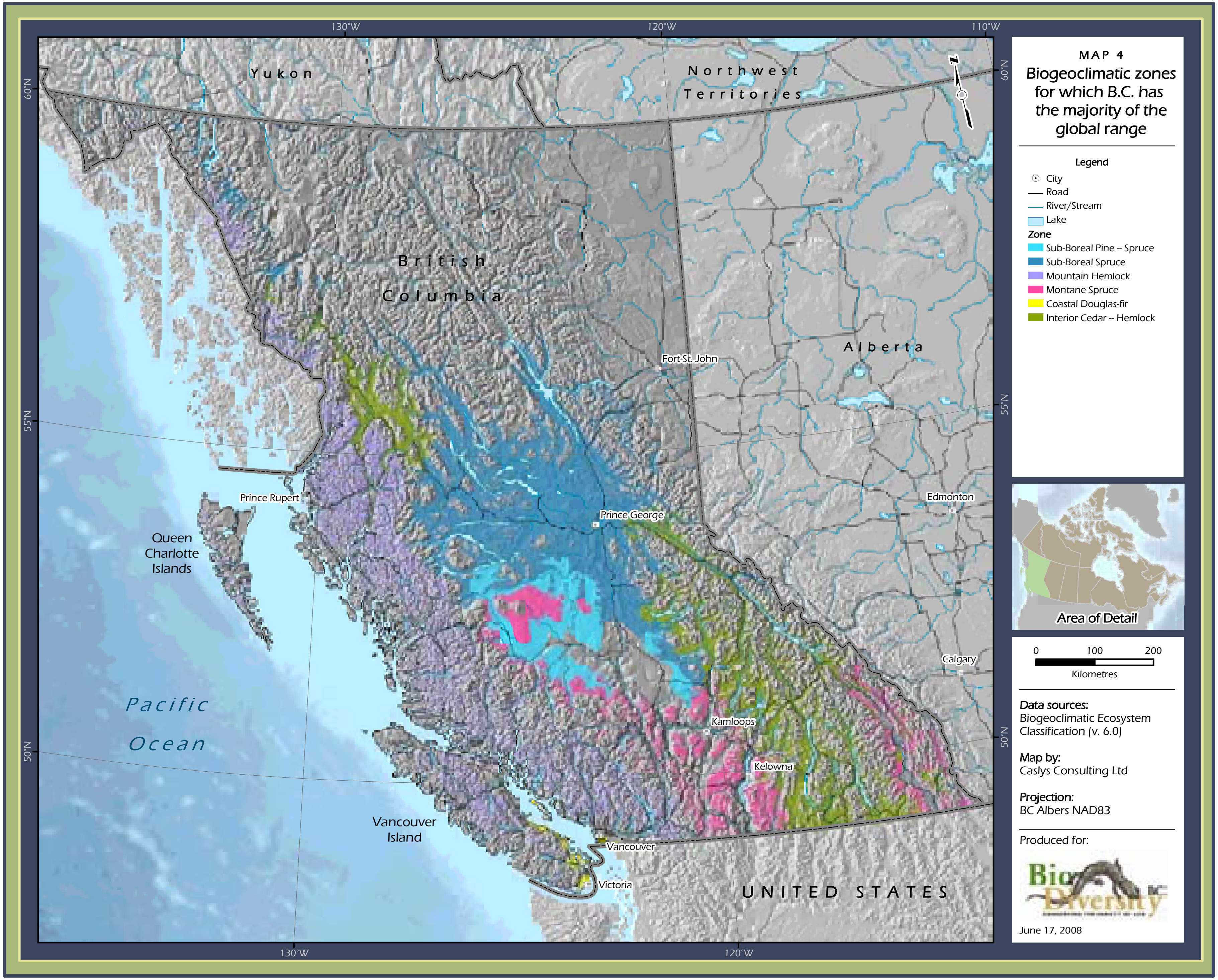
Six of the 16 zones have more than 50% of their global range in B.C. (Classes 1–3) (Table 6; Map 4). These six zones collectively cover about one-quarter of the province. B.C. has 70–80% of the global range of the Coastal Douglas-fir zone, one of the province's four zones of conservation concern, which further emphasizes B.C.'s importance to its conservation. Two zones – the Sub-boreal Pine–Spruce and the Sub-boreal Spruce – are endemic to B.C., meaning they are found nowhere else in the world. Both are forested ecosystems located in the north-central part of the province.

TABLE 5. PROPORTION OF GLOBAL RANGE CLASSIFICATION FOR ECOSYSTEMS AND SPECIES.

GLOBAL RANGE CLASS		DEFINITION (PERCENT OF GLOBAL RANGE, AREA OR POPULATION THAT OCCURS IN B.C.)
1	Endemic	100% of global range
2	Very High	75–99% of global range
3	High	51–74% of global range
4	Moderately High	30–50% of global range
5	Intermediate	11–29% of global range
6	Low and Widespread	<10% of global range, and occurs over >30% of the province
7	Low and Localized	<10% of global range, and occurs over <30% of the province

SOURCE: Adapted from Bunnell, F., L. Kremsater and I. Houde. 2006. Applying the Concept of Stewardship Responsibility in British Columbia. Biodiversity BC, Victoria, BC. 188pp. Available at: www.biodiversitybc.org.

[a] Alpine Tundra, a previous classification, was recently split into three separate alpine zones. Due to the unavailability of complete species distribution data for the three new zones, all are reported under the Alpine Tundra zone.
[b] Ideally, information on the condition of the biogeoclimatic zones in areas outside the province would have been considered (particularly regarding ecosystem conversion); however, those data were not readily available.


MAP 4
Biogeoclimatic zones for which B.C. has the majority of the global range
Legend
City
Road
River/Stream
Lake
Zone
Sub-Boreal Pine – Spruce
Sub-Boreal Spruce
Mountain Hemlock
Montane Spruce
Coastal Douglas-fir
Interior Cedar – Hemlock
Area of Detail
0
100
200
Kilometres
Data sources:
Biogeoclimatic Ecosystem Classification (v. 6.0)
Map by:
Caslys Consulting Ltd
Projection:
BC Albers NAD83
Produced for:
June 17, 2008
130°W
120°W
110°W
60°N
55°N
50°N
Yukon
Northwest Territories
British Columbia
Alberta
Fort St. John
Prince Rupert
Prince George
Edmonton
Queen Charlotte Islands
Calgary
Kamloops
Kelowna
Pacific Ocean
Vancouver Island
Vancouver
Victoria
UNITED STATES

2.2.1.3 SHARED ECOSYSTEMS

Except for the two endemic zones, Sub-boreal Spruce and Sub-boreal Pine–Spruce, all of the province's biogeoclimatic zones are shared with neighbouring jurisdictions (Table 6). For example, the Interior Douglas-fir zone is distributed across British Columbia, Alberta, Montana, Idaho, Washington and Oregon.

TABLE 6. DISTRIBUTION OF BIOGEOCLIMATIC ZONES ACROSS B.C. AND NEIGHBOURING JURISDICTIONS.

BIOGEOCLIMATIC ZONE	JURISDICTION								
	B.C.	Alaska	Yukon	Northwest Territories	Alberta	Montana	Idaho	Washington	Oregon
Sub-boreal Spruce	100%								
Sub-boreal Pine–Spruce	100%								
Coastal Douglas-fir	70-80%							●	
Montane Spruce	70-75%				●	●		●	
Interior Cedar–Hemlock	58%					●	●	●	●
Mountain Hemlock	<58%	●						●	●
Spruce–Willow–Birch	<50%	●	●	●					
Engelmann Spruce–Sub-alpine Fir	30-50%				●	●	●	●	●
Interior Douglas-fir	<44%				●	●	●	●	●
Interior Mountain-heather Alpine	<36%				●	●	●	●	●
Boreal Altai Fescue Alpine	30%	●	●	●					
Coastal Western Hemlock	30%	●						●	●
Coastal Mountain-heather Alpine	<30%	●	●					●	●
Ponderosa Pine	<22%					●	●	●	●
Boreal White and Black Spruce	10% or less	●	●	●	●				
Bunchgrass	<10%					●	●	●	●

SOURCE: Kremsater, L. Draft S Ranks and Surrogate G Ranks for BEC Zones and Draft S Ranks for Ecoprovinces and Major Drainage Areas of B.C.: Preliminary Rankings for Informing the Biodiversity Status Report and Action Plan. Biodiversity BC, Victoria, BC. 64pp. Available at: www.biodiversitybc.org.
NOTES: **Boldface** indicates biogeoclimatic zone is of conservation concern. Dot indicates that the biogeoclimatic zone occurs in the jurisdiction. Percentages are approximate.

2.2.1.4 STATUS OF ECOLOGICAL COMMUNITIES

Ecological communities are ecosystems classified at a much finer resolution than biogeoclimatic zones. The same community can occur in more than one zone. To date, 611 ecological communities have been described

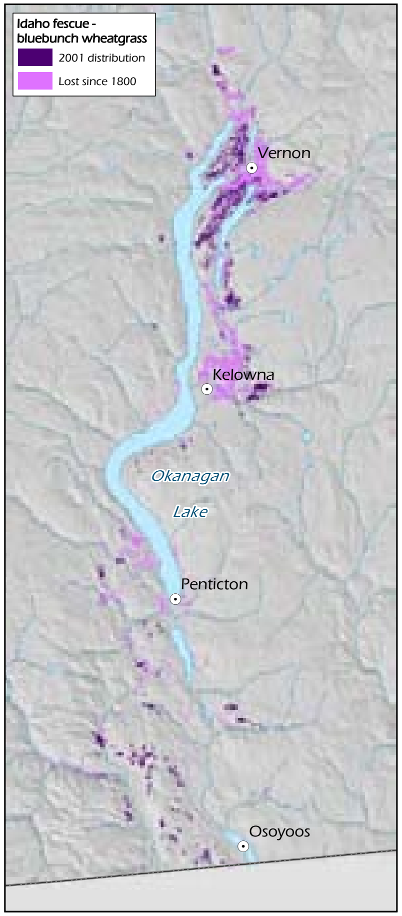


FIGURE 8: Loss of Idaho fescue–bluebunch wheatgrass ecosystem in the Okanagan Valley since 1800.
SOURCE: Prepared for this report with data from T. Lea.

in B.C. (Table 7).[148] Although not all ecological communities in B.C. have been described, the current list represents a majority of the province's ecological communities.[149] Ecological community classification is the most incomplete for alpine ecosystems, but this is a focus of current classification work.[150]

Of the ecological communities described in B.C., 532 (87%) have had their provincial conservation status assessed and 340 (56% of the total number described) are of provincial conservation concern. As with classification, the majority of the ecological communities that have not been assessed are in alpine ecosystems.[151]

TABLE 7. PROVINCIAL CONSERVATION STATUS OF ECOLOGICAL COMMUNITIES IN B.C. BY BIOGEOCLIMATIC ZONE.

BIOGEOCLIMATIC ZONE	NUMBER OF COMMUNITIES DESCRIBED	NUMBER OF COMMUNITIES ASSESSED	NUMBER OF COMMUNITIES OF PROVINCIAL CONSERVATION CONCERN	PERCENT OF COMMUNITIES DESCRIBED THAT ARE OF PROVINCIAL CONSERVATION CONCERN
Coastal Douglas-fir	**36**	**36**	**35**	**97%**
Bunchgrass	**30**	**30**	**28**	**93%**
Ponderosa Pine	**29**	**29**	**27**	**93%**
Coastal Western Hemlock	128	128	106	83%
Interior Douglas-fir	**87**	**87**	**71**	**82%**
Sub-boreal Spruce	92	83	56	61%
Interior Cedar–Hemlock	89	75	46	52%
Sub-boreal Pine–Spruce	38	34	19	50%
Montane Spruce	66	57	31	47%
Boreal White and Black Spruce	52	41	13	25%
Engelmann Spruce–Subalpine Fir	149	99	31	21%
Mountain Hemlock	43	22	8	19%
Spruce–Willow–Birch	21	1	1	5%
Coastal Mountain-heather Alpine	23	1	1	4%
Interior Mountain-heather Alpine	39	2	1	3%
Boreal Altai Fescue Alpine	53	3	1	2%
Province	611	532	340	56%

SOURCE: Prepared for this report with data from the B.C. Conservation Data Centre.
NOTES: **Boldface** indicates biogeoclimatic zone is of conservation concern. Some ecological communities occur in more than one biogeoclimatic zone.

As might be expected, the percentage of ecological communities of conservation concern is relatively high in the four biogeoclimatic zones that are of provincial conservation concern (see Section 2.2.1.1, p. 30). It is notable that every biogeoclimatic zone has at least one ecological community in this category. The Coastal Western Hemlock zone stands out as the biogeoclimatic zone with the greatest number of ecological communities of concern (106). It also has the highest percentage (83%) of ecological communities of concern among the 12 zones that are not of provincial conservation concern.

Global conservation status has been assessed for only 113 ecological communities (18% of the total number described).[152] This is due to the lack of compatible descriptions of ecological communities between jurisdictions, although work is currently underway to address this issue.[153]

TEXT BOX 5. CASE STUDY: LOSS OF GRASSLAND ECOLOGICAL COMMUNITIES IN THE OKANAGAN AND LOWER SIMILKAMEEN VALLEYS

Ecosystem conversion of grasslands has been very extensive in the Ponderosa Pine and Bunchgrass biogeoclimatic zones. For example, historical mapping shows that 77% of the Idaho fescue (*Festuca idahoensis* spp. *idahoensis*) – bluebunch wheatgrass ecosystem and 68% of the antelope-brush (*Purshia tridentata*) / needle-and-thread grass ecosystem have been lost to agriculture and urban and rural development in the Okanagan Valley over the past 100 years (Table 8, Figure 8, Figure 9).[154] Excessive domestic livestock grazing, off-road recreational vehicles and **invasive alien species** continue to degrade much of the remaining grasslands in these areas.[155]

Grasslands are concentrated in the Ponderosa Pine, Bunchgrass and Interior Douglas-fir zones, which is one of the reasons these zones are home to a disproportionate number of B.C.'s terrestrial species of conservation concern (see Table 4, p. 34). Grasslands were rare in B.C. at the time of European contact and have since become rarer because they are found in areas that are attractive for development (e.g., low-elevation areas in the southern part of the province) and are therefore subjected to a high level of ecosystem conversion, as well as fire suppression which results in forest encroachment.

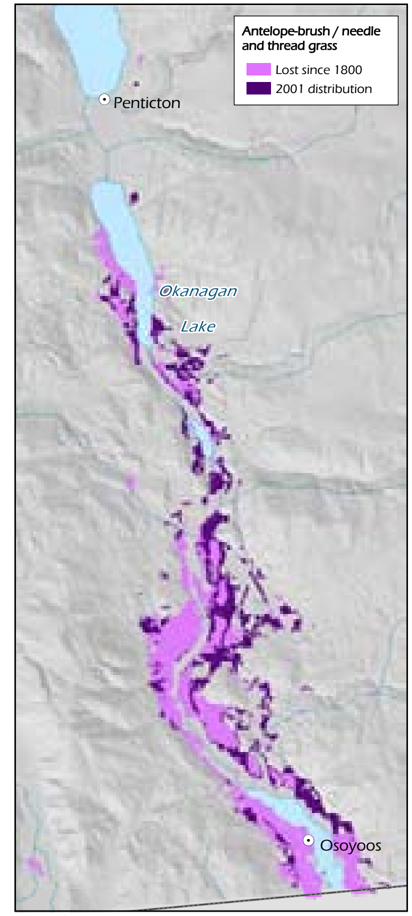


FIGURE 9: Loss of antelope-brush / needle-and-thread grass ecosystem in the Okanagan Valley since 1800.
SOURCE: Prepared for this report with data from T. Lea.

TABLE 8. HISTORICAL LOSS OF GRASSLAND ECOLOGICAL COMMUNITIES IN THE OKANAGAN VALLEY BETWEEN 1800 AND 2005.

GRASSLAND ECOSYSTEM TYPE	YEAR 1800 (ha)	1938 (ha)	2005 (ha)	PERCENT OF ECOSYSTEM LOST
Water birch / roses	14,629	4,557	1,207	92%
Idaho fescue–bluebunch wheatgrass	19,253	8,657	4,395	77%
Antelope-brush / needle-and-thread grass	9,905	7,325	3,160	68%
Black cottonwood / water birch	8,111	5,176	2,864	63%
Ponderosa pine–bluebunch wheatgrass gentle slope forest	15,149	11,471	7,172	53%
Cattail marsh	430	387	257	41%
Big sagebrush shrub-steppe	12,233	10,314	8,266	33%

SOURCE: Lea, T. 2007. Historical (pre-European settlement) ecosystems of the Okanagan and lower Similkameen valleys – applications for species at risk. Saving the Pieces – Restoring Species at Risk Symposium, June 14-16, 2007, Victoria, BC.

TEXT BOX 6. GARRY OAK ECOSYSTEMS OF THE COASTAL DOUGLAS-FIR ZONE[a]

Garry oak ecosystems are found within the Coastal Douglas-fir biogeoclimatic zone, one of B.C.'s four zones of conservation concern and the only one of these four for which B.C. has a majority of the global range. Within Canada, Garry oak ecosystems occur only on southeastern Vancouver Island and the southern Gulf Islands, and in two isolated sites in Vancouver. This is one of the ecosystem types of greatest conservation concern in B.C., primarily due to ecosystem conversion resulting from urbanization and agriculture.[156,157] About 10% of the original area that was Garry oak meadow in the mid 1860s still remains, mostly in fragmented remnants that are often dominated by invasive alien species such as Scotch broom (*Cytisus scoparius*), Himalayan blackberry (*Rubus armeniacus*), English ivy (*Hedera helix*) and a variety of non-native grasses and weeds.[158,159] Less than 5% of the original ecosystem remains in near-natural condition (Figure 10).

Garry oak and related ecosystems are home to species of conservation concern such as the sharp-tailed snake (*Contia tenuis*) and Macoun's meadowfoam, a critically endangered plant for which the province has a majority of the global range.[160,161] The potential range of Garry oak ecosystems could expand with climate change,[162] but it is uncertain whether the associated native plants will be able to compete with the many alien species now found on Vancouver Island without extensive and costly human intervention.

[a]Garry oak ecosystems include a group of ecological communities such as the Garry oak – arbutus ecological community.

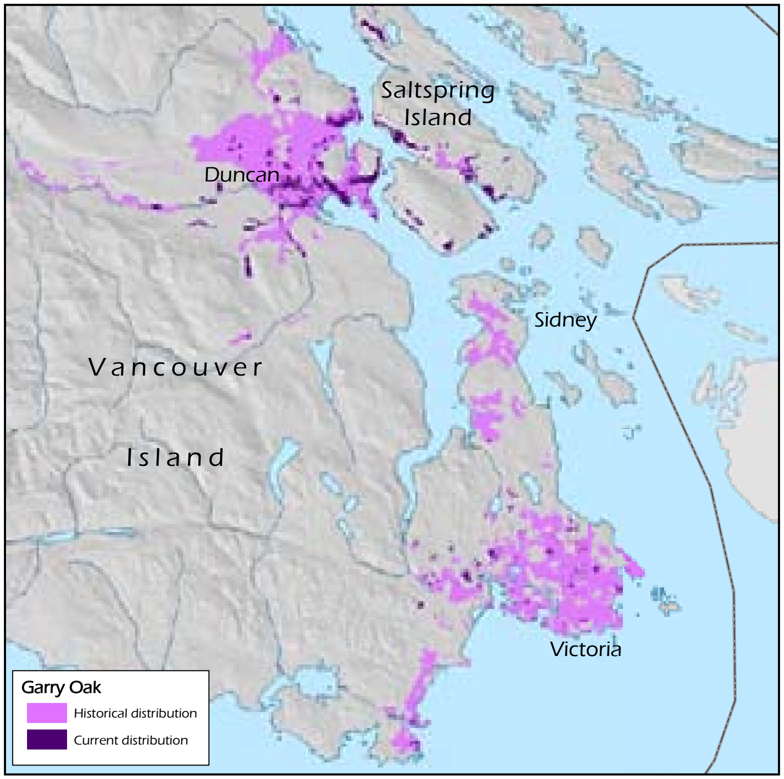
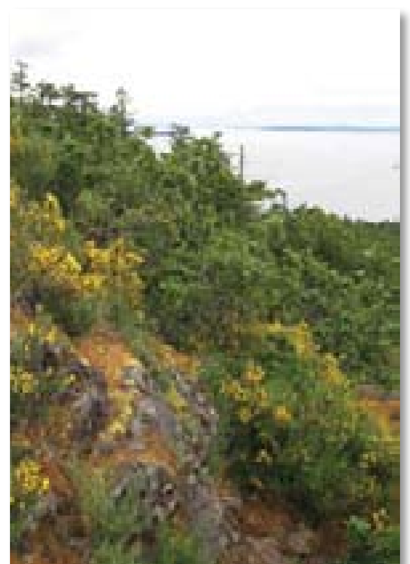


FIGURE 10: **Past and present distribution of Garry oak ecosystems of southern Vancouver Island and the Gulf Islands.**
SOURCE: Lea, T. 2006. Historical Garry oak ecosystems of Vancouver Island, British Columbia, pre-European contact to the present. Davidsonia 17(2): 34-5. Available at: www.davidsonia.org/bc_garryoak.

The extent of Garry oak *(Quercus garryana)* ecosystems, found in the Coastal Douglas-fir biogeoclimatic zone, has been reduced by almost 90% since the 1860s.
PHOTO: ALISON LESLIE.



Fragmented remnants of Garry oak ecosystems are often dominated by invasive alien species, such as Scotch broom *(Cytisus scoparius)*.
PHOTO: ALAN DRENGSON.

2.2.2 FRESHWATER ECOSYSTEMS: MAJOR DRAINAGE AREAS

Fresh water is an essential ingredient for life on earth. Most fresh water is frozen or underground, locked either in polar ice caps and permafrost or in underground aquifers, many with recharge times of thousands of years.[163] Rivers, lakes, wetlands, soil moisture and water vapour together hold 0.01% of the planet's total water supply (including salt water) and just under 0.4% of the world's fresh water.[164] British Columbia has 25% of Canada's supply of flowing fresh water.[165]

Accessible fresh water in lakes, streams, reservoirs and wetlands provides vital habitat for a disproportionate number of B.C.'s species, including a wide variety of plants, fish, mussels, crayfish, snails, reptiles, amphibians, insects, micro-organisms, birds and mammals that live in, on and around water. Approximately 25% of the species of **vertebrates**, **invertebrates** and vascular plants that have been assessed in B.C. are associated with freshwater ecosystems (see Section 2.3.2.1, p. 59). In addition to providing water, food, habitat, and physical, chemical and hydrologic processes, freshwater ecosystems are required for life cycle stages of many organisms, such as salmon (for spawning) and dragonflies (for larval development). Freshwater ecosystems also provide humans with many essential services.

Freshwater ecosystems are highly variable and dynamic. They interact closely with adjacent **riparian** areas and nearshore communities, sharing physical habitats and ecological and environmental processes, and are highly sensitive to the effects of climate change.

2.2.2.1 CONSERVATION STATUS OF MAJOR DRAINAGE AREAS

To assess the status of freshwater ecosystems, Major Drainage Areas (MDAs) were examined.[166,167] With the exception of the Coastal Major Drainage Area, each of B.C.'s nine MDAs encompasses the drainage basin of a major river system in the province (Map 5). The Coastal MDA comprises many small coastal rivers and streams that drain directly into the Pacific Ocean.

According to an assessment of conservation status (using the same methods used for biogeoclimatic zones in Section 2.2.1.1, p. 30),[168] four of the nine MDAs are of conservation concern (Table 9). The Columbia River drainage, which is highly impacted by dams, is ranked as imperilled. The Fraser River drainage, which includes the highly populated Fraser Valley, is ranked as imperilled/vulnerable.

TABLE 9. PROVINCIAL CONSERVATION STATUS OF MAJOR DRAINAGE AREAS IN B.C.

MAJOR DRAINAGE AREA	CONSERVATION STATUS	TOTAL AREA (KM²)	PERCENT OF PROVINCE
Columbia	**Imperilled (S2)**	**102,798**	**11%**
Fraser	**Imperilled/Vulnerable (S2S3)**	**231,459**	**25%**
Coastal	**Vulnerable/Apparently secure (S3S4)**	**164,115**	**17%**
Mackenzie	**Vulnerable/Apparently secure (S3S4)**	**278,667**	**30%**
Taku	Apparently secure/Secure (S4S5)	16,585	2%
Stikine	Apparently secure/Secure (S4S5)	49,631	5%
Yukon	Apparently secure/Secure (S4S5)	24,950	3%
Skeena	Apparently secure/Secure (S4S5)	54,401	6%
Nass	Secure (S5)	21,530	2%

SOURCE: Kremsater, L. 2007. Draft S Ranks and Surrogate G Ranks for BEC Zones and Draft S Ranks for Ecoprovinces and Major Drainage Areas of B.C.: Preliminary Rankings for Informing the Biodiversity Status Report and Action Plan. Biodiversity BC, Victoria, BC. 64pp. Available at: www.biodiversitybc.org.
NOTES: **Boldface** indicates the Major Drainage Area is of conservation concern.

TEXT BOX 7. LOST STREAMS IN THE LOWER FRASER VALLEY

The Lower Fraser Valley (LFV) has been considerably altered by human activity over the past 100 years. Large areas of land have been modified for agricultural use, urban and industrial centres or a variety of other purposes. This conversion of ecosystems to other uses has caused heavy damage to streams that at one time supported salmon and other fish. Damage has been caused by destruction of streamside vegetation, water diversion, stream channelization and pollution; and many streams have been effectively lost (i.e., they no longer exist as surface waterways), as a result of being drained, filled, culverted and/or paved over.

A 1997 survey of the LFV (from the Strait of Georgia inland to Hope, and from the North Shore mountains south to the United States border) found that of the 779 streams classified (excluding the Fraser River mainstem and estuary), 86% were either lost, endangered or threatened (Figure 11a).[169] The majority of the 14% that remain as wild streams are outside the developed area and have low value for fish because they are inaccessible, high-gradient mountain streams. The survey determined that 117 streams, many of them salmon-bearing, had been lost since the 1860s. All of the lost streams were originally in the area of the LFV that is now occupied by humans (Figure 11b). The Lower Fraser Valley is the spawning habitat for 66% of the wild coho salmon in the Fraser River system.[170]

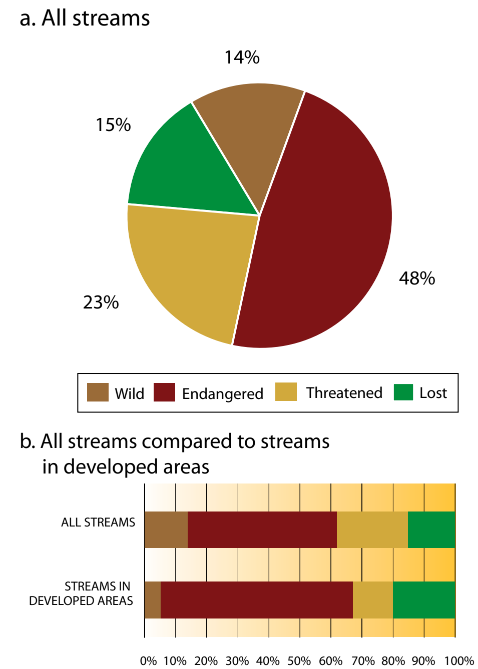
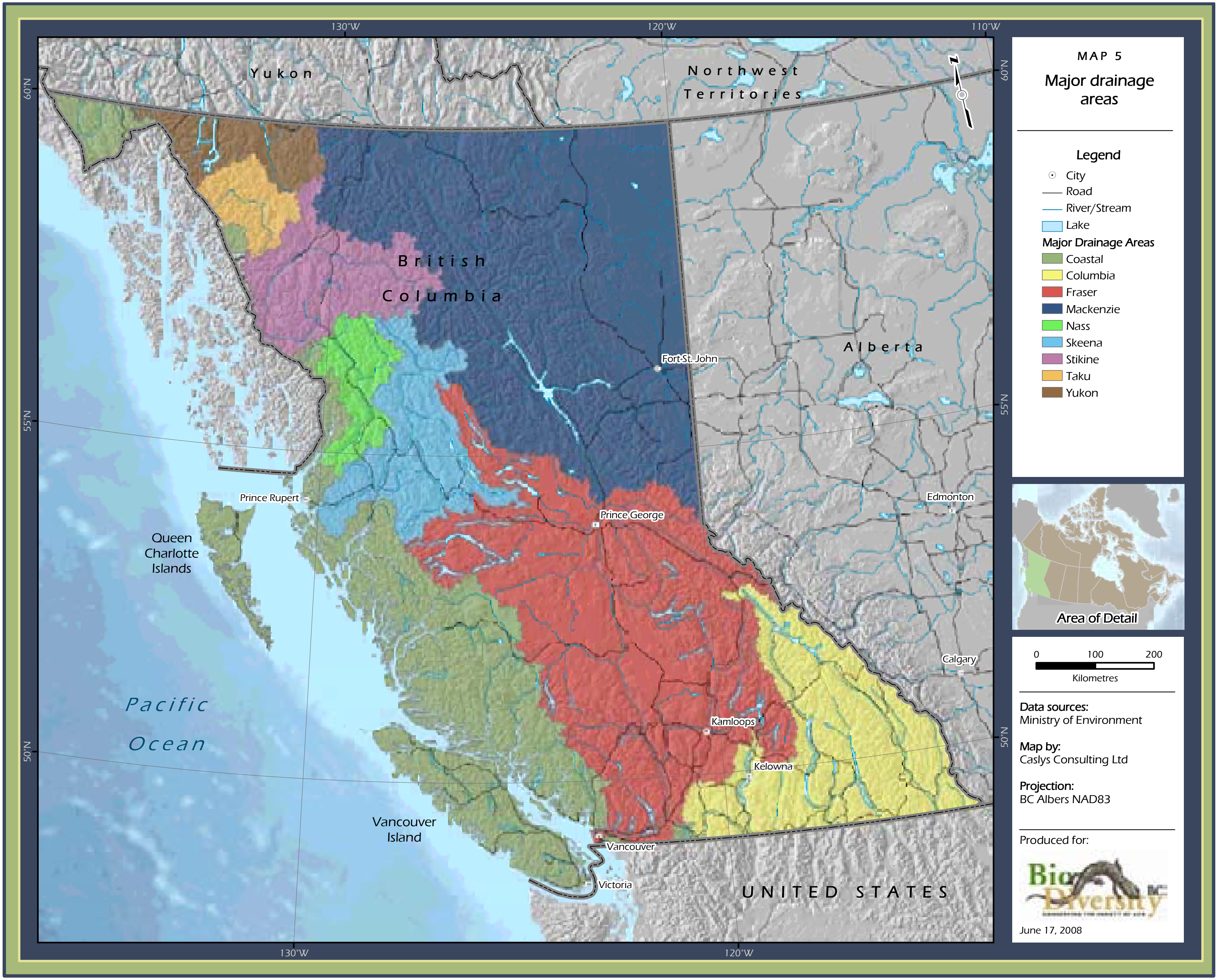


FIGURE 11: Status of streams in the Lower Fraser Valley in 2007
SOURCE: Precision Identification Biological Consultants. 1998. Wild, Threatened, Endangered and Lost Streams of the Lower Fraser Valley: Summary Report 1997. Fraser River Action Plan, Vancouver, BC. 58pp. Available at: www-heb.pac.dfo-mpo.gc.ca/maps/loststrm/loststreams_e.htm.
NOTES: As the identification of historic streams that have been lost contains an element of uncertainty, the number of lost streams is considered a conservative approximation. Eight impact criteria were developed to assess the status of other streams in the Lower Fraser Valley. A threatened stream meets one impact criterion; an endangered stream meets more than one impact criterion; and a wild stream is not significantly impacted by any criteria, but is not necessarily pristine.



MAP 5
Major drainage areas
Legend
City
Road
River/Stream
Lake
Major Drainage Areas
Coastal
Columbia
Fraser
Mackenzie
Nass
Skeena
Stikine
Taku
Yukon
Area of Detail
0
100
200
Kilometres
Data sources:
Ministry of Environment
Map by:
Caslys Consulting Ltd
Projection:
BC Albers NAD83
Produced for:
June 17, 2008
Yukon
Northwest Territories
British Columbia
Alberta
Fort St. John
Edmonton
Prince Rupert
Prince George
Queen Charlotte Islands
Calgary
Kamloops
Kelowna
Pacific Ocean
Vancouver Island
Vancouver
Victoria
UNITED STATES
130°W
120°W
110°W
60°N
55°N
50°N

2.2.3 ECOSYSTEMS THAT OVERLAP THE MARINE REALM

The coastal zone, where land and ocean meet, is a diverse and productive environment that some consider to be a separate realm.[171] There is an exchange of nutrients and energy between the realms through processes such as salmon migration from marine to freshwater ecosystems (see Section 2.5.1.3-F, p. 121) and upland sediment transport (see Section 2.5.1.4-F, p. 131). With a provincial coastline of approximately 29,000 km,[172] the area of overlap between marine, terrestrial and freshwater ecosystems in B.C. contains a rich assemblage of ecosystems of wide-reaching importance to the province's biodiversity. This section focuses on **intertidal** ecosystems and estuaries.

2.2.3.1 INTERTIDAL

The intertidal zone represents the area between the mean high tide line and the mean low tide line, or zero tide, where the **benthic** substrate is regularly exposed through tidal action (Figure 12). Above the intertidal zone is the supratidal zone – the area below terrestrial trees and shrubs, which contains salt-tolerant grasses and sedges and is influenced, but not dominated, by marine processes such as wave splash, wind-generated storm surge and storm deposits of **large woody debris**. Below the intertidal zone is the subtidal zone, where the benthic substrate below the lowest normal tide is permanently covered by water. Subtidal community structure is influenced

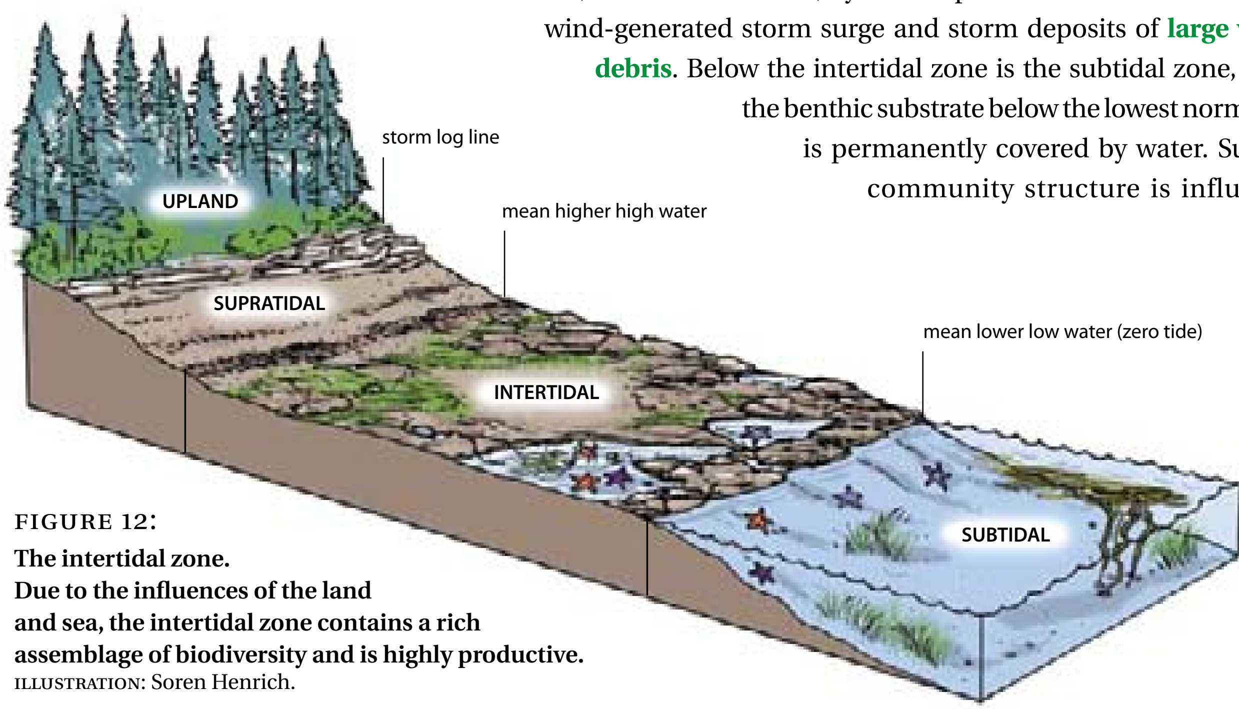


FIGURE 12:
The intertidal zone.
Due to the influences of the land and sea, the intertidal zone contains a rich assemblage of biodiversity and is highly productive.
ILLUSTRATION: Soren Henrich.

by a number of physical factors (e.g., depth, substrate, salinity, water temperature, wave action, currents, upwellings and light) and biological factors (e.g., larval settlement and dispersal characteristics, predation, productivity and prey availability).

The intertidal zone is regularly exposed to air, wind, sun, rain and sea water as the tide moves in and out, so animals and plants that live in this zone have to adapt to an ever-changing environment. Both biotic and abiotic processes act to maintain the diversity of organisms. For example, in rocky intertidal communities, mussels (*Mytilus* spp.) tend to exclude all functionally similar organisms that are potential competitors, but ochre sea stars (*Pisaster ochraceus*) prey on the mussels and prevent them from dominating. Wave action has a similar effect, controlling the most competitive species through desiccation or battering by debris. Vertical zonation of organisms occurs in the intertidal based on the tolerance of each species to desiccation, changes in salinity and light, wave exposure, competition and predation.[173]

The entire B.C. shoreline has been mapped and classified using both physical and biological mapping components (Table 10).[174,175] In a subsequent analysis, estuaries were identified as the most productive habitat, followed by semi-exposed–immobile and current-dominated channel habitats.[176] Instances of high species richness were found in all habitat classes except bare beaches and protected shorelines (habitat types 5, 7 and 9), with the majority of instances in exposed to semi-protected immobile habitats along the west coast of Vancouver

TABLE 10. HABITAT TYPES USED IN B.C. BIOPHYSICAL SHOREZONE MAPPING.

HABITAT TYPE CLASS	HABITAT TYPE	SUBSTRATE CATEGORY
1	Very exposed–immobile	Bedrock
2	Exposed immobile	Bedrock
3	Semi-exposed–immobile	Bedrock/Boulder
4	Semi-protected–immobile	Bedrock/Boulder
5	Protected & very protected–immobile	Bedrock/Boulder
6	Semi-protected–partially mobile	Boulder/Cobble/Pebble
7	Protected & very protected–partially mobile	Boulder/Cobble/Pebble
8	Estuaries	Fines/Organic
9	Bare beaches	Sand/Pebble/Cobble
10	Current-dominated channels	Bedrock, Sediment or combinations
11	Hanging lagoons, brackish lakes	Bedrock, Sediment or combinations

SOURCE: Morris, M., D. Howes and P. Wainwright. 2006. Methodology for Defining B.C. Intertidal ShoreZone Habitats and Habitat Values for the B.C. Oil Spill Shoreline Sensitivity Model. B.C. Ministry of Agriculture and Lands, Victoria, BC. 47pp.

Island, the north and central mainland coast and on Haida Gwaii/Queen Charlotte Islands. Shorelines that are immobile and protected (habitat types 4 and 5) together accounted for about half of the B.C. coast. Estuaries, bare beaches and hanging lagoons were the rarest habitat types, and the majority of these habitats were found on the central and north coast.

Species present in the intertidal are well described compared to **pelagic** species, because the intertidal zone is relatively accessible. They include many terrestrial species that forage in the intertidal. For example, the diet of coastal black bears includes invertebrates such as shore crabs (*Hemigrapsus* spp.), porcelain crabs (*Petrolisthes* spp.), mussels, barnacles (*Balanus* spp.), isopods (e.g., *Idotea* spp.) and sea stars, as well as gunnels (e.g., *Pholis* spp.).[177]

The intertidal zone has been important to humans in B.C. for generations, historically providing a large portion of the diet of coastal First Nations. Because of the relative ease of access, the intertidal is subject to ecosystem conversion and degradation through human activities, including exposure to contaminants such as persistent organic pollutants, heavy metals, oils and hydrocarbons, and excess nutrients (e.g., excess nitrogen runoff from agriculture or nutrients from sewage resulting in **eutrophication**). The greatest challenge for the future, however, may be climate change and the anticipated rise in sea level. Introduced species are also a significant threat to intertidal ecosystems.

2.2.3.2 ESTUARIES

An estuary is generally defined as a partially enclosed body of coastal water, where salt water is measurably diluted by mixing with river runoff. In British Columbia it is estimated that there are more than 440 estuaries occupying approximately 75,000 ha along 2.3% of the length of the coast, with most estuaries ranging in size from 1–10 ha.[178,179] Locations of the larger estuaries in B.C. are known and mapped (Figure 13).

The key feature of an estuary is that fresh water meets the salt water of the sea, resulting in brackish water. As a result, estuaries are characterized by salinity rather than geography. When river runoff reaches the salt water there is not an immediate mixing of the two. Rather, the fresh water floats on or near the surface, forming a freshwater plume, while the salt water, having a higher density due to higher dissolved solids, remains below the fresh water, forming a zone sometimes referred to as the saltwater wedge or salt-wedge (Figure 14). The amount of mixing defines different types of estuaries (see Section 2.5.1.4-G, p. 133).

Estuaries comprise a number of identifiable habitat types, such as intertidal flats, marshes/swamps, rivers/lakes, and islands. They present a good example of how ecosystems and ecosystem function are influenced by abiotic components, including seasonal variation in temperature, wave energy, type and rates of sedimentation (turbidity), and timing and volume of freshwater inputs.

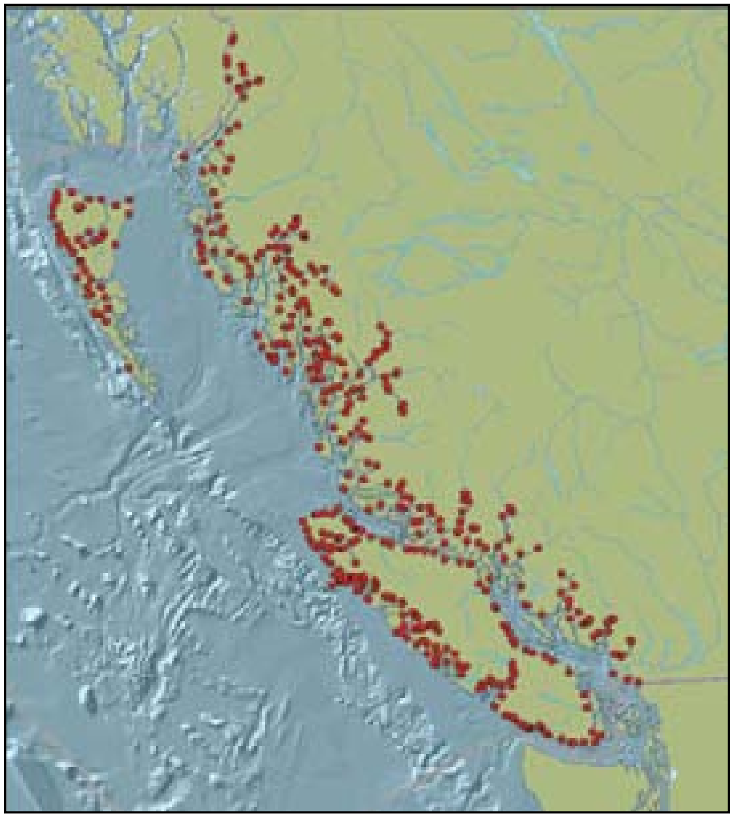


FIGURE 13: Locations of mapped estuaries in B.C.
SOURCE: Adapted from Ryder, J.L., J.K. Kenyon, D. Buffett, K. Moore, M. Ceh and K. Stipec. 2007. An Integrated Biophysical Assessment of Estuarine Habitats in B.C. to Assist Regional Conservation Planning. Canadian Wildlife Service, Pacific and Yukon Region, Delta, BC. Technical Report Series No. 476.

The most extensive estuaries are found where the coastline is relatively flat and the sediments brought by the river build up slowly over a wide area and a long time. As described in Section 1.4 (p. 15), estuaries in B.C. are relatively young in geological terms. B.C.'s largest estuary is the Fraser River estuary, with a mapped area of over 21,000 ha and a sphere of influence that spans the Strait of Georgia.[180] Its significance is recognized internationally,[181,182] but all estuaries make the same kinds of contributions to sustaining biodiversity, albeit at a smaller scale.

Estuaries are nutrient sinks, trapping nutrients from the ocean, land and rivers that are, in turn, dispersed throughout the estuary by tidal movement, wind and currents. The constant mixing creates a productive environment, used by an estimated 80% of all coastal wildlife: for foraging by many species of waterfowl and other birds; and as breeding or rearing grounds by some fish species.[183] Estuaries can also sequester and detoxify waste. The influence of estuaries extends beyond their immediate surroundings; nutrients generated in estuaries provide food for many pelagic marine species. Estuaries are of critical importance to the survival of Pacific salmon, particularly juveniles, for reasons that include the provision of nutrients (the fresh water as a source and the saltwater wedge concentrating nutrients) and habitat (diverse habitat types, refuges from predators); most significantly, their low salinity is important to **anadromous** fish as they make the transition between the marine and freshwater realms.[184]

Because estuaries are productive ecosystems and offer easy access to the sea, humans have long been drawn to settle and develop infrastructure near them, leading to ecosystem conversion and degradation, environmental contamination (of both water and sediment), disturbance and alien species introductions.[185] Section 2.5.1.4-G (p. 133) provides more information on threats to estuaries.

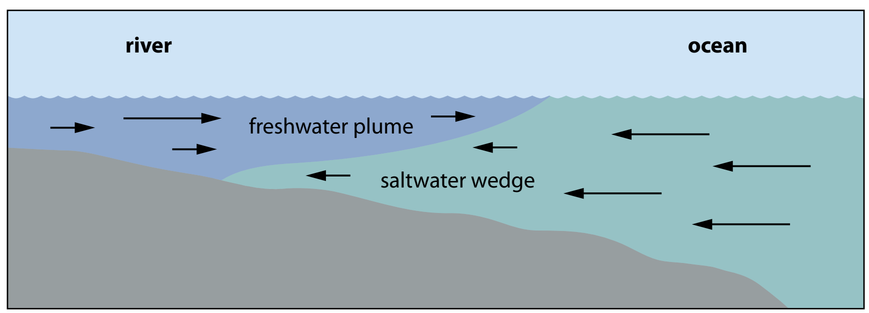


FIGURE 14: The interface between the freshwater plume and the saltwater wedge.
SOURCE: Adapted from Fisheries and Oceans Canada. 2007. Estuaries: The Physical Environment. Available at: www.glf.dfo-mpo.gc.ca/os/bysea-enmer/estuaries-estuaires-e.php.
ILLUSTRATION: Soren Henrich.

2.2.4 DATA GAPS

Within B.C., the classification and mapping of ecological communities is incomplete. The major gaps are in the alpine biogeoclimatic zones and in small communities such as vernal pools, rock outcrops and avalanche tracks.[186,187]

There is no province-wide data source to update the structural stage of ecosystems. For example, there are gaps for forest age in some protected areas and Tree Farm Licenses.[188]

Classification and mapping of freshwater ecosystems is far less advanced than ecosystem mapping in the terrestrial realm. A recent attempt has been made at classifying freshwater systems (drainage units, watersheds, lakes and rivers), but it has not yet been widely adopted.[189]

Global status assessments have not been completed for the majority of ecological communities. The global status assessment of ecosystems is compromised by differences between ecological classification in B.C. and adjacent Canadian and American jurisdictions, lack of comparisons of these ecological classifications and limited information on impacts and trends.[190] This lack of information also impacts the ability to determine what proportion of the global range of ecological communities occurs in B.C.

Information on trends for ecosystems is very incomplete. For example, baseline information on the historic extent of ecosystems is limited to a small number of ecosystems in specific areas.[191]

Although climate change will cause species distributions to shift, ecosystems will not move.[192] Instead they will change in terms of their species composition, as well as their structure and function. As a result, any ecosystem classification scheme will become obsolete over time.[193] This places added importance on the use of units that will not change as the climate changes, such as terrain units, which are based on topography and soils. However, the provincial coverage of terrain units is incomplete.[194]

2.3 Diversity of Species in British Columbia

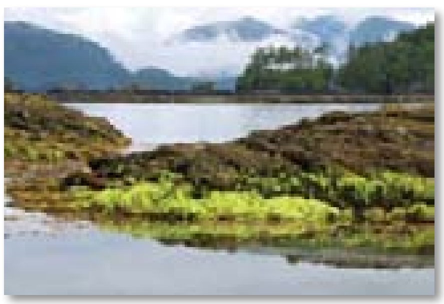
Species interact within ecosystems, performing essential ecological functions necessary for life on earth (see Section 1.2, p. 10). This section summarizes information on the status of about 3,800 native species,[a] including more than 2,000 vascular plants, 563 vertebrate animals, 423 invertebrates and over 729 **non-vascular plants**. These are the species we know the most about, but they represent only a fraction of the approximately 50,000 species (not including single-celled organisms) that exist in B.C.[195]

[a] Includes mammals, birds, freshwater fish (including anadromous species such as salmon), reptiles and turtles, amphibians, butterflies and skippers, dragonflies and damselflies, non-marine molluscs, flowering plants (monocots and dicots), ferns and fern allies, mosses and conifers. Only full species with scientifically accepted taxonomic names are included. Alien species are not included, nor are 'accidental' species (i.e., those that occur in B.C. infrequently and unpredictably, as B.C. is outside their usual range).

Information about most species in British Columbia is limited. Surveys and incidental observations are often sporadic, inconsistent and/or concentrated along roads and in areas of higher human population. Parts of the province have never been surveyed and a number of **taxonomic groups** have never been assessed (see Appendix B, p.232).[a]

The number of species included in each of the analyses presented in this section varies according to the availability of data (Table 11). For the species richness analysis, non-marine molluscs and mosses were excluded due to concerns that the available data were overly biased by survey effort, and the analysis of birds was limited to passerines (perching birds) due to the lack of data for other types of birds. Also for the species richness analysis, there were some species in other groups for which no recent documented occurrences were available (records prior to 1961 were excluded for all groups). Mosses were excluded from the realm overlap analysis due to the lack of expertise to assign them to a realm or realms. Other differences in the number of species considered for each analysis are generally very minor and are due to varying species lists.

2.3.1 RICHNESS



B.C.'s large coastal islands are relatively species-rich.
PHOTO: PAUL MORTON.

Species richness is one common measure of biodiversity, calculated as the number of species in an area of interest. For this analysis of species richness, the province was divided into a grid of 1,208 squares on a map.[b] The number of species recorded in each grid square was then calculated from computerized location data.[196] The species groups assessed were those from the best-studied groups of plants and animals for which adequate computerized location data (recorded between 1961 and 2006) were available.

Map 6 shows patterns of species richness across the province for 2,640 vertebrates, invertebrates and vascular plants. Species richness varies markedly across the province and is highest in the south of the province and on Vancouver Island, which are also areas of highest human population density. The biogeoclimatic zones with the highest species richness are Ponderosa Pine, Coastal Douglas-fir, Bunchgrass and Interior Douglas-fir, all ecosystems of conservation concern (see Section 2.2.1.1, p. 30).

The data are biased because surveys and incidental observations most often occur close to roads. For example, high species-richness points occur along the Alaska Highway north of Fort St. John at Pink Mountain, known for its wildflowers and rare Arctic butterflies, and at Liard Hot Springs, a provincial park. Some of the large areas depicted as having low species richness are the most inaccessible in the province (e.g., north of Spatsizi Provincial Park) and have not been well surveyed. Such is also the case along much of B.C.'s rugged coastline.

[a] Conservation status is only assessed for entire taxonomic groups subject to the availability of information; it is not focused on species that are suspected to be of conservation concern.
[b] Grid squares correspond to 1:50,000-scale map sheets and range in size from 1,030 to 780 km^2 (the size decreases moving from south to north). For more information, see the National Topographic Service website: http://maps.nrcan.gc.ca/topo_e.php.

TABLE 11. NUMBER OF SPECIES CONSIDERED FOR THE ANALYSES OF SPECIES RICHNESS, CONSERVATION STATUS, PROPORTION OF GLOBAL RANGE AND REALM OVERLAP, BY TAXONOMIC GROUP.

TAXONOMIC GROUP	SPECIES RICHNESS ANALYSIS	CONSERVATION STATUS ANALYSIS	PROPORTION OF GLOBAL RANGE ANALYSIS	REALM OVERLAP ANALYSIS
Birds	187	353	352	349
Conifers	25	26	26	26
Flowering Plants (Monocots)	525	552	556	549
Flowering Plants (Dicots)	1,339	1,404	1,403	1,402
Non-marine Molluscs	0	157	157	157
Mosses	0	729	760	0
Ferns and Fern Allies	103	111	111	111
Reptiles and Turtles	12	14	14	13
Amphibians	20	20	20	20
Mammals	102	109	109	109
Freshwater Fish	70	67	67	67
Dragonflies and Damselflies	85	86	86	86
Butterflies and Skippers	172	180	180	180
Total	2,640	3,808	3,841	3,069

SOURCE: Prepared for this report.

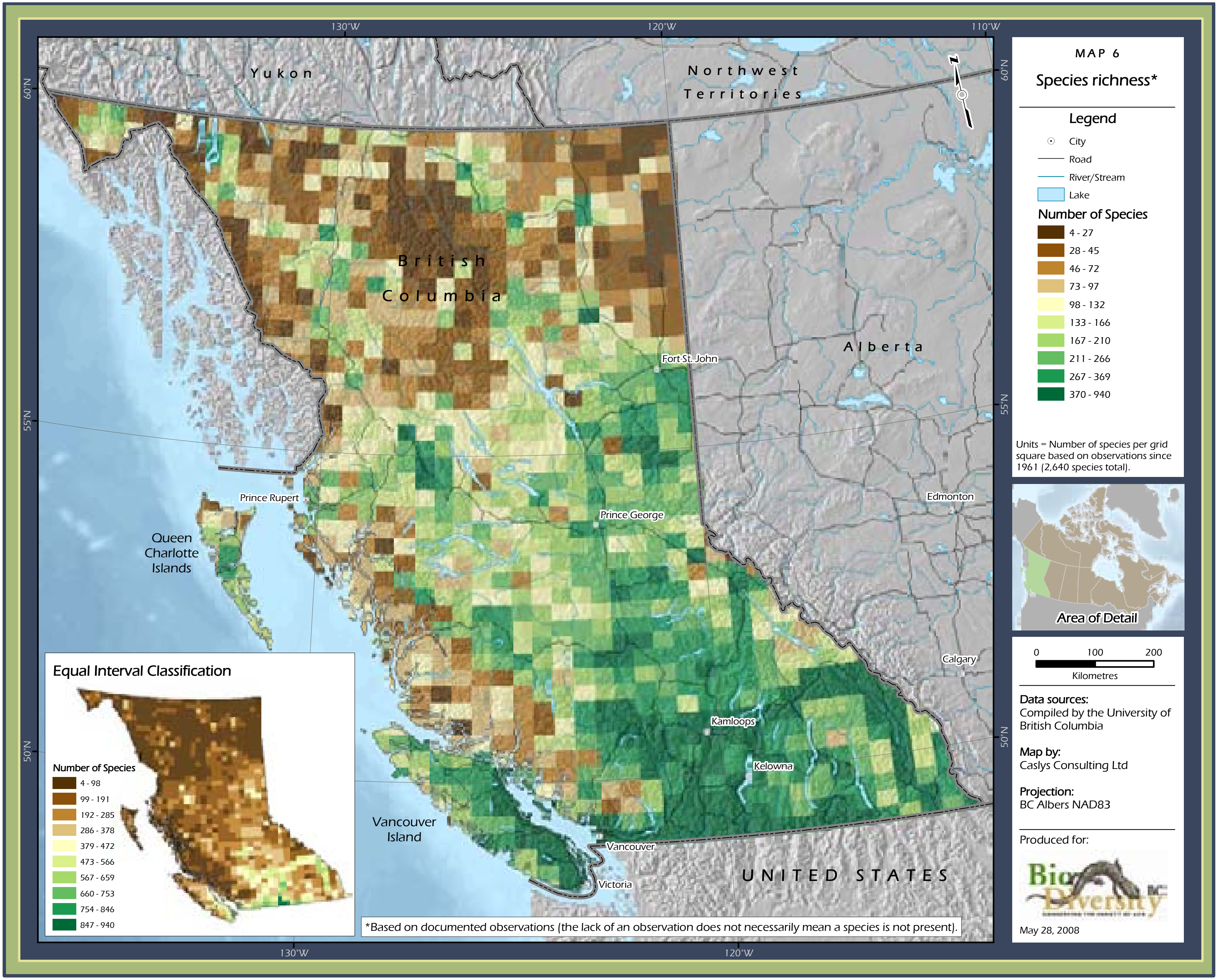
Liard Hot Springs, just off the Alaska Highway in northern B.C.
PHOTO: BC PARKS.

Despite these limitations, the observed pattern is consistent with the global pattern of decreasing species richness at higher latitudes[197] and elevations.[198]

The patterns of high species richness on the province's large coastal islands (Vancouver Island and Haida Gwaii/Queen Charlotte Islands) are notable. As a rule, islands have lower diversity than areas of equal size on the adjacent mainland, with decreasing disparity as island size increases and distance from the mainland decreases.[199] Although this seems to hold true for B.C.'s smaller islands, which have low species richness due to little variation in habitat, the province's larger islands are species-rich relative to the adjacent mainland, likely because they have a mild, moist climate, large elevational range, variation in climate and close proximity to the mainland, and because portions of these islands were refugia during the last glaciation (see Section 2.4.1.3, p. 78).

2.3.2 CONSERVATION STATUS

Conservation status rankings (Table 12) were compiled for 13 of the best-studied groups of native plants and animals based on information current to 2007.[200] Criteria for these rankings included rarity, population size


MAP 6
Species richness*
Legend
City
Road
River/Stream
Lake
Number of Species
4 - 27
28 - 45
46 - 72
73 - 97
98 - 132
133 - 166
167 - 210
211 - 266
267 - 369
370 - 940
Units = Number of species per grid square based on observations since 1961 (2,640 species total).
Area of Detail
0 100 200
Kilometres
Data sources:
Compiled by the University of British Columbia
Map by:
Caslys Consulting Ltd
Projection:
BC Albers NAD83
Produced for:
May 28, 2008
130°W
120°W
110°W
60°N
55°N
50°N
Yukon
Northwest Territories
British Columbia
Alberta
Fort St. John
Prince Rupert
Prince George
Edmonton
Queen Charlotte Islands
Calgary
Kamloops
Kelowna
Vancouver Island
Vancouver
Victoria
UNITED STATES
Equal Interval Classification
Number of Species
4 - 98
99 - 191
192 - 285
286 - 378
379 - 472
473 - 566
567 - 659
660 - 753
754 - 846
847 - 940
*Based on documented observations (the lack of an observation does not necessarily mean a species is not present).

and trends, and the level of threat from human activity. For the purposes of this analysis, species falling into the categories Extirpated (X), Historical (H), Critically Imperilled (1), Imperilled (2) and Vulnerable (3) were considered to be species of conservation concern (also termed 'at risk') in British Columbia. Information was compiled at two scales: global (G), indicating the status of a species in its worldwide range, and subnational/provincial (S), indicating the status of a species within B.C.

The conservation status of a species may vary according to the area considered. For example, the sharp-tailed snake has a global conservation status of G5, indicating its secure status across its entire range, but a provincial conservation status rank of S1 to convey its limited occurrence and high level of imperilment in British Columbia. The provincial status ranking of a species can never be lower (i.e., more secure) than its global status ranking.

Of the 3,808 native species in British Columbia for which conservation status has been assessed, 91% are globally secure (G5) or apparently secure (G4), whereas only 54% are provincially secure (S5) or apparently secure (S4) (Table 13). In B.C., 233 species (6%) are of global conservation concern and 1,640 species (43%) are

TABLE 12. CONSERVATION STATUS RANKS FOR SPECIES IN B.C.

RANK	DEFINITION	DESCRIPTION
X	**Extinct or Presumed Extirpated**	**Not located despite intensive searches and no expectation of rediscovery.**
H	**Historical**	**Possibly extinct or extirpated; known only from historical occurrences, but still hope of rediscovery.**
1	**Critically Imperilled**	**At very high risk of extirpation or extinction due to extreme rarity (often 5 or fewer populations), steep declines or other factors, making the species especially susceptible to extirpation or extinction.**
2	**Imperilled**	**At high risk of extirpation or extinction due to very restricted range, few populations (often 20 or fewer), steep declines, or other factors.**
3	**Vulnerable**	**At moderate risk of extirpation or extinction due to a restricted range, relatively few populations (often 80 or fewer), recent and widespread declines, or other factors.**
4	Apparently Secure	Uncommon but not rare, and usually widespread in the range. Some cause for long-term concern.
5	Secure	Common or very common, and widespread and abundant. Not susceptible to extirpation or extinction under current conditions.
NA	Not Assessed	Species whose pattern of occurrence in the province is not compatible with the assessment process.
NR	Not yet Ranked	Rank is not yet assessed.
U	Unrankable	Suitable information is not available for ranking.

SOURCE: Adapted from Anions, M. 2006. Global and Provincial Status of Species in British Columbia. Biodiversity BC, Victoria, BC. 16pp. Available at: www.biodiversitybc.org.

NOTES: For analyses in this report, range ranks (given when not enough information is available to score a specific rank) are rounded to the higher rank (e.g., S2S3 is rounded to S2; S2S4 is averaged to S3).

Boldface indicates that species with these ranks are of conservation concern.

of provincial conservation concern. The proportion of species in B.C. that are of global conservation concern is relatively low; of the 32,487 native species in the U.S. and Canada assessed by NatureServe, 12,700 (39%) are considered to be of global conservation concern.[201] The high proportion of species of provincial conservation concern reflects, in part, the high number whose habitat in B.C. was rare even before European contact and the concentration of ecosystem conversion in these areas; for example, in some warm, dry, low-elevation areas of southern B.C. (see Section 3.2.1, p. 159).

Three percent of the species considered are not assessed (NA), not yet ranked (NR) or are unrankable (U). Species not assessed are those whose pattern of occurrence in the province is not compatible with the assessment process, such as some migratory species that do not breed in B.C. (e.g., short-tailed albatross [*Phoebastria albatrus*]).

Within the taxonomic groups assessed, the non-marine molluscs have the highest proportion of species of global conservation concern (22%), followed by the mosses (12%), ferns and fern allies (12%) and reptiles and turtles (7%) (Figure 15). The groups with the highest numbers of species of global conservation concern are the mosses (88 species), **dicots** (58 species) and non-marine molluscs (34 species). Map 7 shows the distribution of the 233 species of global conservation concern for which computerized location data were available.

TABLE 13. SUMMARY OF B.C. SPECIES ASSESSED FOR GLOBAL AND PROVINCIAL CONSERVATION STATUS.

CONSERVATION STATUS RANK	GLOBAL		PROVINCIAL	
	Number of Species	Percentage of Species	Number of Species	Percentage of Species
Extinct or Extirpated (GX, SX)	1	<1%	14	<1%
Historical (GH, SH)	1	<1%	28	<1%
Critically Imperilled (G1, S1)	19	<1%	301	8%
Imperilled (G2, S2)	40	<1%	629	17%
Vulnerable (G3, S3)	172	5%	668	18%
Total species of conservation concern	**233**	**6%**	**1,640**	**43%**
Apparently Secure or Secure (G4, S4, G5, S5)	3,475	91%	2,055	54%
Not Assessed, Not Ranked, or Unrankable (NA, NR, or U)	100	3%	113	3%
Total number of species assessed	**3,808**		**3,808**	

SOURCE: Prepared for this report with data from the B.C. Conservation Data Centre.

Within the taxonomic groups assessed, the mosses have the highest proportion of species of provincial conservation concern (65%), followed by the reptiles and turtles (64%), ferns and fern allies (58%) and dicots (46%) (Figure 16). The groups with the highest numbers of species of conservation concern in the province are the dicots (651 species), mosses (471), **monocots** (196), birds (70) and ferns and fern allies (64). Map 8 shows the distribution of the 1,640 species of provincial conservation concern for which computerized location data were available.

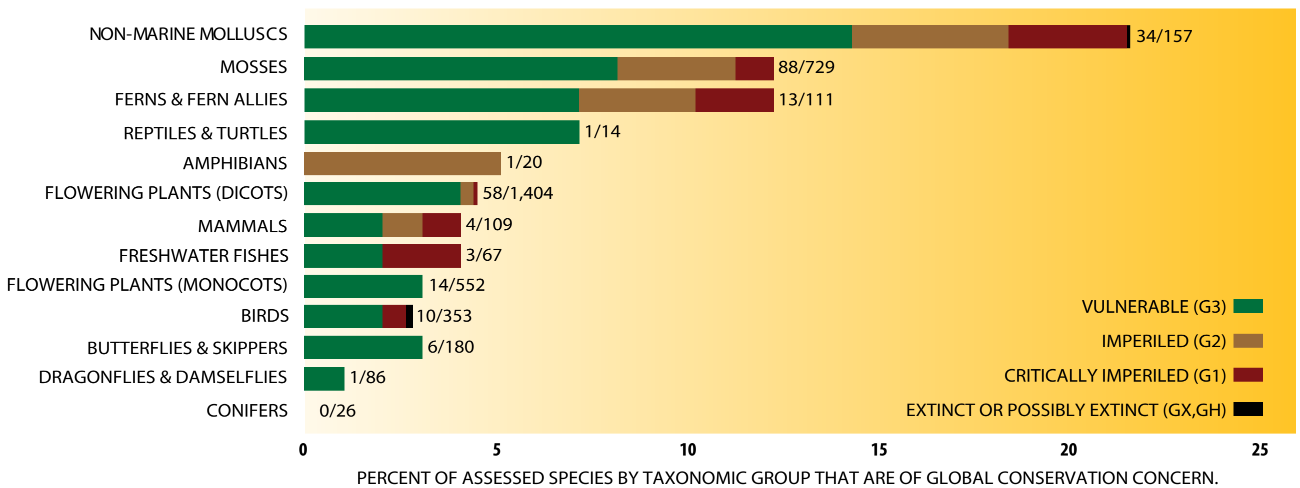


FIGURE 15: Species of global conservation concern as percent of total number of plant and animal species assessed in B.C.
NOTES: Total number of species assessed = 3,808. For each species group, numbers shown represent the number of species assessed as being of global conservation concern and the total number of species in the group (e.g., birds: 10 species of global conservation concern / 353 species in total).

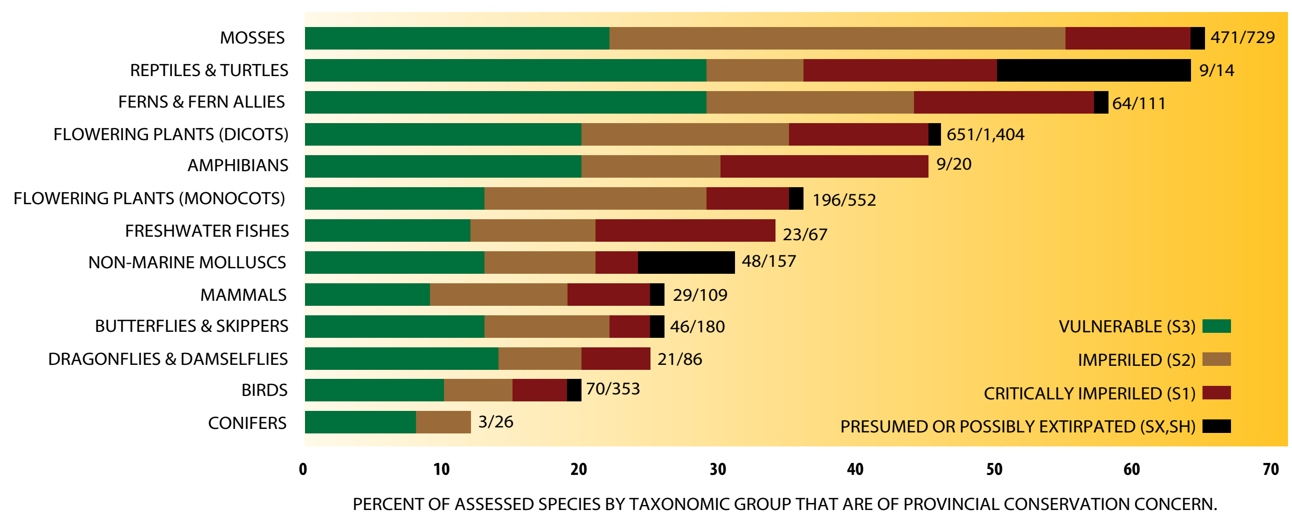
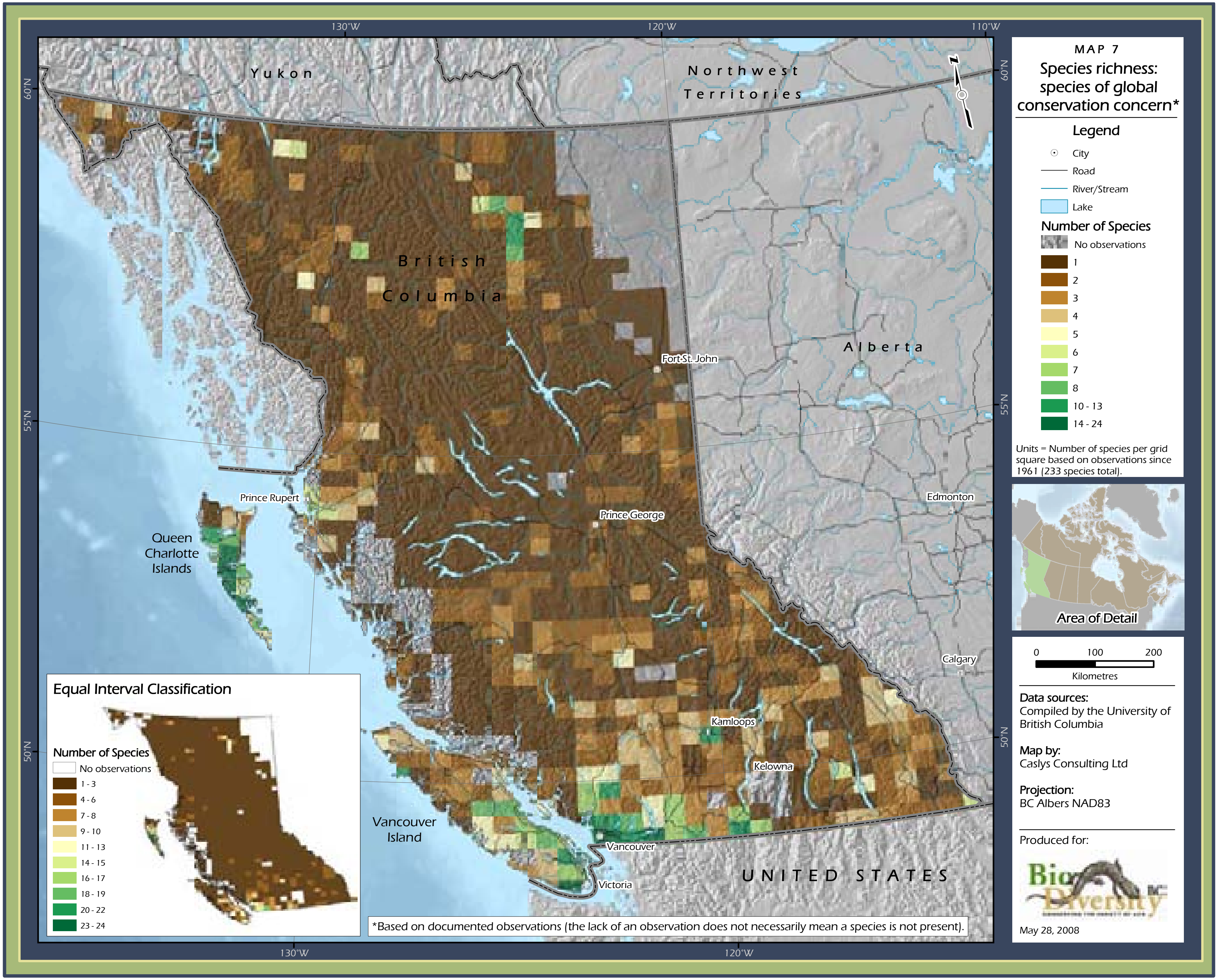
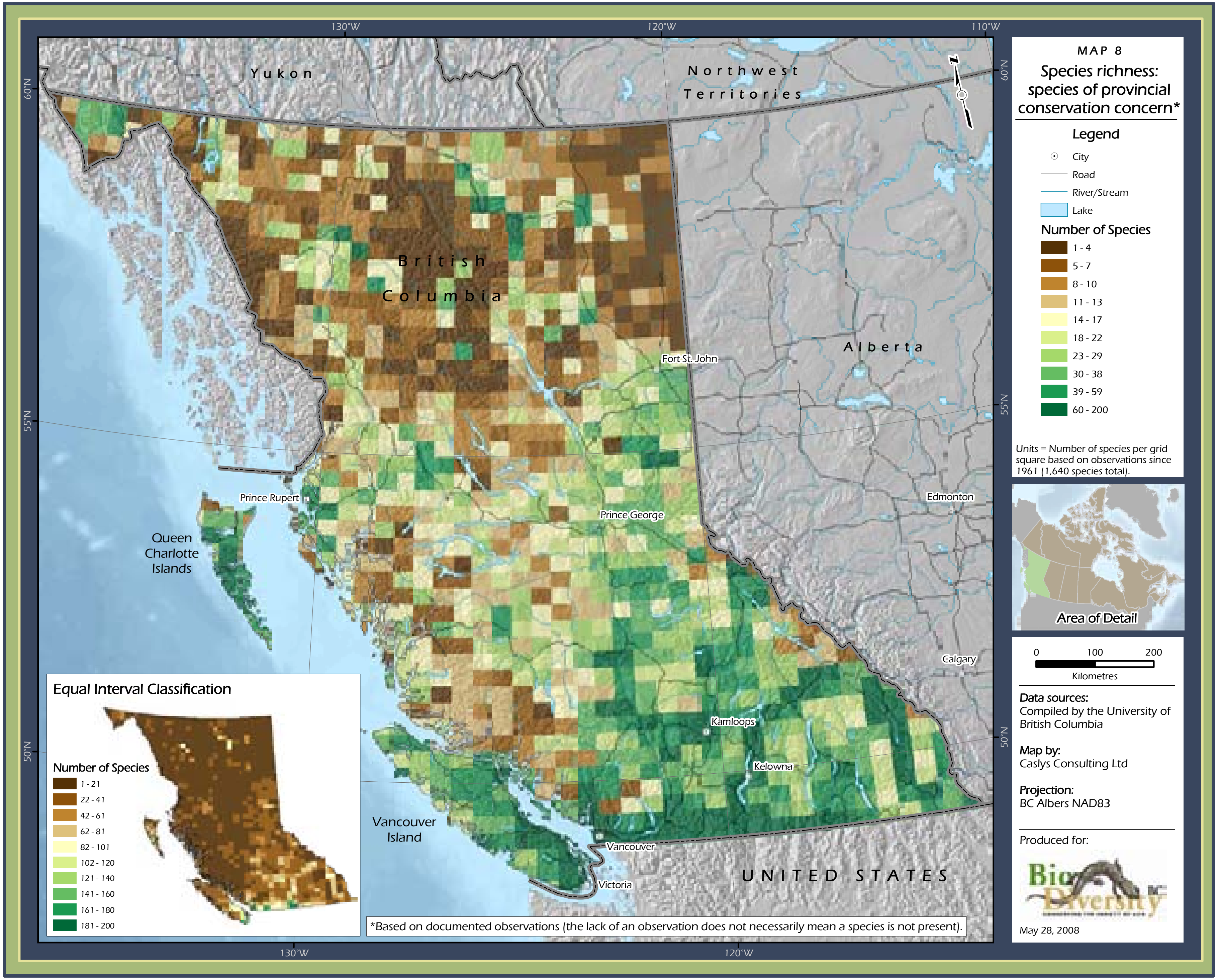


FIGURE 16: Species of provincial conservation concern as percent of total number of plant and animal species assessed in B.C.
NOTES: Total number of species assessed = 3,808. For each species group, numbers shown represent the number of species assessed as being of provincial conservation concern and the total number of species in the group (e.g., birds: 70 species of provincial conservation concern / 353 species in total).


MAP 7
Species richness: species of global conservation concern*
Legend
City
Road
River/Stream
Lake
Number of Species
No observations
1
2
3
4
5
6
7
8
10 - 13
14 - 24
Units = Number of species per grid square based on observations since 1961 (233 species total).
Area of Detail
0
100
200
Kilometres
Data sources:
Compiled by the University of British Columbia
Map by:
Caslys Consulting Ltd
Projection:
BC Albers NAD83
Produced for:
May 28, 2008
130°W
120°W
110°W
60°N
55°N
50°N
Yukon
Northwest Territories
British Columbia
Alberta
Fort St. John
Prince Rupert
Prince George
Edmonton
Queen Charlotte Islands
Calgary
Kamloops
Kelowna
Vancouver Island
Vancouver
Victoria
UNITED STATES
Equal Interval Classification
Number of Species
No observations
1 - 3
4 - 6
7 - 8
9 - 10
11 - 13
14 - 15
16 - 17
18 - 19
20 - 22
23 - 24
*Based on documented observations (the lack of an observation does not necessarily mean a species is not present).


MAP 8
Species richness: species of provincial conservation concern*
Legend
City
Road
River/Stream
Lake
Number of Species
1 - 4
5 - 7
8 - 10
11 - 13
14 - 17
18 - 22
23 - 29
30 - 38
39 - 59
60 - 200
Units = Number of species per grid square based on observations since 1961 (1,640 species total).
Area of Detail
0
100
200
Kilometres
Data sources:
Compiled by the University of British Columbia
Map by:
Caslys Consulting Ltd
Projection:
BC Albers NAD83
Produced for:
May 28, 2008
130°W
120°W
110°W
60°N
55°N
50°N
Yukon
Northwest Territories
British Columbia
Alberta
Fort St. John
Prince Rupert
Prince George
Edmonton
Queen Charlotte Islands
Calgary
Kamloops
Kelowna
Vancouver Island
Vancouver
Victoria
UNITED STATES
Equal Interval Classification
Number of Species
1 - 21
22 - 41
42 - 61
62 - 81
82 - 101
102 - 120
121 - 140
141 - 160
161 - 180
181 - 200
*Based on documented observations (the lack of an observation does not necessarily mean a species is not present).

TEXT BOX 8. EXTINCT AND EXTIRPATED SPECIES

An extinct species is one that has disappeared from its global range. An extirpated species is one that is no longer found in a given area (i.e., in B.C., for the purposes of this report) despite intensive searches, and for which there is little hope of rediscovery. Extinct species are gone forever, but an extirpated species has the potential to be reintroduced.[202] Fourteen species once found in B.C. have been designated extinct or extirpated (Table 14). An additional 28 species are considered historic, meaning there is no verified record of their presence in the past 40 years; although they are possibly extinct or extirpated, rediscovery remains a possibility (see Appendix A, p.231). Extinct and extirpated **taxa** below the species level (subspecies, populations, varieties) are discussed in Section 2.4.2 (p. 82).

TABLE 14. EXTINCT AND PRESUMED EXTIRPATED SPECIES IN B.C.

TAXONOMIC GROUP	SCIENTIFIC NAME	COMMON NAME	CONSERVATION STATUS
Birds	*Centrocercus urophasianus*	Greater sage grouse	Extirpated
	Coccyzus americanus	Yellow-billed cuckoo	Extirpated (breeding populations)
	Ectopistes migratorius	Passenger pigeon	Extinct
Reptiles and Turtles	*Actinemys marmorata*	Western pond turtle	Extirpated
	Phrynosoma douglasii	Pigmy short-horned lizard	Extirpated
Butterflies	*Limenitis archippus*	Viceroy	Extirpated
Non-marine Molluscs	*Cryptomastix devia*	Puget oregonian	Extirpated
Vascular Plants	*Downingia elegans*	Common downingia	Extirpated
	Epilobium torreyi	Brook spike-primrose	Extirpated
	Lepidium oxycarpum	Sharp-pod peppergrass	Extirpated
	Lupinus oreganos	Kincaid's lupine	Extirpated
Non-vascular Plants	*Micromitrium tenerum*	[no common name]	Extirpated
	Physcomitrium immersum	[no common name]	Extirpated
	Pseudephemerum nitidum	[no common name]	Extirpated

SOURCE: Prepared for this report with data from the B.C. Conservation Data Centre.

NOTES: Kincaid's lupine (*Lupinus oreganus* var. *kincaidii*) is the only variety of *Lupinus oreganus* represented in B.C. and is therefore listed at the species level.

The western pond turtle has not been recorded since 1966 and there are only two previous specimen records. It may have been introduced, but there is no concrete evidence to suggest this. Proximity to Puget Sound populations suggests that a B.C. native population was a possibility (Cannings, S.G., L.R. Ramsay, D.F. Fraser and M.A. Fraker. 1999. Rare amphibians, reptiles, and mammals of British Columbia. Wildlife Branch and Resources Inventory Branch, Ministry of Environment, Lands and Parks, Victoria, BC. 198pp.).

2.3.2.1 SPECIES OF CONSERVATION CONCERN IN THE TERRESTRIAL, FRESHWATER AND MARINE REALMS

For the analysis of species status within the terrestrial and freshwater realms, as well as those that overlap with the marine realm, the number of species associated with each realm was determined by classifying species according to their requirements for terrestrial, freshwater or marine ecosystems for at least one of their life requisites (food, shelter or reproduction). Species that require both marine and freshwater, or both marine and terrestrial, ecosystems were included in the analysis. Exclusively marine species were not included.

The assessment of 3,079 species of vertebrates, invertebrates and vascular plants[a] showed that 2,612 species (85%) are associated with terrestrial ecosystems, 769 (25%) with freshwater ecosystems and 152 (5%) with marine ecosystems (Table 15).[b] Species that require more than one ecosystem type to meet all of their life requisites are counted in each appropriate realm. For example, Merriam's shrew (*Sorex merriami*) relies only on terrestrial ecosystems for all of its life requisites and is classified as terrestrial, whereas the Pacific water shrew (*Sorex bendirii*) dens on land and forages in or near water and is classified as both terrestrial and freshwater. Because the marbled murrelet (*Brachyramphus marmoratus*) nests in old-growth trees in forests, forages for both marine and freshwater prey, and winters at sea, it is counted in all three realms.

TABLE 15. CONSERVATION STATUS FOR B.C. VERTEBRATE, INVERTEBRATE AND VASCULAR PLANT SPECIES ASSOCIATED WITH THE TERRESTRIAL, FRESHWATER AND MARINE REALMS.

REALM	TOTAL ASSOCIATED SPECIES	CONSERVATION STATUS RANK (NUMBER OF SPECIES)											
		PRESUMED EXTINCT OR EXTIRPATED		POSSIBLY EXTINCT OR EXTIRPATED		CRITICALLY IMPERILLED		IMPERILLED		VULNERABLE		SPECIES OF CONSERVATION CONCERN AS PROPORTION OF SPECIES ASSESSED	
		Provincial (SX)	Global (GX)	Provincial (SH)	Global (GH)	Provincial (S1)	Global (G1)	Provincial (S2)	Global (G2)	Provincial (S3)	Global (G3)	Provincial	Global
Terrestrial	2,612	10	1	18	0	203	6	327	14	459	100	39%	5%
Freshwater	769	1	0	10	1	55	5	81	5	97	18	32%	4%
Marine	152	0	0	1	0	11	2	17	0	22	11	34%	9%

SOURCE: Prepared for this report with data from the B.C. Conservation Data Centre.
NOTES: Total number of species assessed = 3,079 (including vertebrates, invertebrates and vascular plants; excluding mosses). Some species are associated with more than one realm. 'Marine' includes species that require both marine and freshwater, or both marine and terrestrial, ecosystems, but does not include exclusively marine species.

[a] Mosses were excluded due to lack of information.
[b] Species were assigned to the marine, terrestrial and freshwater realms by J. Cooper, B. Costanzo, A. Eriksson, J. Heron, D. Nagorsen, G. Scudder or L. Warman.

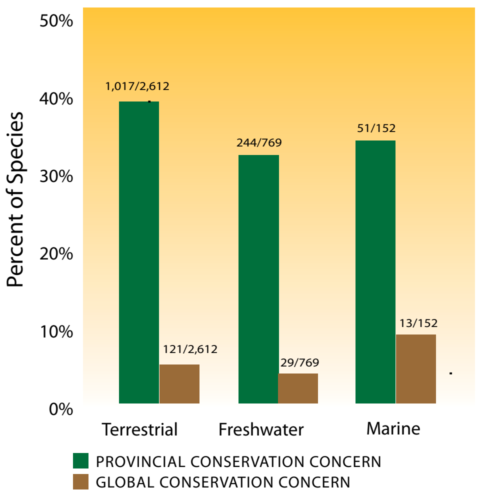


FIGURE 17: Species of global and provincial conservation concern in the terrestrial, freshwater and marine realms. NOTES: Total number of species assessed = 3,079 (including vertebrates, invertebrates and vascular plants; excluding mosses). Some species are associated with more than one realm.

Of the species assessed, 1,017 (39%) terrestrial species, 244 (32%) freshwater species, and 53 (34%) marine overlap species are of provincial conservation concern, and 121 (5%) terrestrial species, 29 (4%) freshwater species and 14 (9%) marine overlap species are of global conservation concern (Figure 17).

TEXT BOX 9. TRENDS IN CONSERVATION STATUS OF SELECT GROUPS OF SPECIES AND SUBSPECIES[203,204]

The B.C. Conservation Data Centre annually reviews the conservation ranks for B.C. species and subspecies. The conservation rank for a species can change because of a genuine improvement or deterioration in the status of the species or for several other reasons. For example, a species rank may be adjusted because the assessor has access to improved information or because a previously unknown population has been discovered.

To determine the true change in status for the groups of species shown in Figure 18, all available species ranks were compared between a point in the 1990s and one in the 2000s. All changes in rank that were due to changes in knowledge about that species, how it was assessed or how it was classified taxonomically were removed.

This analysis of four of B.C.'s best-studied groups shows that for mammals, freshwater fish and vascular plants of highest conservation concern, more species and subspecies have experienced a deterioration in conservation status since the 1990s than have experienced an improvement. The large number of breeding birds with improved status is in large part due to new immigrant species (i.e., species that have entered the province without human assistance). Because of their initial small populations, they were originally ranked as being of high conservation concern, but many of these species have since expanded their ranges, resulting in gradual improvement in their conservation status ranks. As a group, breeding birds also had the largest proportion and largest total number of species whose conservation status deteriorated. Due to their mobility, it is possible that birds respond more rapidly – both positively and negatively – to habitat change and climate change. A majority of species in all four of the groups analyzed showed no change in conservation status during the period examined.

2.3.3 PROPORTION OF GLOBAL RANGE FOR SPECIES

The proportion of global range was assessed based on seven classes, ranging from 1 (Endemic; 100% of global range or population in British Columbia) to 7 (Low and Localized; <10% of range or population in British Columbia and occurs over <30% of the province) (Table 5, p. 35). Species in classes 1–3 (Endemic, Very High and High) have a majority (>50%) of their range, area or population within the province.

Consideration of the proportion of a species' global range in B.C. should be balanced by consideration of how the species is distributed across other jurisdictions. This is particularly important for species that are low and widespread (meaning a low proportion of their global range occurs in B.C., but they still occupy >30% of the province and by extension must have a large global range). For example, fishers (*Martes pennanti*) are sufficiently widespread that no jurisdiction has more than 10% of the global range.[205]

Most of the assessments for species were based on the proportion of global range occurring in British Columbia using range maps and available presence or absence information. Although ideally the proportion of the population within a jurisdiction would be used, this could only be approximated for three broad groups of species – birds showing strong seasonal aggregations, some marine mammals that congregate on land (e.g., Steller sea lion [*Eumetopias jubatus*]), and well-monitored game species – as well as for a few species of conservation concern (e.g., American white pelican [*Pelecanus erythrorhynchos*], Vancouver Island marmot).

TABLE 16. SUMMARY OF B.C. SPECIES BY GLOBAL RANGE CLASS.

GLOBAL RANGE CLASS	NUMBER OF SPECIES IN RANGE CLASS	PERCENT OF TOTAL SPECIES ASSESSED
Endemic (1)	15	<1%
Very High (2)	15	<1%
High (3)	69	2%
Total number of species with a majority of global range in B.C.	**99**	**3%**
Moderately High (4)	189	5%
Intermediate (5)	497	13%
Low and Widespread (6)	1,249	33%
Low and Localized (7)	1,714	45%
Not ranked	93	2%
Total number of species assessed	**3,841**	

SOURCE: Bunnell, F., L. Kremsater and I. Houde. 2006. Applying the Concept of Stewardship Responsibility in British Columbia. Biodiversity BC, Victoria, BC. 188pp. Available at: www.biodiversitybc.org.

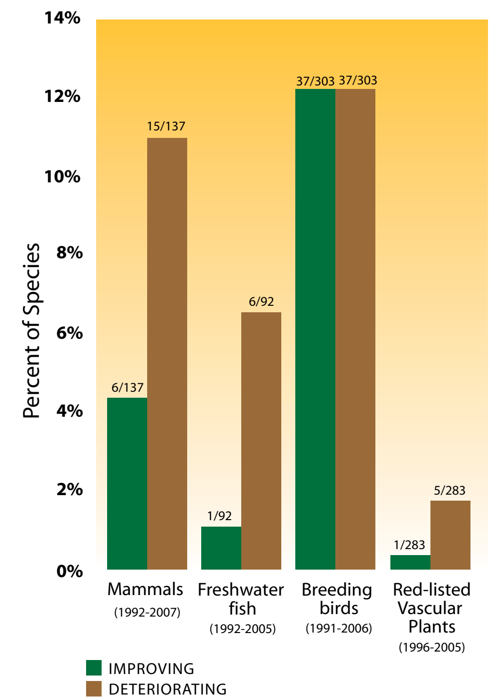


FIGURE 18: **Species and subspecies with changed conservation status in B.C. since the 1990s.**
NOTES: Period of assessment varies by species group: mammals (1992–2007); freshwater fish (1992–2005); breeding birds (1991–2006); vascular plants of highest conservation concern (1996–2005). Data do not include species introduced by humans. Breeding birds include new immigrant species.

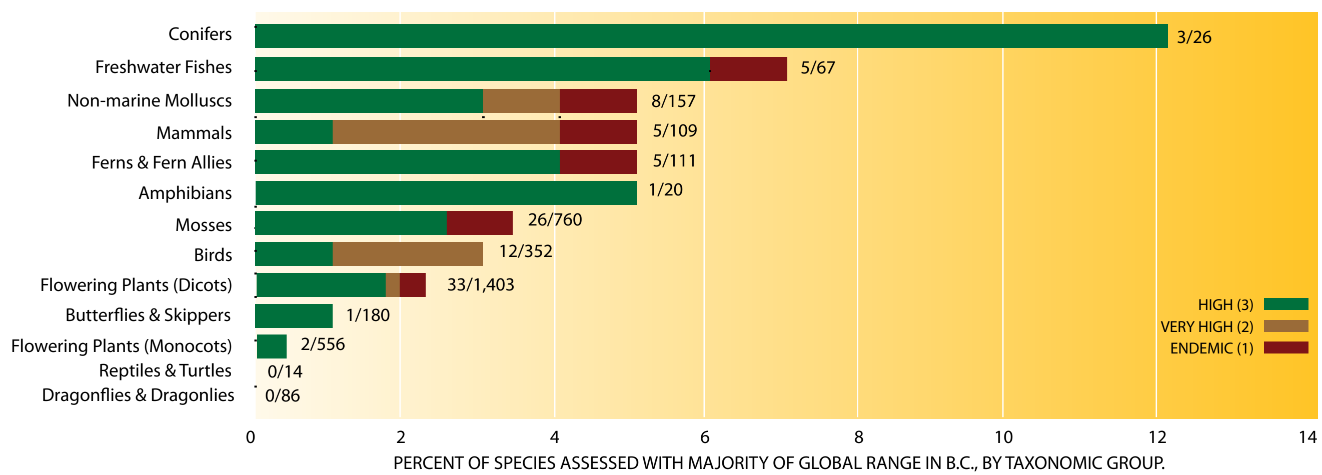
The proportion of global range was assessed for 3,841 native species in 13 taxonomic groups (Table 16). Of these, 99 species (3%) have a majority of their global range in the province. Fifteen species, 10 of which are plants, are endemic (Class 1). Only one B.C. endemic species, Newcombe's butterweed (*Sinosenecio newcombei*), is not of conservation concern.

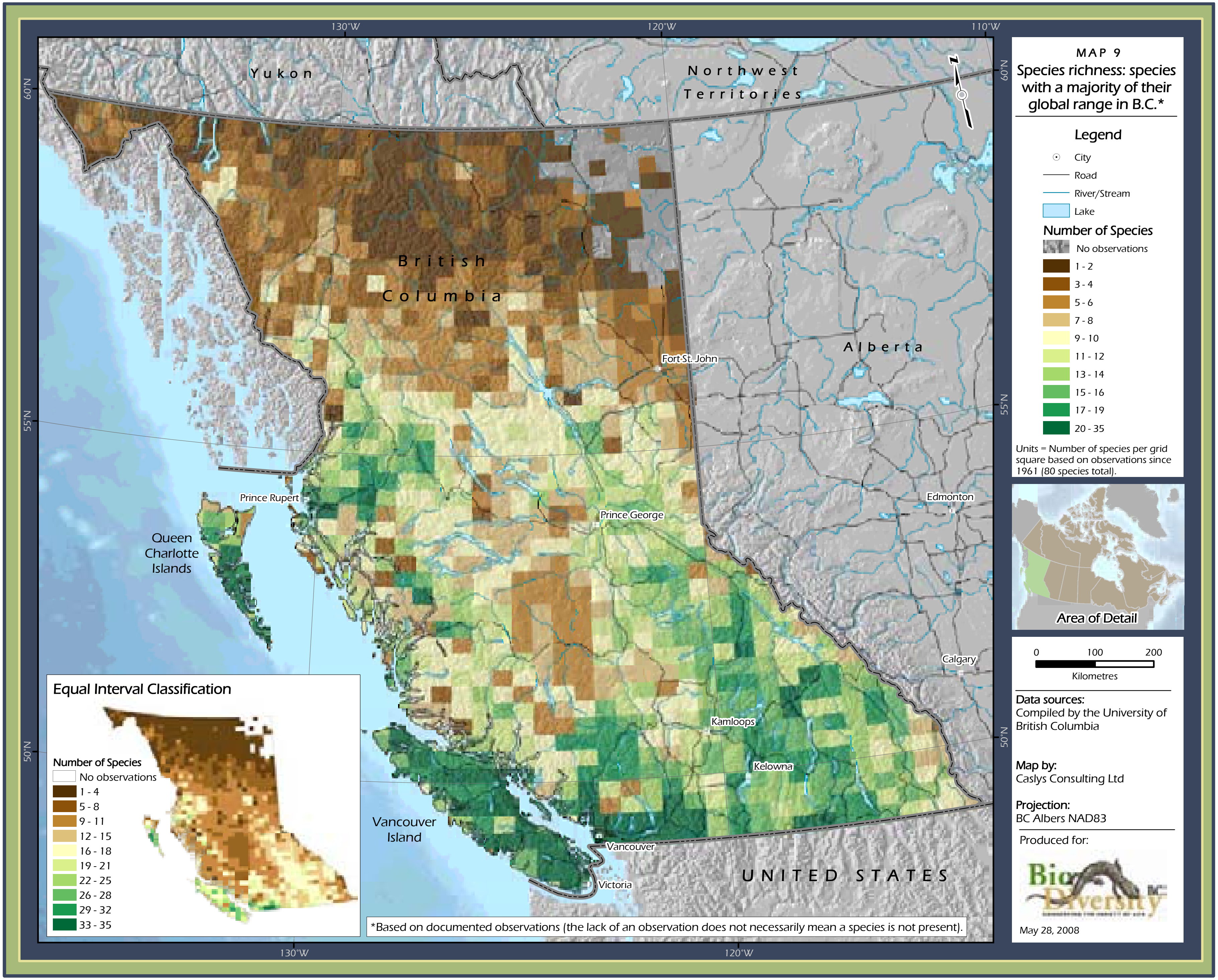
The groups with the highest proportion of species that have a majority of their global range in B.C. are the conifers (12%), freshwater fish (7%), non-marine molluscs (5%), birds (3%) and amphibians (5%) (Figure 19). The dicots have the highest number of species with a majority of their global range in B.C. (33).

Computerized location data were available for 82 of the 99 species with a majority of their global range in B.C. Species richness for these species is shown in Map 9.

Currently, 30 of the 233 B.C. species that are of global conservation concern are also among the 99 species with a majority of their global range in B.C. (Table 17).[206] An additional 11 species with a majority of their global range in B.C. are among the 1,640 of provincial conservation concern, but are not of global conservation concern. It should be noted that not all species in the province have been assessed, including most invertebrate groups.

FIGURE 19: Species with a majority of their global range in B.C. as a percent of the species assessed.
NOTES: Total number of species assessed = 3,841. For each species group, numbers shown represent the number of species assessed as having the majority of their global range in B.C. and the total number of species in the group (e.g., birds: 12 species of global conservation concern / 352 species in total).





MAP 9
Species richness: species with a majority of their global range in B.C.*
Legend
City
Road
River/Stream
Lake
Number of Species
No observations
1 - 2
3 - 4
5 - 6
7 - 8
9 - 10
11 - 12
13 - 14
15 - 16
17 - 19
20 - 35
Units = Number of species per grid square based on observations since 1961 (80 species total).
Area of Detail
0 100 200
Kilometres
Data sources:
Compiled by the University of British Columbia
Map by:
Caslys Consulting Ltd
Projection:
BC Albers NAD83
Produced for:
May 28, 2008
130°W
120°W
110°W
60°N
55°N
50°N
Yukon
Northwest Territories
British Columbia
Alberta
Fort St. John
Prince Rupert
Prince George
Edmonton
Queen Charlotte Islands
Calgary
Kamloops
Kelowna
Vancouver Island
Vancouver
Victoria
UNITED STATES
Equal Interval Classification
Number of Species
No observations
1 - 4
5 - 8
9 - 11
12 - 15
16 - 18
19 - 21
22 - 25
26 - 28
29 - 32
33 - 35
*Based on documented observations (the lack of an observation does not necessarily mean a species is not present).

At the species level, B.C. has a very low level of endemism, considering that 5,000 or more species have been recorded elsewhere in global hot spots of plant endemism.[207,208] This is consistent with the province's recent history of glaciation. Of the insects, only the dragonflies and butterflies were included in this assessment. Although many other invertebrate species are currently listed as endemic in British Columbia,[209] they may not be true endemics and their listing may be due to a lack of collecting and knowledge of their full distribution. Information is also very incomplete on mosses and lichens endemic to the Pacific Northwest and known to occur in B.C.[210]

TABLE 17. SPECIES OF PROVINCIAL OR GLOBAL CONSERVATION CONCERN WITH A MAJORITY OF THEIR GLOBAL RANGE IN B.C.

SCIENTIFIC NAME	COMMON NAME	CONSERVATION STATUS RANK		PROPORTION OF GLOBAL RANGE CLASS
		GLOBAL CONCERN	PROVINCIAL CONCERN	
Birds				
Ptychoramphus aleuticus	Cassin's auklet	G4	S2S3 (breeding) S4 (non-breeding)	Very High (2)
Freshwater Fish				
Lampetra macrostoma	Vancouver (or Cowichan Lake) lamprey	G1	S1	Endemic (1)
Salvelinus confluentus	Bull trout	G3	S3	High (3)
Mammals				
Marmota vancouverensis	Vancouver Island marmot	G1	S1	Endemic (1)
Myotis keenii	Keen's myotis	G2G3	S1S3	Very High (2)
Sorex bendirii	Pacific water shrew	G4	S1S2	High (3)
Non-marine Molluscs				
Fossaria truncatula	Attenuate fossaria	G3	S3	High (3)
Fossaria vancouverensis	[no common name]	GH	SH	Very High (2)
Hemphillia dromedarius	Dromedary jumping slug	G3G4	S2	High (3)
Physella wrighti	Hotwater physa	G1	S1	Endemic (1)
Planorbella columbiensis	Caribou rams-horn	G1G2	SH	Endemic (1)
Pristiloma chersinella	Black-footed tightcoil	G3G4	S3S4	High (3)
Vascular Plants				
Asplenium adulterinum	Corrupt spleenwort	G3	S2S3	Endemic (1)
Aster paucicapitatus	Olympic mountain aster	G3	S3	High (3)
Bidens amplissima	Vancouver Island beggarticks	G3	S3	Very High (2)
Enemion savilei	Queen Charlotte false rue-anemone	G3G4	S3S4	Endemic (1)
Erigeron trifidus	Three-lobed daisy	G2G3	S2	High (3)
Geum schofieldii	Queen Charlotte avens	G2	S2	Endemic (1)
Impatiens aurella	Orange touch-me-not	G4	S2S3	High (3)
Isoetes minima	Midget quillwort	G1G2	S1	High (3)

CONTINUED ON PAGE 65

TABLE 17. CONTINUED

SCIENTIFIC NAME	COMMON NAME	CONSERVATION STATUS RANK GLOBAL CONCERN	PROVINCIAL CONCERN	PROPORTION OF GLOBAL RANGE CLASS
Vascular Plants				
Ligusticum caldera	Calder's lovage	G3G4	S3S4	Very High (2)
Limnanthes macounii	Macoun's meadow-foam	G2	S2	Endemic (1)
Listera convallarioides	Broad-leaved twayblade	G5	S3S4	High (3)
Saxifraga taylori	Taylor's saxifrage	G3G4	S3S4	Endemic (1)
Senecio moresbiensis	Queen Charlotte butterweed	G3	S3	High (3)
Sinosenecio newcombei	Newcombe's butterweed*	G4	S4	Endemic (1)
Talinum sediforme	Okanagan fameflower	G3	S2S3	High (3)
Viola biflora	Queen Charlotte twinflower violet	G5	S3	High (3)
Non-vascular Plants				
Andreaea sinuosa	[no common name]	G2	S1	High (3)
Brotherella roellii	[no common name]	G3	S3	Endemic (1)
Bryhnia hultenii	[no common name]	G4	S1	High (3)
Ctenidium schofieldii	[no common name]	G2G3	S2S3	Endemic (1)
Orthotrichum pulchellum	[no common name]	G4	S3S4	High (3)
Pohlia cardotii	[no common name]	GU	S2S3	High (3)
Pohlia columbica	[no common name]	G3G5	S1S3	High (3)
Pohlia pacifica	[no common name]	GU	S1S3	Endemic (1)
Seligeria careyana	[no common name]	G1	S1	Endemic (1)
Trematodon boasii	[no common name]	G1	S1	High (3)
Trematodon montanus	[no common name]	G1	S1	High (3)
Ulota obtusiuscula	[no common name]	GU	S3S4	High (3)
Wijkia carlottae	[no common name]	G2	S2	Endemic (1)
Zygodon gracilis	[no common name]	G2	S1	High (3)

SOURCES: Anions, M. 2006. Global and Provincial Status of Species in British Columbia. Biodiversity BC, Victoria, BC. 16pp.; and Bunnell, F., L. Kremsater and I. Houde. 2006. Applying the Concept of Stewardship Responsibility in British Columbia. Biodiversity BC, Victoria, BC. 188pp. Both available at: www.biodiversitybc.org.
NOTES: *Newcombe's butterweed is the only B.C. endemic species that is not of conservation concern. It is included here to provide a complete list of endemic species. Only one subspecies (ssp. *carlottae*) of *Viola biflora* occurs in B.C., therefore it is included at the species level. All non-vascular plants listed in the table are mosses.

2.3.3.1 SPECIES AT THE EDGE OF THEIR RANGE

Of the species that were assessed for the proportion of their global range in B.C., 2,963 (78%) have <10% of their range, area or population within the province (global range classes 6 and 7) (Table 16, p. 61). Most of these species are at the edge of their range in B.C. and are sometimes called '**geographically marginal**' or '**peripheral**' species (see Section 2.4.1.1, p. 74).

Steller sea lions (*Eumetopias jubatus*) are marine mammals that haul out on B.C.'s rocky islets.
PHOTO: NANCY NEHRING.

The proportion of the global range that occurs in B.C. is increasing for some species.[211] Species range shifts due to climate change are generally expected to be northwards, [212, 213,214,215,216,217] and such shifts are facilitated by the north-south orientation of mountain ranges in B.C. Researchers have also found that mammal species that are reduced to less than 25% of their historic range tend to become limited to the periphery of their range; 74% of those studied showed this trend, and the most common direction of the collapse was from east to west and from south to north.[218] This suggests there may be a tendency for species ranges to collapse toward B.C.

2.3.4 SPECIES OVERLAP: REALM AND JURISDICTIONAL

Species and ecosystems transcend lines on maps. Natural processes and human actions in one realm or jurisdiction can have a profound impact on biodiversity in adjacent realms or jurisdictions. Some species, such as the eulachon, marbled murrelet and anadromous salmon, spend portions of their life cycles in different realms. Others, like the Steller sea lion, may transit between the terrestrial and marine realms on a daily basis and between jurisdictions over the course of their life.

2.3.4.1 SPECIES THAT OVERLAP WITH THE MARINE REALM

Some species require marine ecosystems in addition to freshwater and/or terrestrial ecosystems in order to live or complete their life cycle. These species have adapted to take advantage of the different structures of the two realms (see Section 2.2.3, p. 45). Marine mammals such as harbour seals (*Phoca vitulina*) haul out on rocky islets. Seabirds often nest near freshwater lakes or on cliffs, or, like the marbled murrelet, in the tops of trees. Some grasses and sedges are found in brackish tidal marshes, providing habitat for terrestrial and marine species.

TABLE 18. TERRESTRIAL AND FRESHWATER SPECIES IN B.C. THAT OVERLAP WITH THE MARINE REALM.

TAXONOMIC GROUP	NUMBER OF OVERLAP SPECIES	NUMBER OF SPECIES OF CONSERVATION CONCERN		NUMBER OF SPECIES WITH MAJORITY OF GLOBAL RANGE IN B.C. (CLASSES 1-3)
		PROVINCIAL CONCERN	GLOBAL CONCERN	
Birds	77	17	7	2
Freshwater Fish	8	3	1	1
Mammals	6	2	2	0
Vascular Plants	61	29	3	0
TOTAL	**152**	**51**	**13**	**3**

SOURCE: Prepared for this report.
NOTES: For number of species considered, see Table 11, p. 51. For taxonomic groups listed in Table 11 and not listed in this table, there were no species that overlap with the marine realm. Vascular plants include flowering plants (monocots and dicots) and conifers.

Of the 152 species of vertebrates, invertebrates and vascular plants identified as marine overlap species (Table 18), 51 are of provincial conservation concern and 13 are of global conservation concern. The latter include the pink-footed shearwater (*Puffinus creatopus*), a seabird that is critically imperilled in its global range; the Steller sea lion, which congregates in rookeries, generally on remote rocky islands, for breeding and pupping (see Section 2.5.2.1-B, p. 139); and Alaskan orache (*Atriplex alaskensis*), an annual herb that grows in saline soils along coastlines and is possibly extirpated from B.C. The three marine overlap species of global conservation concern that have the majority of their global range in B.C. are Barrow's goldeneye (*Bucephala islandica*), Cassin's auklet (*Ptychoramphus aleuticus*) and sockeye salmon.

2.3.4.2 SPECIES THAT OVERLAP WITH OTHER JURISDICTIONS

Plants and animals do not recognize political boundaries. They may migrate, travel throughout their home ranges, swim along river systems or, in some cases, travel with the wind or attached to other organisms that move from one place to another. Habitats are often intersected by jurisdictional boundaries, which, like the boundary between Canada and the United States, frequently follow non-ecological lines. Even within British Columbia, management responsibility for species and habitats may shift from one entity to another, with overlapping responsibilities.

British Columbia shares its boundaries with seven other jurisdictions: three in Canada – the Yukon, Alberta and the Northwest Territories – and four in the United States – Alaska, Washington, Montana and Idaho. Because B.C. has very few endemic species (see Table 16, p. 61), the province shares almost all of its species with one or more of these other jurisdictions. To complicate matters, some species of butterflies, birds and anadromous fish migrate between British Columbia and distant jurisdictions or have **disjunct** seasonal distributions.

Using data from NatureServe and WildSpecies[a,219] the status of 140 species of vertebrates (amphibians, birds, freshwater fish, mammals, and reptiles and turtles) of conservation concern in B.C. was compared with their status in adjacent jurisdictions (Table 19). This analysis was limited to vertebrate species because they are the most consistently assessed across jurisdictions and have the greatest amount of data to support the assessments conducted.

Taxonomic groups with the highest numbers of shared species are those that are most mobile, such as birds. The jurisdictions with the highest numbers of shared species are those located south of B.C. This corresponds with the higher levels of species richness in the southern parts of the province.

Most species have been assessed in at least one neighbouring jurisdiction, but only 20% of species are not of conservation concern in any jurisdiction other than B.C., although 60% are not of conservation concern in at

[a] WildSpecies data were used to identify conservation status for species in the Northwest Territories that were not found in the NatureServe database.

least one neighbouring jurisdiction. More than 35% of the species are of conservation concern in all neighbouring jurisdictions in which they are present and have been assessed. Each jurisdiction has some species that are present, but have not been assessed.

Of particular interest are the recorded occurrences of species that are of conservation concern in B.C., yet secure in other jurisdictions. For example, the sage thrasher (*Oreoscoptes montanus*) is critically imperilled in B.C. and secure in Idaho. This may be the result of a common species from an adjacent jurisdiction expanding its range into B.C., where it establishes small, discrete populations that are of greater conservation concern than the core population.[220] Other possible explanations include species being historically and naturally rare in B.C., or species being impacted by threats in B.C. that are not as prevalent in adjacent jurisdictions.

Several species that are presumed or possibly extirpated (SX, SH) in B.C. are found in Washington, but are all either critically imperilled, imperilled or possibly extirpated in that jurisdiction.[221] Only two of the species that are presumed or possibly extirpated in B.C. are found in jurisdictions other than Washington. Both are found in Montana and Idaho, where they are either of conservation concern or unranked.

TABLE 19. NUMBER OF VERTEBRATE SPECIES OF PROVINCIAL CONSERVATION CONCERN IN B.C. THAT ARE SHARED WITH ADJACENT JURISDICTIONS.

TAXONOMIC GROUP	BRITISH COLUMBIA	ALBERTA	YUKON TERRITORY	NORTHWEST TERRITORIES	ALASKA	MONTANA	IDAHO	WASHINGTON	NOT OF CONSERVATION CONCERN IN ANY ADJACENT JURISDICTION*	MIXED CONSERVATION STATUS IN ADJACENT JURISDICTIONS*	OF CONSERVATION CONCERN IN ALL ADJACENT JURISDICTIONS*	ENDEMIC TO B.C.	NOT ENDEMIC BUT NOT ASSESSED IN ANY ADJACENT JURISDICTION
Amphibians	9	2	0	1(1)	0	4	5	8(1)	4	2	3	0	0
Birds	70	45(8)	27(4)	29(6)	37(1)	43(7)	43(6)	59(5)	8	38	24	0	0
Freshwater Fish	23	10(1)	4(4)	11(1)	10(1)	9(2)	8(2)	10	9	6	5	1	2
Mammals	29	13(1)	7	7(1)	9(4)	20	18(1)	25(2)	5	8	15	1	0
Reptiles and Turtles	9	3(1)	0	0	0	4	7(1)	9	2	4	3	0	0
Total	**140**	**73**	**38**	**48**	**56**	**80**	**81**	**111**	**28**	**58**	**50**	**2**	**2**

SOURCE: Adapted from Ohlson, D. 2007. Overlap: Investigations and Review. Biodiversity BC, Victoria, BC. 55pp.
NOTES: Numbers in parentheses are the number of species occurring in the jurisdiction that have not been assessed.
*Does not include jurisdictions where the species are known to occur but have not been assessed.

2.3.4.3 MIGRATORY SPECIES IN B.C.

Many B.C. species migrate to areas outside the province during their life cycle. However, their migrations are often poorly understood. Many migrating species are particularly vulnerable to local threats at those times of the year when they are concentrated in large numbers or when many individuals pass through particular areas.

The taxonomic group with the largest known number of migratory species is birds. Migrants include shorebirds, waterfowl, land birds and water birds. B.C. is important as both a breeding area and migration area, with 306 species that breed in the province, but spend portions of their life elsewhere.[222,223] For example, Hammond's flycatcher (*Empidonax hammondii*), MacGillivray's warbler (*Oporornis tolmiei*) and the western tanager (*Piranga ludoviciana*) breed in many areas of B.C., but winter in southern regions, from Baja California to Costa Rica. Other species, such as Wilson's phalarope (*Phalaropus tricolor*) and Swainson's hawk (*Buteo swainsoni*) travel even farther, to winter in southern South America.

B.C.'s location along the Pacific Flyway, which extends from Alaska to Mexico, makes it important as a wintering, migratory stopover or breeding area for many migratory birds. Significant global or continental populations of migrating shorebirds in B.C. include the black turnstone (*Arenaria melanocephala*), dunlin (*Calidris alpina*), long-billed dowitcher (*Limnodromus scolopaceus*), rock sandpiper (*Calidris ptilocnemis*), surfbird (*Aphriza virgata*) and western sandpiper (*Calidris mauri*).[224] The Fraser River delta is a key area of species concentration, with up to 1.2 million sandpipers and 600,000 dunlins migrating through each year (see Section 2.5.2.1-A, p. 137),[225] as is the east coast of Vancouver Island.[226] Currently, approximately 25% of the North American trumpeter swan (*Cygnus buccinator*) population uses the Pacific Flyway to migrate to and winter on the east coast of Vancouver Island.[a,227] Significant populations of geese, including 50% of the Wrangel Island population of the snow goose (*Chen caerulescens*), and approximately 2,000 western high-Arctic brant and black brant (*Branta bernicla nigricans*), use the Pacific Flyway to access key estuaries and mudflats such as those found in Boundary Bay and the Parksville-Qualicum area.[228] Thayer's gulls (*Larus thayeri*) also breed in the Arctic and winter along the Pacific coast.[229]

The largest wintering population of birds of prey in Canada is found in the Fraser River delta.[230] Various duck species winter along the coast, especially north of Prince Rupert, on Haida Gwaii/Queen Charlotte Islands and near estuaries in the Fraser River delta and Baynes Sound. The Interior Plateau supports the highest densities of breeding waterfowl in B.C. (approximately 420,000 breeding ducks) and serves as an important stopover point for migrating waterfowl.[231] Sandhill cranes (*Grus canadensis*) use stopover sites in B.C. on the way to their Alaska breeding grounds, and also breed in several locations in the province.[232]

[a] Until recently, the east coast of Vancouver Island supported 50% of the continental population of the trumpeter swan. The percentage has gradually declined with the extension of this species' range into Washington State (A. Breault, Environment Canada, personal communication).

Migratory butterflies that breed in B.C. and winter in the southwestern U.S. and Mexico include the monarch (*Danaus plexippus*), painted lady (*Vanessa cardui*) and west coast lady (*V. annabella*).[233] Some bats, such as the hoary bat (*Lasiurus cinereus*), are thought to breed in B.C. and winter outside the province.[234] The green sturgeon (*Acipenser medirostris*) breeds in rivers in northern California and Oregon, but migrates in small numbers to the west coast of Vancouver Island and to the Skeena River.[235] Historically, this species was found in the Fraser River, but there is no evidence that it spawned in B.C. Salmon are also migratory, as they lay eggs and rear within freshwater systems and, during the marine phase of their life, many individuals migrate outside B.C. waters to feed for several years before returning to B.C. streams to spawn.

TEXT BOX 10. WESTERN SANDPIPER: A FAR-RANGING SPECIES

The western sandpiper breeds in western Alaska and eastern Siberia, but the primary migration route for almost the entire world population of this species incorporates the B.C. coast.[236] In the fall, the birds migrate south along the Pacific Flyway, pausing at major stopover sites in the Kachemak lowlands and Copper River delta in Alaska, the Stikine, Copper and Fraser River deltas in B.C., Gray's Harbor, Washington and San Francisco Bay, California, on their way to overwintering sites in the coastal southeastern U.S., northwestern Mexico and Panama Bay, and even as far south as northern Peru.[237] During the northward migration back to Alaska in the spring, western sandpipers can number up to one million on a single day at Canadian and U.S. sites, aggregations that are 10 to 15 times larger than during the fall migration.

Western sandpipers use muddy intertidal habitats along their migration route, consuming seven times their body weight per day.[238] Migrating sandpipers are dependent on specific stopover sites where **biofilm**, which accounts for 50% of their daily energy budget, is available on mud flats.[239] This makes them vulnerable to changes in environmental conditions. Furthermore, this species has a relatively low rate of reproduction, making it difficult for populations to recover from impacts.

Threats, both localized and widespread, include wetland conversion and degradation, runoff of agricultural pesticides and industrial pollutants, oil spills and sea-level rise resulting from climate change, which could inundate intertidal wetlands or alter wetland ecosystems through saltwater incursion. Some threats to breeding groups, stopover sites or overwintering sites are outside B.C.'s control. The U.S. Shorebird Conservation Plan considers this to be a species of moderate concern with known or potential threats.[240]

Most of the global population of the western sandpiper *(Calidris mauri)* migrates along B.C.'s coast every year.
PHOTO: TOM MUNSON.

2.3.5 DATA GAPS

Appendix B (p.232) summarizes the state of knowledge and information gaps for the major taxa of native terrestrial and freshwater organisms in British Columbia, focusing on the availability of up-to-date species checklists, handbooks or systematic monographs, computerized geo-referenced distributional databases, and taxonomic/systematic expertise at the local (i.e., B.C.) level.

For many taxa, up-to-date species checklists are lacking and there are few handbooks or systematic monographs available.

There are computerized geo-referenced occurrence (point) databases for vertebrates, vascular plants and a few insect groups (e.g., butterflies, dragonflies and damselflies), but these are biased by being concentrated close to roads. Many parts of B.C. have never been surveyed or have not been surveyed for decades. Species distribution mapping is unavailable for all but a handful of species. These limitations affect the completeness of the species richness analyses in this report.

There is little local taxonomic expertise and many existing experts have retired and not been replaced. As elsewhere in the world, an 'extinction of experience' is occurring.[241] This is particularly significant for the conservation of invertebrate and non-vascular plant species that have not yet been documented in the province or described scientifically; the number of such species is believed to be large.

Except for birds, large mammals and certain salmon stocks, there is no ongoing monitoring of distribution or population trends. As a result it will be difficult to detect and respond to these changes in a timely fashion.

Conservation status has not been assessed for the majority of B.C. species, with only approximately 3,800 having been assessed out of an estimated total of 50,000,[242] not including single-celled organisms. For those species that have been assessed, global status often has not been updated for over a decade.[243] Information on the global range of most species is very coarse, which limits the ability to accurately estimate the proportion of the global range that occurs in B.C. Some species have been assessed in B.C., but not in neighbouring jurisdictions, making inter-jurisdictional comparisons of species status difficult.

2.4 Genetic Diversity in British Columbia

Genes are the functional units of heredity, and genetic diversity permits species to adapt to changing environments and continue to participate in life's processes (see Section 1.1, p. 5). By limiting movement between populations and creating varied ecosystems, British Columbia's complex topography, climate and glacial

Genetic data helps biologists identify distinctive lineages, which may not be apparent from observations of size, shape, appearance or behaviour.
PHOTO: BRUCE MCLELLAN.

history have facilitated the evolution of a wide variety of local **adaptations**. In B.C., many species are made up of numerous geographically separate subspecies or populations, which each have a distinctive genetic makeup and characteristic appearance, environmental tolerances and/or behaviour.[244,245,246,247,248,249] Recently, some of these subspecies have been shown to represent true species, that are endemic to the region,[250] and it is certain that additional variation below the species level exists, particularly in taxonomic groups that have so far received little attention from science (e.g., **bryophytes**, invertebrates, lichens). Even in well-studied plant and animal groups, some species remain undescribed.

Many subspecies that were historically isolated in coastal B.C., Beringia or the Rocky Mountains diverged from ancestral types as glaciers advanced, then later radiated out from these historic refugia to hybridize with ancestral forms that were previously restricted to the south and east (see Section 1.4, p. 15). [251,252,253,254,255] **Hybrid suture zones** (see Section 2.4.1.4, p. 82) can represent regions of very high genetic diversity and rapid evolution, depending on their degree of subspecies differentiation, the frequency of hybridization and the success of the hybrids produced.[256]

Because human activities modify natural landscapes and species distributions, humans may also influence the rate of evolution and the persistence of populations that are uniquely adapted to the B.C. environment.

Although more than 60 species inhabiting B.C. have been subjects of genetic analysis,[257] practical limits on research and the very large number of unstudied species generally preclude genetic classification below the species level. Consequently, biologists use simplifying concepts and measures to establish rules of thumb for conserving genetic diversity and use genetic data (where it exists) along with observations of size, shape, appearance and behaviour (collectively called **phenotype**) to identify distinctive lineages. Although our knowledge of genetic diversity is limited, it is vital to any discussion of biodiversity.

WHAT IS GENETIC VARIATION?

Genetic variation can be thought of as a species' tool kit for life, with some genes being more or less useful in current environments (adaptive genetic variation) and others having no current influence, despite being potentially influential in the future or past (neutral genetic variation). Genetically diverse populations – those with well-equipped 'toolboxes' – are thought to be best able to survive, to pass on adaptive traits to descendents and to contribute positively to their persistence. This may be particularly true for populations at the periphery of a species' range, where organisms are more likely to encounter, and potentially adapt, to novel environmental challenges, such as those associated with climate change.[258,259]

Genes vary in their frequency of occurrence in populations and their interaction with companion genes. Unique combinations of genes result in genetic diversity. In nature, new genes arise regularly via mutation, with beneficial, deleterious or no detectable effect on the individuals carrying them. At the population level, whether or not mutations persist depends on their effect on individuals and the size and degree of isolation of populations. Conserving genetic diversity at the population level is an overall goal of biodiversity conservation because genetic variation affects the adaptability and viability of organisms, populations and species.[260,261] This is particularly important in the face of climate change.[262]

GENETIC VARIATION, DIVERGENCE AND POPULATION SIZE

Larger populations typically retain more genetic diversity than smaller ones,[263] but diversity also depends on history, population distribution and life history traits of species. The actual number of individuals in a population, referred to as the **census population size**, tends to overestimate genetic diversity because many factors act to reduce the variety of genes inherited by successive generations. Thus, geneticists focus on **effective population size** (N_e): an estimate based on the number of individuals contributing genes to future generations and the rate at which populations lose genetic variation over time. Factors such as population sex ratio, mating system, population bottlenecks, growth rate, inbreeding and population fragmentation can all influence the N_e and, in doing so, affect the ability of a population to retain genetic variation.[264]

Genetic patterns in isolated populations are governed by the forces of mutation, drift and selection. N_e influences how genetic variation is retained in populations and, potentially, how effectively populations respond to environmental change. Ideally, natural selection removes deleterious genes and favours beneficial ones, leading to changes in gene frequency (i.e., the frequency of a gene in a given population). This process, also known as adaptation, can act rapidly in small, isolated populations, such as those on actual islands or habitat islands, and on populations at the edge of a species' range. It has undoubtedly contributed to the divergence of isolated populations inhabiting coastal archipelagos, mountain ranges, drainages and specialized habitats (e.g., **karst**, bogs) in B.C. For these reasons, populations that have been isolated for many generations often contain unique genetic diversity. Genetic diversity can be lost if human activities facilitate dispersal between genetically differentiated populations.

Small population size also facilitates reductions in genetic diversity and population viability, particularly in species that were once widely distributed, but have become isolated due to habitat loss and fragmentation, or whose numbers have been greatly reduced due to exploitation.[265] B.C. species that have experienced severe population fragmentation and decline include the Vancouver Island marmot and many species associated with Garry oak ecosystems or inhabiting dammed rivers. Reductions in genetic diversity become more likely in such species because random effects may eliminate beneficial genes from, or embed deleterious genes in, small populations.

Overall, N_e is the single most important factor affecting genetic diversity in populations, and is therefore a key parameter in making decisions related to gene conservation. Studies of natural populations suggest that N_e averages about 11% of the census population size.[266] Thus, in a population of 300 individuals, the effective population size is about 33 individuals. Long-term viability analyses indicate that minimum N_e ranges from 500 to 5,000,[267,268] implying census populations of 5,000 to 50,000 individuals.[269]

Populations or individual **genotypes** from one area may be genetically incompatible with local environmental conditions elsewhere. For example, in B.C., a long history of 'common garden' research trials on conifers, in which seeds from different regions are planted together, has shown that genotype can dramatically affect performance.

2.4.1 GENETIC DIVERSITY CONCEPTS AND B.C. EXAMPLES

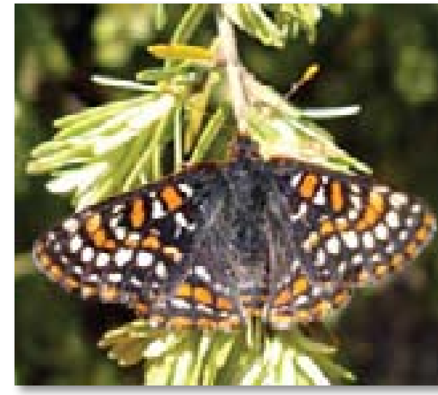
Because genetic changes occur most rapidly in isolated populations, most studies of genetic variation in B.C. have focused on areas of historic isolation and novel environments, including islands, glacial refugia and areas at the edges of species ranges. Several areas of potential special interest are considered below, with the caveat that most B.C. taxa were scientifically described decades ago, when underlying evolutionary differences were less well known than they are currently.

2.4.1.1 GEOGRAPHICALLY MARGINAL POPULATIONS

There is growing evidence that geographically marginal populations (also known as peripheral populations) are often genetically different from populations at the core of the species range.[270] Peripheral populations of Sitka spruce, for example, are known repositories for rare **alleles** (alternative forms of a gene) and locally adapted types.[271] Due to B.C.'s large size and biophysical variability, many species exist as peripheral or marginal populations within the province, potentially representing evolutionarily significant lineages. Species that are at the edge of their range in B.C. may have the core of their range to the north, south or west of the province.

Distributional data is available for 3,841 B.C. taxa; of these, 2,963 species (78%) have <10% of their range, area or population within the province (see Table 16, p. 61).[272] Some of these geographically marginal populations show clearly defined genetic variation and are of conservation concern. They include several species confined to the South Okanagan–Similkameen region (e.g., sage thrasher, Mormon metalmark

[*Apodemia mormo*], Behr's hairstreak [*Satyrium behrii*]) and the Gulf Islands (e.g., propertius duskywing [*Erynnis propertius*], Edith's checkerspot [*Euphydryas editha taylori*]). Peripheral species or marginal populations in northern B.C. include two butterflies: the eastern pine elfin (*Callophrys niphon*), which is confined to the northeast provincially, and the phoebus parnassian (*Parnassius phoebus*), which is found in Siberia, Alaska and the western Yukon, as well as the northwestern corner of B.C.[273]



The *taylori* subspecies of Edith's checkerspot (*Euphydryas editha taylori*) is a geographically marginal subspecies, found on the Gulf Islands. PHOTO: JENNIFER HERON.

2.4.1.2 ISLAND AND DISJUNCT POPULATIONS

In many taxa, island populations are recognized as subspecies due to **phenotypic** differences and geographic isolation. Similarly, disjunct populations, which are isolated either by a geographical or environmental barrier within a former contiguous range or by long-distance dispersal, can be subspecies.[274] Many island and disjunct subspecies are endemic to B.C. and a number of them are of conservation concern (Table 20).

The Kermode or spirit bear is an impressive example of the insular effect on genetically based traits (see Figure 3, p. 7). The trait known as kermodism is expressed as a white coat displayed by any bear that carries two copies of a certain recessive allele. Genetic analyses indicate that most coastal black bears, regardless of colour, have descended from populations that were once restricted to glacial refugia and were the source of the recessive allele; those populations now mix with continental lineages, which lack this trait.[275] However, the white individuals are most common on islands. The high frequency of this trait on coastal islands (perhaps 25% of individuals in some populations) is consistent with the idea that water-barriers to dispersal and small population size have acted to increase its frequency via random **genetic drift**.[276]

TABLE 20. B.C. ENDEMIC TAXA BELOW THE SPECIES LEVEL THAT ARE OF PROVINCIAL CONSERVATION CONCERN.

SCIENTIFIC NAME	COMMON NAME	PROVINCIAL CONSERVATION STATUS
Birds		
Aegolius acadicus brooksi	Northern saw-whet owl, *brooksi* subspecies	Imperilled
Cyanocitta stelleri carlottae	Steller's jay, *carlottae* subspecies	Vulnerable
Glaucidium gnoma swarthi	Northern pygmy-owl, *swarthi* subspecies	Vulnerable
Lagopus leucura saxatilis	White-tailed ptarmigan, *saxatilis* subspecies	Vulnerable
Picoides villosus picoideus	Hairy woodpecker, *picoideus* subspecies	Vulnerable
Pinicola enucleator carlottae	Pine grosbeak, *carlottae* subspecies	Vulnerable (breeding pop)

CONTINUED ON PAGE 76

TABLE 20. CONTINUED

SCIENTIFIC NAME	COMMON NAME	PROVINCIAL CONSERVATION STATUS
Freshwater Fish		
Acipenser transmontanus pop. 3	White sturgeon (Nechako River population)	Critically imperilled
Acipenser transmontanus pop. 4	White sturgeon (Lower Fraser River population)	Imperilled
Acipenser transmontanus pop. 6	White sturgeon (Middle Fraser River population)	Critically imperilled
Coregonus sp. 1	Dragon Lake limnetic whitefish	Extinct
Coregonus sp. 1	Dragon Lake benthic whitefish	Extinct
Cottus sp. 2	Cultus pygmy sculpin	Critically imperilled
Gasterosteus aculeatus pop. 1	Charlotte unarmoured stickleback	Imperilled
Gasterosteus sp. 1	Giant black stickleback	Critically imperilled
Gasterosteus sp. 12	Hadley Lake limnetic stickleback	Extinct
Gasterosteus sp. 13	Hadley Lake benthic stickleback	Extinct
Gasterosteus sp. 16	Vananda Creek limnetic stickleback	Critically imperilled
Gasterosteus sp. 17	Vananda Creek benthic stickleback	Critically imperilled
Gasterosteus sp. 18	Misty Lake "lake" stickleback	Critically imperilled
Gasterosteus sp. 19	Misty Lake "stream" stickleback	Critically imperilled
Gasterosteus sp. 2	Enos Lake limnetic stickleback	Critically imperilled
Gasterosteus sp. 3	Enos Lake benthic stickleback	Critically imperilled
Gasterosteus sp. 4	Paxton Lake limnetic stickleback	Critically imperilled
Gasterosteus sp. 5	Paxton Lake benthic stickleback	Critically imperilled
Lampetra richardsoni pop. 1	Western brook lamprey (Morrison Creek population)	Critically imperilled
Spirinchus sp. 1 Critically imperilled		Pygmy longfin smelt
Thymallus arcticus pop. 1	Arctic grayling (Williston Watershed population)	Critically imperilled
Mammals		
Gulo gulo vancouverensis	Wolverine, *vancouverensis* subspecies	Possibly extinct
Microtus townsendii cowani	Townsend's vole, *cowani* subspecies	Critically imperilled
Mustela erminea anguinae	Ermine, *anguinae* subspecies	Vulnerable
Mustela erminea haidarum	Ermine, *haidarum* subspecies	Imperilled
Neotamias minimus selkirki	Least chipmunk, *selkirki* subspecies	Critically imperilled
Sorex palustris brooksi	American water shrew, *brooks* subspecies	Imperilled

CONTINUED ON PAGE 77

TABLE 20. CONTINUED

SCIENTIFIC NAME	COMMON NAME	PROVINCIAL CONSERVATION STATUS
Butterflies		
Plebejus saepiolus insulanus	Greenish blue, *insulanus* subspecies	Possibly extinct
Vascular Plants		
Viola biflora ssp. *carlottae*	Queen Charlotte twinflower violet	Vulnerable
Lloydia serotina var. *flava*	Alp lily	Vulnerable
Trillium ovatum var. *hibbersonii*	Dwarf trillium	Critically imperilled

SOURCE: Prepared for this report with data from the B.C. Conservation Data Centre.

Both Haida Gwaii/Queen Charlotte Islands and Vancouver Island are home to a wide array of subspecies. In northern B.C., Hecate Strait has been a formidable barrier to dispersal, contributing to the distinctiveness of several bird and mammal species on Haida Gwaii/Queen Charlotte Islands and adding to the historic importance of these islands as a glacial refugium (see Section 2.4.1.3, p. 78). Dawson caribou (*Rangifer tarandus dawsoni*) historically inhabited Haida Gwaii/Queen Charlotte Islands, but this small forest caribou subspecies was last seen in 1908.[277] Other mammal subspecies unique to the archipelago include the largest subspecies of black bear (*Ursus americanus carlottae*) and a subspecies of ermine (*Mustela erminea haidarum*) that was once relatively common, but is now thought to be extinct or reduced to very low numbers. Notable birds found on these islands include subspecies of the Steller's jay (*Cyanocitta stelleri carlottae*), hairy woodpecker (*Picides villosus picoideus*), pine grosbeak (*Pinicola enucleator carlottae*) and northern saw-whet owl (*Aegolius acadicus brooksi*).

Endemic species and subspecies found on Vancouver Island include the critically imperilled Vancouver Island marmot, the Vancouver Island wolverine (*Gulo gulo vancouverensis*), which has not been seen since 1982, a white-tailed ptarmigan subspecies (*Lagopus leucura saxatilis*) and a northern pygmy-owl subspecies (*Glaucidium gnoma swarthi*). A number of butterfly subspecies and endemic plants are also found on Vancouver Island.

Although genetic comparisons of species in this region remain scarce, recent studies of the northwestern and North American deermouse (*Peromyscus keenii* and *P. maniculatus*, respectively), both resident in coastal B.C., suggest that glacial history and small effective population sizes have led to substantial genetic differentiation between populations. This raises the possibility that additional taxa of B.C. plants and animals remain undescribed, particularly on coastal islands and within many sedentary species of plants, vertebrates, and invertebrates (Text box 11).

The two forms of the winter wren (*Troglodytes troglodytes*) found in B.C. are difficult to differentiate, except by their songs, without genetic analysis.
PHOTO: DARREN IRWIN.

TEXT BOX 11. CRYPTIC SPECIES: DIVERSITY HIDING IN PLAIN SIGHT

The advent of genetic analysis has begun to reveal a large number of 'cryptic' species. These are cases where what was previously considered to be a single species is found to actually be a complex of two, and sometimes more, species that are very similar in appearance.

Species do not have to be small to be cryptic. Recently, the African elephant was recognized as two genetically distinct, non-interbreeding species, one retaining the name African elephant (*Loxodonta africana*) and the other now known as the African forest elephant (*Loxodonta cyclotis*).[278] In B.C., the seaside juniper (*Juniperus maritima*) was recently described based on genetic and other information; it was previously included in the Rocky Mountain juniper (*Juniperus scopulorum*).[279] Another example of this hidden diversity is the possible division of the winter wren (*Troglodytes troglodytes*) into two species with a contact zone in northeastern B.C.[280]

Further genetic analysis is very likely to identify more cryptic species and thereby add to the number of recognized species in B.C.

2.4.1.3 GLACIAL REFUGIA

Haida Gwaii/Queen Charlotte Islands and the Brooks Peninsula on Vancouver Island, two of the most prominent areas identified as glacial refugia within B.C., provide homes to a significant component of the province's genetic biodiversity. For example, Haida Gwaii/Queen Charlotte Islands, which encompasses 250 islands, has been termed 'the Galapagos of the North' due to the archipelago's high levels of biodiversity and **relict species**, including numerous endemic species: five vascular plant species, four insects, two **liverworts** (hepatics) and five mosses. However, the isolation and ecological novelty that gave rise to such diversity also makes these areas vulnerable, and both areas have been significantly impacted by alien species. Since Sitka black-tailed deer were introduced to Haida Gwaii/Queen Charlotte Islands in the late 1800s, they have dramatically altered the ecology of entire rainforest ecosystems, with deleterious impacts on many species (see Section 1.1.2, p. 7).[281] In addition to introducing alien species, human activities have the potential to disrupt island populations by reducing historic barriers to dispersal between divergent populations, and converting and fragmenting significant habitats. When activities lead to demographic decline or to the dilution or loss of locally adapted traits, extinction risk increases.

Much of the species-level diversity evident in B.C. freshwater fish is a product of Pleistocene range fragmentation and genetic divergence, followed by recolonization from refugia.[282] For example, the Salish sucker (*Catostomus* sp. 4) and Nooksack dace (*Rhinichthys* sp. 4) may be the only Canadian representatives from the

Chehalis refugium, which was centred around southern Puget Sound during the most recent glacial maximum[283] (Text box 12), although a recent study of the Olympic shrew (*Sorex rohweri*)[a] indicates colonization from the same refugium.[284] The Salish sucker has no formal taxonomic status, but is identified as an **evolutionarily significant unit**. Similarly, the Nooksack dace has not been given a formal taxonomic rank, since it is not yet clear whether it is a true species or is a subspecies of the widespread longnose dace (*Rhinichthys cataractae*).[285] Both the Nooksack dace and the Salish sucker are of conservation concern. Another example is the pygmy whitefish (*Prosopium coulterii*). While scattered populations of pygmy whitefish are found across northern North America, usually in deep, nutrient-poor lakes, two nutrient-rich B.C. lakes are home to a 'giant' form that is found nowhere else.

Although glacial retreat restored **connectivity** between many populations of plants and animals, it isolated others as the land rebounded from under the immense weight of the ice. The rising land mass confined some anadromous fish, such as the Pacific lamprey (*Lampetra tridentata*) and longfin smelt (*Spirinchus thaleichthys*), to freshwater locations, resulting in rapid divergence of new forms. In some cases, this process produced species endemic to British Columbia. A particularly well-researched example involves the complex genetics of sticklebacks in six lakes on three islands in the Strait of Georgia. Each lake has given rise to two forms of sticklebacks: benthics, which are stout and wide-mouthed and forage at lake margins; and limnetics, which are slender and slim-mouthed and forage in the open waters of the lake. The two forms carry different alleles and rarely hybridized until recent human influences altered these communities. The genetic differences evident in these species are particularly interesting because they appear to have arisen very recently (since the last ice age) from a common ancestor and in parallel in all three lakes. Because these differences represent adaptive genetic variation that affects individual survival and reproduction and, therefore, population persistence, the forms are each recognized as endemic taxa.[286] Such patterns of divergence provide a remarkable snapshot of evolution in action.

Recent DNA studies of the alpine plant, mountain sorrel, suggest the existence of one or more refugia in the mountains of northern B.C.[287] Other genetic research shows that southern red-backed voles (*Myodes gapperi*) at higher altitudes are more closely related to central continental populations than to eastern or western populations.[288]

Haida Gwaii/Queen Charlotte Islands (one of the major glacial refugia in B.C.) has been called 'the Galapagos of the North' because of its unique biodiversity. PHOTO: JASON VERSCHOOR.

[a] There has not been an official publication on the common name. An alternative possibility is Rohwer's shrew.

TEXT BOX 12. **FISH AND GLACIAL REFUGIA**[289]

From the four corners of the province, more than 65 fish species recolonized B.C. after the last glaciation, originating from three major refugia: the Pacific (including the Chehalis and Columbia minor refugia), the Great Plains, and the Beringian (including the Nahanni) (Figure 20) . Twenty-four of these species (36%) came from more than one unglaciated area. Therefore, much of the province's within-species diversity in fish is due to range fragmentation as a result of glaciation, followed by genetic divergence and subsequent recolonization from different refugia.

The Pacific refugium was the largest contributor to B.C. fish fauna, with fish using two dispersal routes: salt water and fresh water. Species that dispersed by sea included lampreys (*Lampetra* spp.), sturgeons (*Acipenser* spp.), smelts (*Spirinchus* spp.), trout and salmon (*Oncorhynchus* spp.) and sticklebacks. Those that were restricted to freshwater habitats and required drainage connections included northern pikeminnow (*Ptychocheilus oregonensis*) and suckers (*Catostomus* spp.). Species that could tolerate harsher conditions were able to move from the Columbia refugium to northern areas such as the Nass, Skeena and Peace river drainages, while species unable to tolerate those conditions were able to colonize only the Fraser River system.

One of the minor refugia, the Chehalis, provided a dispersal route from Puget Sound in Washington, allowing two saltwater-intolerant fish, the Salish sucker and Nooksack dace, to disperse into the lower Fraser River valley.

With the retreat of the glaciers, fish species migrated through the Columbia system into several large glacial lakes (including Kamloops, Thompson and Shuswap lakes), allowing species such as the peamouth (*Mylocheilus caurinus*), longnose dace and northern pikeminnow to disperse farther north. *Oncorhynchus* fossils found near Savona in Kamloops have been dated at 18,000 years ago,[290] indicating that salmon existed in the province 3,000 to 4,000 years before the glacial maximum. The connection between these lakes and the Columbia River was later severed and the lakes then drained into the Fraser River system,[291] eliminating the opportunity for other species from the Columbia River to colonize farther north. In fact, coho salmon that now occur in the interior reaches of the Fraser River came from the Columbia River basin[292] and have sufficient genetic differences to distinguish them from coho salmon in the lower Fraser River.[293]

Thirteen thousand years ago, a corridor between the Missouri River system and the lower Peace River[294] allowed species from the Great Plains refugium, such as goldeye (*Hiodon alosoides*) and flathead chub (*Platygobio gracilis*), to colonize northeastern B.C. After this period, intermittent connections with other drainages, such as the Fraser River drainage, allowed colonization by some other Great Plains species (e.g., white sucker [*Catostomus commersonii*], lake whitefish [*Coregonus clupeaformis*] and brassy minnow [*Hybognathus hankinsoni*]). Another temporary connection to northeastern B.C. occurred from the Mississippi River system through the Canadian prairies (Lake Agassiz in Saskatchewan and Manitoba), and from the Northwest Territories to the Beaufort Sea. Although the Nahanni refugium in northeastern B.C. is not accepted by all researchers,[295] there is evidence that it was a source of colonizing lake whitefish[296] and lake trout (*Salvelinus namaycush*).[297]

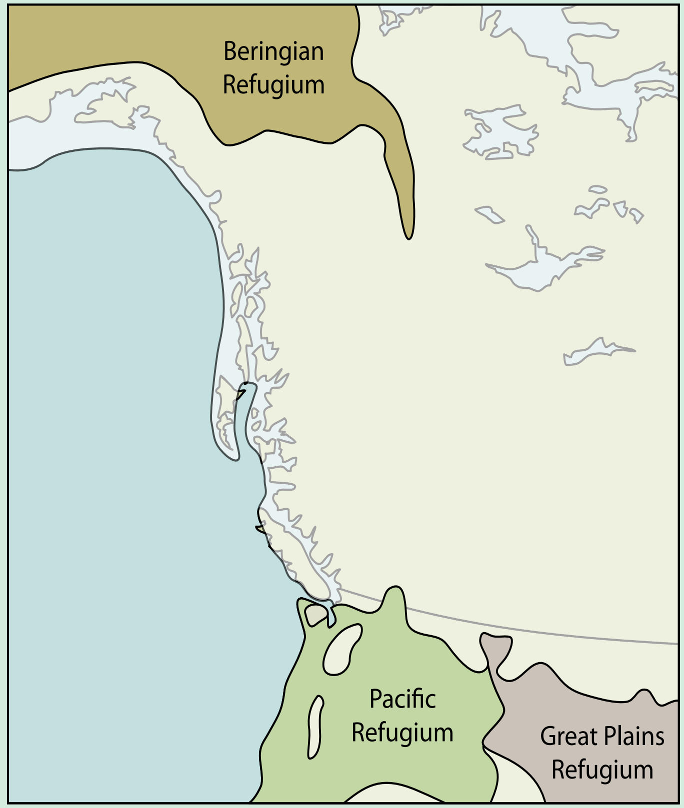
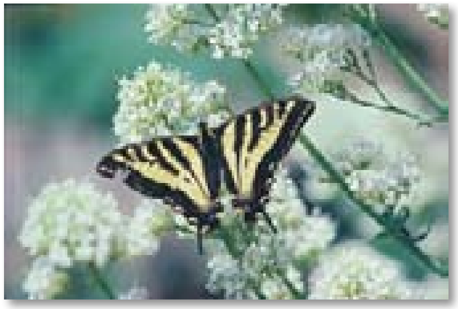


FIGURE 20: **The three major ice-free refugia from which freshwater fish recolonized British Columbia.**
SOURCE: McPhail, J.D. 2007. Freshwater Fishes of British Columbia. University of Alberta Press, Edmonton, AB. 620pp.

Compared to the Pacific and Great Plains refugia, the Beringian refugium contributed a relatively small number of species. There were some limited opportunities for species to disperse to the Liard and Stikine river systems from the Yukon and portions of Alaska. Species that were able to colonize during this short period include the round whitefish (*Prosopium cylindraceum*) and Arctic grayling (*Thymallus arcticus*).[298] Beringian refugium species that were able to use marine environments, such as salmon, colonized southward, while salmon from the Pacific refugium moved northward.[299]



Two species of tiger swallowtail, the western (*Papilio rutulus*), pictured here, and the Canadian (*Papilio canadensis*), are only known to hybridize in the Okanagan and Kootenay valleys.
PHOTO: NEIL K. DAWE.

2.4.1.4 MAJOR HYBRIDIZATION ZONES

Hybrids often hold a tenuous place in conservation because, once they are detected, the appropriateness of the 'species' designation for the two forms involved is often questioned. Although hybridization is a potentially serious problem for populations with unique evolutionary histories, many naturally occurring hybrid zones are known to be stable in ecological timeframes, perhaps contributing novel lineages and species in evolutionary time. For plants in particular, hybridization is an important process for creating new species[300,301] Hybrid zones are therefore fascinating laboratories for evolutionary study and potential hot spots of genetic variation and local adaptation.

Research suggests that in North America there are 13 hybrid suture zones,[302] where divergent taxonomic groups overlap and some species hybridize as a result of landscape change and the historic expansion and contraction of species ranges. Although not well studied, B.C. likely has the highest density of these zones in Canada. One major suture zone extends from the southeast corner of the province to the central interior, representing the channelling effects of mountain ranges on species as they radiated across the landscape during global shifts in climate.[303] Several 'superspecies' (complexes of closely related species) are found in this region; many of them rarely hybridize, but some do so extensively. For example, the northern flicker (*Colaptes auratus*) occurs across North America, but in a band stretching from B.C. to Texas, 95% of the flickers are hybrids between the red-shafted and yellow-shafted subspecies or between the red-shafted subspecies and the closely related gilded flicker (*Colaptes chrysoides*).[304]

Another species that provides insights into the role of continental divides in divergence and **speciation** is Swainson's thrush (*Catharus ustulatus*), which has two distinct populations, one coastal and one continental, with both populations found in B.C.[305] A similar east-west separation occurs amongst other populations of land birds, such as Wilson's warbler (*Wilsonia pusilla*).[306] The Okanagan and Kootenay valleys are the only place in North America where two species of tiger swallowtails (*Papilio* spp.) have overlapping ranges and are known to hybridize.[307] For freshwater fish, a major hybridization zone exists in the lower Peace River system, which provided a postglacial dispersal corridor where several western populations crossed and hybridized with eastern populations.[308]

2.4.2 STATUS OF BRITISH COLUMBIA TAXA BELOW THE SPECIES LEVEL

Only about 60 B.C. taxa have been the subject of peer-reviewed genetic studies and those studies have focused mainly on evolutionary history, population genetic structure, geography of evolutionary lineages and fine-scale effects of forest practices on genetics and hybridization.[309] Eight of the studies (four on fish, two on birds and one each on a mammal and an invertebrate) recognized evolutionarily significant units below the species level.

Table 21 summarizes the conservation status of 457 B.C. taxa below species level and shows the number that have the majority of their global range in B.C. However, it provides only a limited picture of the status of genetic diversity in the province, as a reliable list of taxa below the species level is not available for most groups and, of those that are known, many have not been assessed. The lack of described taxa below the species level does not necessarily indicate a lack of genetic differentiation at that level. Conservation status rankings are explained in Section 2.3.2 (p. 51) and proportion of global range is explained in Section 2.3.3 (p. 61).

Eleven subspecies or populations have been assessed as extinct or extirpated (Table 22), including three birds, four freshwater fish, two mammals, one reptile and one butterfly.

TABLE 21. NUMBER OF TAXA BELOW THE SPECIES LEVEL OF GLOBAL AND PROVINCIAL CONSERVATION CONCERN, AS WELL AS THOSE THAT HAVE A MAJORITY OF THEIR GLOBAL RANGE IN B.C.

TAXONOMIC GROUP	NUMBER OF TAXA OF GLOBAL CONSERVATION CONCERN	NUMBER OF TAXA OF PROVINCIAL CONSERVATION CONCERN	NUMBER OF TAXA WITH MAJORITY OF GLOBAL RANGE, DISTRIBUTION OR POPULATION IN B.C.
Vertebrates			
Amphibians	0	0	0
Birds	0	24	8
Freshwater Fish	11	29	25
Mammals (excluding cetaceans)	0	20	6
Reptiles and Turtles	0	4	0
Invertebrates			
Butterflies and Skippers	1	32	8
Dragonflies and Damselflies	0	0	0
Non-marine Molluscs	0	1	0
Coleopterans (beetles)	0	0	0
Vascular Plants			
Ferns and Fern Allies	1	8	0
Conifers	0	0	0
Monocots	0	43	3
Dicots	2	220	16
Non-vascular Plants			
Mosses	0	76	not assessed
TOTAL	**15**	**457**	**66**

SOURCE: Prepared for this report with data from the B.C. Conservation Data Centre.
NOTES: Taxa below the species level include subspecies, populations and varieties, as well as taxa lacking formal scientific species names (e.g., *Gasterosterus* sp.1). Some taxa that are of provincial conservation concern (e.g., the mountain caribou ecotype) are not assessed globally. In cases where only one taxon below the species level occurs in B.C., it has been included in the species analysis and not included here.

TABLE 22. EXTINCT AND EXTIRPATED TAXA BELOW THE SPECIES LEVEL IN B.C.

TAXONOMIC GROUP	SCIENTIFIC NAME	COMMON NAME	CONSERVATION STATUS
Birds	*Eremophila alpestris strigata*	Horned lark, *strigata* subspecies	Extirpated
	Melanerpes lewis pop. 1	Lewis's woodpecker (Georgia Depression population)	Extinct
	Sturnella neglecta pop. 1	Western meadowlark (Georgia Depression population)	Extirpated
Freshwater Fish	*Coregonus* sp.	Dragon Lake limnetic whitefish	Extinct
	Coregonus sp.	Dragon Lake benthic whitefish	Extinct
	Gasterosteus sp. 12	Hadley Lake limnetic stickleback	Extinct
	Gasterosteus sp. 13	Hadley Lake benthic stickleback	Extinct
Mammals	*Bos bison bison*	Plains bison	Extirpated
	Rangifer tarandus dawsoni	Dawson caribou	Extinct
Reptiles and Turtles	*Pituophis catenifer catenifer*	Gopher snake, *catenifer* subspecies	Extirpated
Butterflies	*Euchloe ausonides insulanus*	Island large marble	Extirpated

SOURCE: Prepared for this report with data from the B.C. Conservation Data Centre.
NOTES: The only plains bison currently found in B.C. are considered aliens because they belong to an introduced population located outside the historic range of this subspecies. Kincaid's lupine (var. *kincaidii*) is listed at the species level in Table 14 (p. 58) because it is the only representative of *Lupinus oreganus* that occurs in B.C.

2.4.3 DATA GAPS

Relatively little is known about the status of genetic diversity in B.C., particularly for certain taxonomic groups. While some species of fish and birds have been the subjects of multiple studies, genetic data are rare to nonexistent for amphibians, invertebrates, bryophytes and vascular plants other than trees. The existing designation of subspecies is questionable in some cases and there is disparity in how biologists deal with variation in different taxonomic groups (i.e., subspecific taxa are not formally described in all groups). The fact that molecular markers for given species can often be readily applied to close relatives means that genetic surveys will become more feasible in future. There are important data gaps in relation to appropriate taxonomic units for subspecies that are difficult to differentiate (see Text box 11, p.78) and populations of particularly high or low genetic diversity.

Identifying uniquely adapted taxa documents genetic diversity and divergence, and may contribute to the persistence of local populations. Hot spots of genetic distinctiveness [310] and divergent populations may be identified by observable physical characteristics in some cases, but some taxa are difficult to differentiate and require genetic markers for identification.[311]

TEXT BOX 13. MOUNTAIN CARIBOU IN SOUTHEASTERN BRITISH COLUMBIA

The woodland caribou (*Rangifer tarandus caribou*) is one of four subspecies of caribou currently found in North America and the only one occurring in British Columbia.[a] There are three ecotypes of woodland caribou: boreal, northern and mountain. Of these, the mountain caribou ecotype is of the greatest conservation concern, due to its small population size.

Mountain caribou populations have probably existed in southern B.C. for more than 10,000 years and likely advanced and retreated with glacial events.[312] Mountain caribou are found primarily in the Cariboo, Selkirk, Purcell, Monashee and Rocky mountains in the southeastern part of the province (Figure 21). They are threatened by ecosystem degradation, including fragmentation, disturbance, predation (due to altered predator-prey dynamics resulting from ecosystem degradation) and climate change.[313,314] The estimated population of mountain caribou has decreased by 17% from 2,300 in 2000, to about 1,900 in 2006.[315] These animals constitute almost all of the global population of this ecotype.[316] Since 2000, two of the 18 herds – the George Mountain and Central Purcells herds – have been extirpated. Extirpation of a herd results in the loss of that population's genetic contribution to the larger population.

In 2007, the provincial government announced the Mountain Caribou Recovery Implementation Plan, with the goal of restoring the mountain caribou population to pre-1995 levels of more than 2,500 animals throughout their existing range. The plan includes: habitat conservation; managing human recreational activities; managing wolf and cougar populations where they threaten caribou recovery; managing the prey of mountain caribou predators; augmenting small herds by transplanting caribou; and adaptive management, including monitoring.[317]

FIGURE 21: Distribution of the three ecotypes of woodland caribou in B.C.
SOURCE: B.C. Integrated Land Management Bureau.

Nearly the entire global population of the mountain caribou (*Rangifer tarandus caribou* mountain ecotype) is now found in southeastern B.C.
PHOTO: ROLLAND USHER, MOUNTAIN CARIBOU INSTITUTE OF B.C.

[a] A fifth subspecies, the Dawson caribou, is extinct (see Table 22, p. 84).

Genetic analyses can provide information about how historic and recent population-size fluctuations have affected population viability, migration routes, dispersal barriers and sex ratios.[318] For example, uncertainty about the value of dispersal corridors for a particular species might be resolved by genetic analysis to identify whether historic dispersal patterns have been interrupted by habitat fragmentation and whether re-established corridors are actually used.[319]

Data gaps for specific taxonomic groups are summarized below.

Mammals: Mammals are one of the best-studied groups, but most taxonomic studies rely on physical features and have not been confirmed by genetic analysis. Genetic studies using molecular markers for closely related species (e.g., bats) are lacking. Another gap is identification of subspecies that are difficult to differentiate, especially for taxonomic groups in historic refugia and geographically disjunct populations that exhibit low dispersal ability despite having a moderate to large effective population size.

Birds: There is an established history of genetic research on birds. In B.C., several studies of birds are currently being undertaken to investigate how hybrid suture zones contribute to biodiversity through both speciation and hybridization[320] and how historic refugia and population isolation affect micro-geographic variation in phenotype, genetic diversity and population persistence.[321]

Freshwater fish: Freshwater fish populations exhibit high genetic differentiation[322] and often differ in phenotype and genotype across major drainages in B.C. due to historic and recent isolation.[323] For example, there are more than 400 genetically distinct populations among five species of Pacific salmon in B.C.[324] Because of a long history of commercial, recreational and scientific interest, this group is among the best studied with respect to taxonomic and genetic diversity. However, genetic studies that use recent taxonomic reviews are lacking.

Amphibians: This group may incorporate higher levels of genetic differentiation in B.C. than are currently recognized, since meta-analysis (a method of analysis that combines the results of a number of studies to investigate underlying processes) shows that amphibian populations tend to be more differentiated than bird populations[325] and since some amphibians potentially have isolation histories similar to those of fish. Genetic research that considers geographic distribution and the potential for **adaptive divergence** based on life history is lacking.

Reptiles and turtles: Information about divergence in geographically isolated populations is lacking. Many detailed studies of genetic differentiation in adaptive traits related to predation and colouration have focused on the garter snakes (*Thamnophis* spp.), including species common in B.C. and on coastal islands.

Invertebrates: Genetic studies of invertebrates elsewhere in the world often find strong differentiation within species based on geographic distribution and food-plant specialization. This suggests that there may be genetic variants in B.C. that have not been described. One study of ground beetles (*Nebria charlotte* and *N. haida*) on Haida Gwaii/Queen Charlotte Islands indicates **genetic variability** within that population.[326] No peer-reviewed genetic studies of dragonflies, damselflies or non-marine molluscs have been done in B.C.

Vascular plants: The degree to which differences between populations are due to different environmental conditions (e.g., soil nutrients) or genetic differences stemming from adaptation to historically isolated sites is not well understood.

A long history of empirical studies has demonstrated pronounced adaptive divergence among conifer populations in B.C. More recently, this has been also demonstrated for some Garry oak ecosystem plants, including sea blush (*Plectritis congesta*), broad-leaved stonecrop (*Sedum spathulifolium*)[327] and blue-eyed Mary (*Collinsia* spp.).[328]

Non-vascular plants: No peer-reviewed genetic studies of these taxa in B.C. have been published.

FIGURE 22: The hidden majority plays a weighty role in the functioning of ecosystems.
SOURCE: F. Bunnell and I. Houde, University of British Columbia.
ILLUSTRATION: I. Houde.

TEXT BOX 14. THE HIDDEN MAJORITY[329]

Many elements of biological diversity are overlooked because they are either too small to see easily or are processes rather than single plants or animals. For example, many invertebrates are hidden in soil or under the bark of trees or are microscopic. An estimated two million soil invertebrates inhabit every square metre of ground in the Pacific Northwest.[330] About 30 to 40 species of oribatid mites, totalling 40,000 to 50,000 individuals, live on the surface of a single stump, feeding on 25 or so species of fungi.[331,332,333] There are at least 94 species of terrestrial snails and slugs in B.C.[334]

Invertebrates make up most of the 'hidden majority' of species, but they are only part of B.C.'s little-noticed diversity (Figure 22). Forty to 75 species of mosses, liverworts and lichens can grow on the trees in a forest plot the size of a football field (approximately 0.5 ha),[335,336,337,338,339,340] with a mass of up to 2.6 tonnes per hectare in coastal old-growth forests.[341] An additional 20 to 50 species of crustose lichens[342] and many more bryophytes live on the rocks and soil.

Even though they are not easily identified by most people, these small organisms perform critical functions such as nutrient cycling. For example, mosses absorb up to 10 times their weight in water and help regulate water flow (see Section 2.5.1.3-B, p. 115). The role played by many species in ecosystem functioning is unknown, and the inadvertent loss of critical species is a very real danger.

2.5 Selected Key and Special Elements of Biodiversity in British Columbia

Genes, species, ecosystems and the processes that link them are the major components of biodiversity, but not all are equal when it comes to conserving other elements of biodiversity. Section 2.5.1 examines key elements – pieces of the biodiversity puzzle that are essential and/or have a disproportionate influence on ecosystem function. Many of these key elements are not tidily encompassed by the three levels of organization (genes, species and ecosystems). Section 2.5.2 (p.137) looks at special elements – elements of biodiversity that are uncommon and often globally significant.

2.5.1 KEY ELEMENTS

The following pages describe a small subset of the multitude of components, structures and functions of biodiversity that help sustain life on earth. These key elements are known to play fundamental or disproportionately large roles in the functioning of ecosystems. For each element, its status in B.C. is described, if known.

Table 23 lists the key elements chosen to illustrate some of the functions, structures and components that are essential for maintaining healthy ecosystems and the services derived from them. These were chosen at a series of workshops in 2007, using a framework to identify essential ecosystem characteristics.[343] Each composite piece is engaged in functions and creates structure. The more that communities of species remain intact, the more likely it is that ecological processes will be maintained. Scientific knowledge is generally insufficient to evaluate the apparent importance of the processes or the species involved (except in the case of a few well-documented **keystone species**). With some exceptions, the value of many elements of biodiversity is unknown until they fail.

TABLE 23. SELECTED KEY ELEMENTS OF BIODIVERSITY IN B.C.

REALM	KEY ELEMENT COMPONENT (C), STRUCTURE (S) OR FUNCTION (F)	STATUS	THREATS
Cross-realm	**Connectivity (F, S)**	Declining.	Ecosystem conversion and degradation, particularly road building in the terrestrial realm, and dams and culverts in the freshwater realm.
	Riparian areas (C)	Declining.	Ecosystem (streambank) conversion, livestock activities.
Terrestrial	**Decomposition and nutrient cycling (F)**	Unknown.	Climate change, acidification.
	Pollination (F)	Unknown.	Ecosystem conversion and degradation, environmental contamination from pesticides.
	Large mammal predator prey dynamics (F)	Relatively unimpaired.	Fragmentation, loss of roadless areas, direct mortality.
	Succession/Disturbance (F)	Severely altered successional patterns in some areas.	Forestry, fire suppression, dams, climate change.
	Southern red-backed voles (C)	Not of conservation concern at the species level. Two subspecies of conservation concern.	Loss of mature and old forest.
	Wildlife trees (S)	Declining.	Loss of old forests.
	Broadleaf trees (C)	Unknown but suspected to be declining. All 12 cottonwood communities are of conservation concern.	Forestry practices that result in conifer monocultures.
	Soil (S)	Varying levels of degradation.	Forestry, grazing, conversion of forest or grasslands to agriculture, urbanization.
	Coarse woody debris (CWD) (S)	Volumes of CWD in managed forests stable but size of pieces is declining.	Forestry, firewood collecting.
Freshwater	**Wetlands (C)**	Declining.	Ecosystem conversion (draining and filling), pollution.
	Sphagnum (C)	Unknown but suspected to be declining.	Ecosystem conversion, peat mining
	Lake-level patterns (F)	Natural variation declining.	Water extractions and diversions, climate change.

CONTINUED ON PAGE 91

TABLE 23 CONTINUED

REALM	KEY ELEMENT COMPONENT (C), STRUCTURE (S) OR FUNCTION (F)	STATUS	THREATS
Freshwater	**Headwater streams (F)**	Level of degradation of headwaters unknown.	Disruption of colluvial streams, channelization, loss of large woody debris, loss of connectivity, sedimentation from road building.
	Groundwater (F)	Locally of concern.	Water diversion and withdrawl, urban paving, alteration of drainage patterns, foresty, mountain pine beetles, climate change.
	Anadromous salmonids and nutrient cycling (C)	Many stocks in decline.	Fishing, habitat loss, environmental contamination, alien species, climate change.
	Willows (C)	44% of species are of conservation concern.	Alien species (i.e., the poplar and willow borer).
	Beavers (C)	Secure but habitat impacted.	Trapping, habitat alteration in lowland areas.
	Waterfowl herbivory of aquatic plants (F)	Unknown.	Loss of wetlands.
Marine Overlap	**Macroalgae (C)**	Local shifts in abundance.	Climate change.
	California mussels (C)	Stable with local declines and shifts in abundance.	Recreational harvesting.
	Sea otters (C)	Of conservation concern in B.C., but population and distribution increasing.	Oil spills, low genetic variability, entanglement in fishing nets, poaching.
	Crustaceans (C)	Stable with local declines and shifts in abundance	Ocean acidification.
	Seagrass meadows (S)	Declining.	Dredging, log handling, sedimentation, shoreline structures, pollutants, alien species, boat traffic.
	Upland sediments and large woody debris in the intertidal (S)	Loss of large woody debris size and volume; sediment deposition impacted by dams and riparian activities.	Ecosystem conversion and degradation, climate change.
	Estuaries (C, F)	Declining.	Ecosystem conversion and degradation, water diversion, marine sediment.

NOTE: Elements in this table are just a small sample of the key elements of biodiversity in B.C. They are used for illustrative purposes.

2.5.1.1 CROSS-REALM ELEMENTS

A. CONNECTIVITY

What is it? Connectivity is the degree to which ecosystem structure facilitates or impedes the movement of organisms between resource patches.[344] What constitutes connectivity is scale-dependent and varies for each species depending on its habitat requirements, sensitivity to disturbance and vulnerability to human-caused mortality.[345] A spotted owl (*Strix occidentalis*) may avoid flying across large clearcuts,[346] while a grizzly bear may avoid crossing a highway with a high volume of traffic.[347] A smaller organism such as a butterfly, which may fly no more than a few hundred metres in its lifetime, can be dramatically affected by urban or agricultural development.[348] In stream systems, connectivity occurs upstream and downstream (see Section 2.5.1.3-D, p. 118), between **groundwater** and surface water (see Section 2.5.1.3-E, p. 119), and between aquatic and terrestrial ecosystems.

Why is it important? Connectivity allows individual organisms to move in response to changing conditions, such as seasonal cycles, a forest fire or climate change. It also permits linkages between individuals in geographically separated populations. Connected populations are much less vulnerable to being extirpated as a result of chance or random events, because they can be 'rescued' or recolonized by immigration from other populations.[349] In addition, large, connected populations are more influenced at a genetic level by natural selection, while small, fragmented populations are vulnerable to the random, often damaging effects of genetic drift and inbreeding.[350] Freshwater species that are confined to water cannot escape the deleterious effects of lost connectivity. Poorly designed stream crossings can disrupt connectivity by preventing fish passage upstream or downstream. This can prevent the dispersal of some aquatic invertebrates, such as freshwater mussels,[a] whose larvae travel throughout stream systems on the fins or gills of fish.[351] Freshwater mussels perform important ecological functions such as water filtration.

Status/threats in B.C. For many species in both the terrestrial and freshwater realms, ecosystem conversion and degradation are resulting in the loss of connectivity (also referred to as habitat fragmentation). Species that rely on the core areas of old-growth forests are less able to move through landscapes where large areas have been recently logged. Sensitive species such as grizzly bears, wolverines (*Gulo gulo*) and bull trout (*Salvelinus confluentus*) avoid areas with high levels of human use.[352] Off-road use of four-wheel drives, ATVs and snowmobiles can also contribute to the loss of connectivity for sensitive species such as elk (*Cervus canadensis*)[353] and mountain caribou[354] (see Section 3.3.8, p. 205).

[a] There are six species of freshwater mussels in B.C. The rarest is the Rocky Mountain ridged mussel (*Gonidea angulata*), found only in the Okanagan and Kootenay rivers.

An estimated 66,000 stream crossings were built in B.C. between 2000 and 2005, with an average increase of 13,369 stream crossings per year.[355,356] A 2006 assessment of 178 culverts in the Carp and MacGregor river watersheds found that 88% of the culverts were a potential barrier to fish passage.[357] Figure 23 shows the amount of potential fish habitat that is lost upstream of a culvert that fails to allow fish passage.

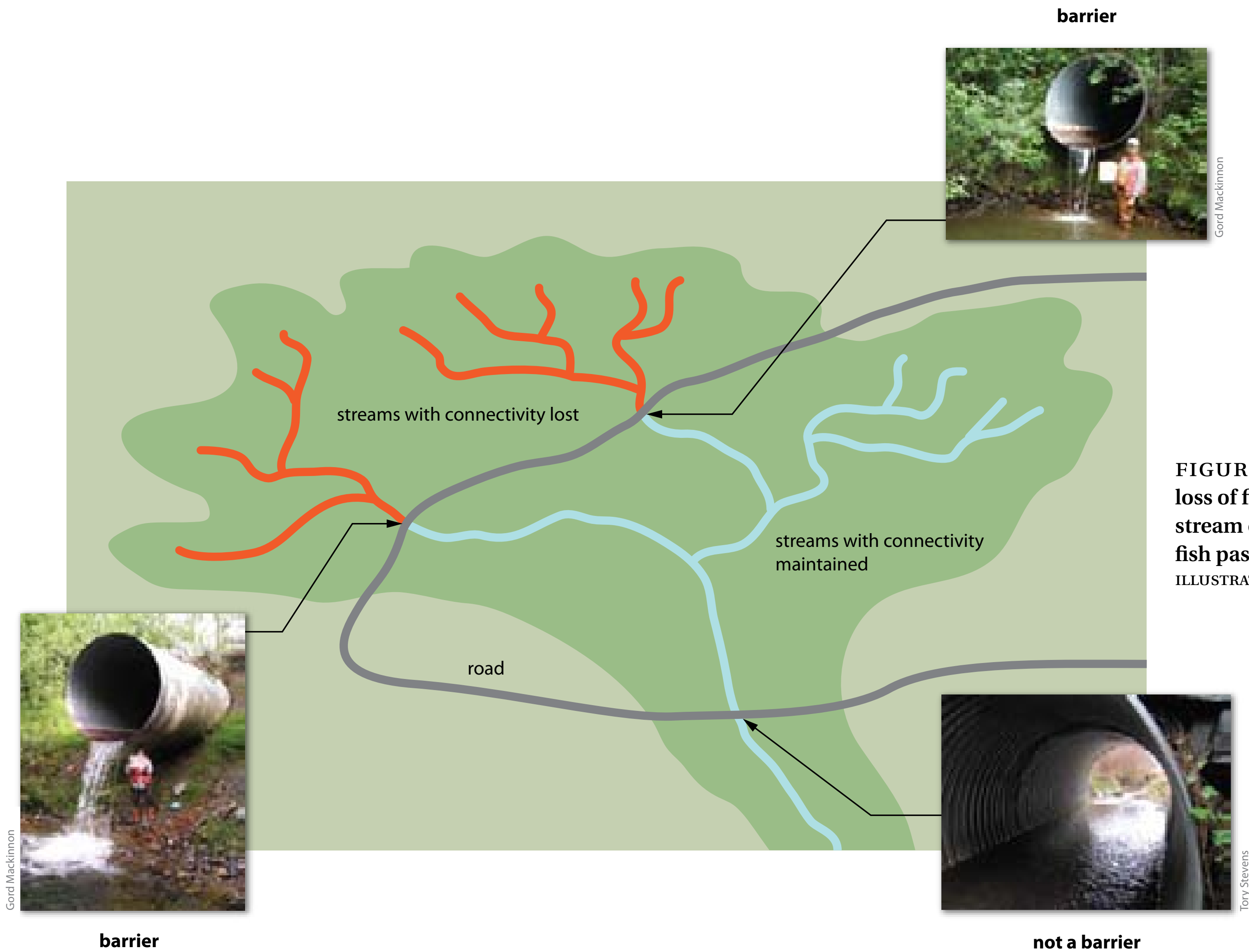


FIGURE 23: Potential loss of fish habitat owing to stream crossings that block fish passage.
ILLUSTRATION: Soren Henrich.

Lowland riparian areas of the Okanagan Valley provide important nesting habitat for Lewis's woodpeckers (*Melanerpes lewis*).
PHOTO: TOM MUNSON.

Data gaps: Rigorous assessments to identify linkages have not been conducted for most of the province and much of the work that has been done has focused on large carnivores.[358,359,360,361] There is also the issue (which is not unique to B.C.) of determining exactly what constitutes linkage for particular species.

B. RIPARIAN AREAS

What are they? Riparian refers to the transition zone between an aquatic and a terrestrial system that is influenced by either surface or subsurface water. A riparian area may be located beside a lake or estuary or an ephemeral, intermittent or perennial stream or creek. Riparian areas are dynamic ecosystems that may be subject to temporary, frequent or seasonal flooding. They support plant communities that tolerate moister conditions than those found in upland areas. They are typically linear, but can extend over large landscapes and are found in all areas of the province.

Hydro-riparian ecosystems extend beyond the riparian zone to encompass both the water and the adjacent land in one integrated ecosystem that includes above- and below-ground processes.[362,363,364]

Why are they important? Riparian area functions include the influence of land on adjacent water, the influence of water on adjacent land, and connectivity.[365] Land influences adjacent water as vegetation moderates temperature and water input, filters sediment, provides structure and nutrients and stabilizes banks. In addition, bedrock and soil determine water chemistry and channel form. Water influences adjacent land by eroding banks, depositing sediments that create soil, modifying microclimates and influencing vegetation and productivity. In well-drained soils, flooding creates mosaics of diverse and productive communities. Riparian and hydro-riparian ecosystems link landscapes, providing corridors for animal and plant movement, sediment transport and water transport. In hydro-riparian ecosystems, the connectivity includes underground connections (see Section 2.5.1.3-E, p. 119). The phreatic (groundwater) zone and the **hyporheic** zone (the saturated sediment zone between groundwater and surface waters) provide water purification and transport, as well as habitat and nutrients for plants and animals.

Riparian wetlands play an important role in storage and filtering of water, the maintenance of water quality and the reduction of sediment levels, nutrients and toxic chemicals in outflow water.

Riparian areas support a variety of vegetation cover types, from trees and shrubs to emergent and herbaceous plants. Because of this high plant diversity, they provide foraging, nesting and/or breeding habitat for an abundance of terrestrial and freshwater life (Figure 24).[366,367,368] The vegetation in riparian areas directly influences and provides important fish habitat.[369] It builds and stabilizes stream banks and channels, provides cool water

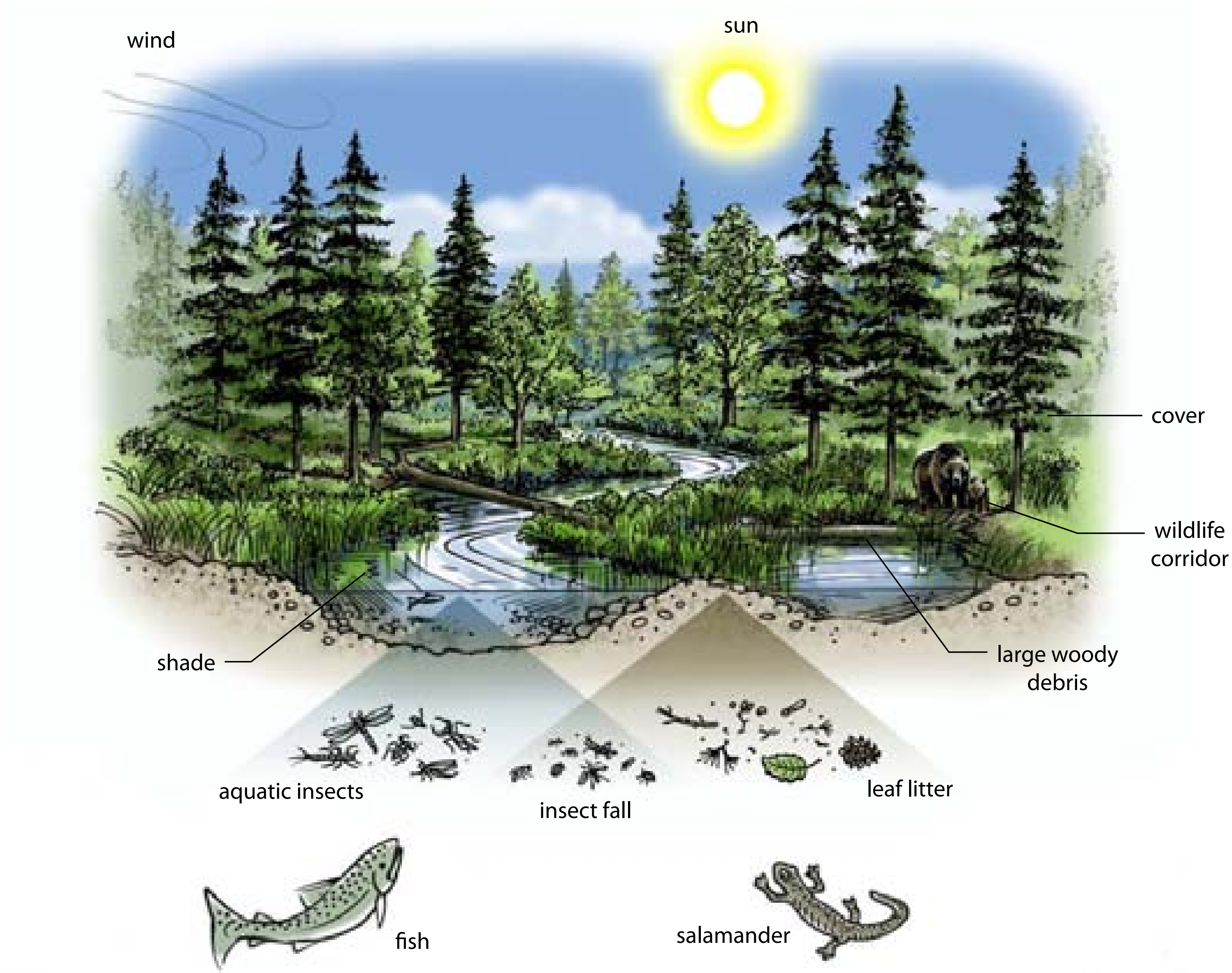


FIGURE 24: Relationships between riparian areas and terrestrial and freshwater species.
SOURCE: Adapted from B.C. Ministry of Water, Land and Air Protection. 2006. Riparian Areas Regulation Implementation Guidebook. Biodiversity Branch, Victoria, BC. 87pp. Available at: www.env.gov.bc.ca/habitat/fish_protection_act/riparian/documents/ImplementationGuidebook.pdf.
ILLUSTRATION: Soren Henrich.

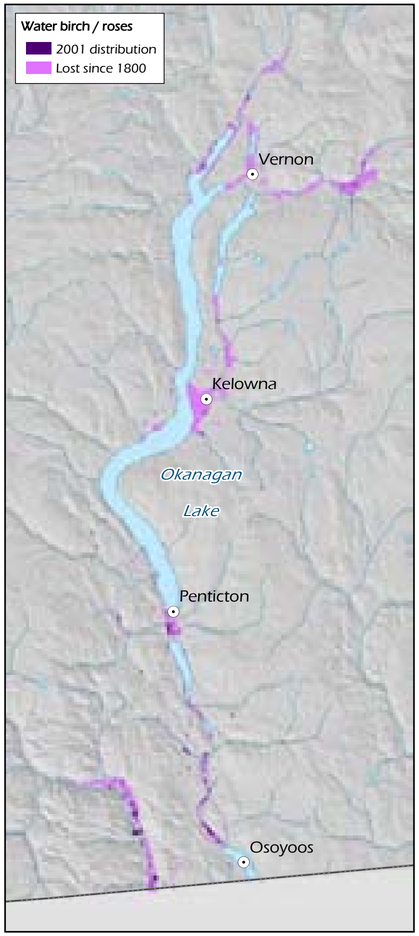


FIGURE 25: **Loss of water birch / roses riparian shrub wetland in the Okanagan Valley since 1800.**
SOURCE: Prepared for this report with data from T. Lea.

through shade[370] and provides shelter for fish. The leaves and insects that fall into the water are a source of food for fish.[371,372] The hyporheic zone in hydro-riparian areas provides habitat for a variety of insects and microfauna, which are in turn prey for larger species. It is a source of nutrients and water for plants and is where much of the water purification occurs, reducing sediment levels, nutrients and toxic chemicals in outflow water. Accounting for only a small portion of British Columbia's land base, riparian areas are often more productive than the adjoining upland. Hydro-riparian ecosystems are important as hot spots of biodiversity.[373]

Although riparian areas generally support disproportionately high numbers of species relative to the area they occupy on the land base, their presence is even more critical in dry ecosystems such as grasslands. Riparian wetlands adjacent to grasslands support a variety of species of conservation concern. They contain high-quality habitat that provides for many of the diverse needs of species, including water, food and cover. In areas where grasslands dominate, lowland riparian areas may be the only source of large trees and snags for several kilometres, providing habitat for species that would otherwise not be present. For example, although Lewis's woodpeckers *(Melanerpes lewis)* are adapted to recent fire-created ecosystems, in B.C. the highest nesting density of this species of conservation concern is in lowland riparian areas in the Okanagan Valley – a higher density than in coniferous forests in the same area.[374,375,376] The *macfarlanei* subspecies of the western screech owl (*Megascops kennicottii macfarlanei*) is very closely associated with riparian habitats below 950 m and this dependence is at least partly related to the presence of cottonwoods of sufficient size to provide nest cavities.[377]

Status/threats in B.C. Riparian systems are affected by topography, surficial materials and the duration and magnitude of flood events. These factors influence their response to disturbances. Intensive recreational activities along the edges of wetlands can reduce plant cover, compact soil and disturb nesting birds. However, riparian wetlands are known to be resilient in response to disturbance.[378] Tree mortality caused by mountain pine beetles also affects riparian areas (see Text box 16, p. 105).

Riparian areas and adjacent wetlands are rare in grassland landscapes. They are extremely vulnerable to vegetation removal, filling or draining, and overuse by livestock.[379,380] Riparian areas in dry ecosystems are often lost through conversion of stream banks and riparian wetlands to fields, lawns and pavement owing to urbanization and agriculture (see Text box 5, p. 39).

In the Okanagan region, 63% of the black cottonwood / water birch (*Betula occidentalis*) riparian shrub wetland ecological community and 92% of the water birch / roses (*Rosa* spp.) riparian shrub wetland ecological community have been lost (Figure 25), along with 41% of the cattail marsh ecological community (see Table 8, p. 40).[381]

Data gaps: Found in narrow strips along watercourses and water bodies, riparian areas are dynamic ecosystems influenced by topography, surficial materials and stream flow, which are challenging to map and monitor, particularly at a broad scale. Data gaps include knowledge about disturbance and recovery regimes and the cumulative effects of disturbance regimes over space and time.[382] Research on sediment production, terrain stability and channel stability is being undertaken in relation to watershed sensitivity in riparian areas.[383] There are also gaps in the current knowledge about riparian soils, the role of trees in maintaining system integrity and system-scale properties of resilience.[384]

Bracket fungi are the fruiting bodies of one of many types of tree-decay fungi.
PHOTO: ARKADIUSZ STACHOWSKI.

2.5.1.2 TERRESTRIAL ELEMENTS

A. DECOMPOSITION AND NUTRIENT CYCLING

What is it? Decomposition is the process of breaking down the tissue of once-living organisms into their component parts. The breakdown of these building blocks is an important part of nutrient cycling. Brown rot fungi, which comprise one group within the suite of wood-decomposing fungi, were present 300 million years ago, when ancestors of conifers began to appear.[385] They likely evolved along with conifers and influenced the evolution of coniferous forests, including the defence systems of trees that wall off the fungus, creating potential habitat for cavity-using vertebrates (see Section 2.5.1.2-F, p. 108). A more complex interaction involves fungi creating suitable substrates for bryophytes and lichens, which encourages the presence of various invertebrates and microbes, all leading to the gradual decomposition of wood.

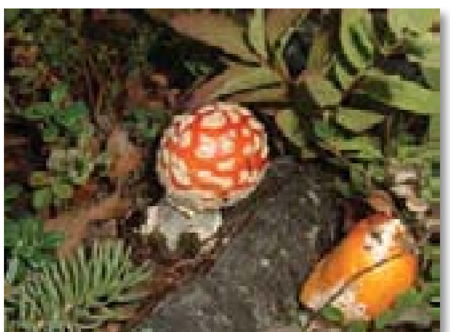
Why is it important? Without fungi breaking down dead plant and animal matter, carbon and other molecules essential to life would be locked into organic molecules too large for plants to absorb. Fungi break down large organic molecules into inorganic constituents, such as carbon and nitrogen, which are small enough for the fungi to absorb; they do this by sending parts of their body (**hyphae**) directly into their food, secreting chemicals that help to break it down into simpler molecules, then absorbing the food directly into their cells. There is very little that fungi cannot or will not digest. Bacteria and **arthropods** help fungi break down organic compounds, but fungi are the engine. Organic compounds can be very complex, so it takes a suite of fungi and their enzyme systems to decompose wood, and other suites to decompose fur, feather, insects and dung. An example of nutrient cycling in the freshwater realm is described in Section 2.5.1.3-F (p. 121).

Truncocolumella citrina **ectomycorrhizal system on a Douglas-fir (*Pseudotsuga menziesii*) root.**
PHOTO: RENETA OUTERBRIDGE © 2007 HER MAJESTY THE QUEEN IN RIGHT OF CANADA, NATURAL RESOURCES CANADA, CANADIAN FOREST SERVICE.

TEXT BOX 15. MYCORRHIZAE: A TREE'S BEST FRIEND

Fungi on plant roots form complex, mutually beneficial associations called **mycorrhizae**. They aid the roots of almost all vascular plants in several ways. For example, they increase the surface area of the roots dramatically. One centimetre of root has about 3 m of hyphae, effectively increasing the root's length by 300 times. This increases the surface area for absorption of water. One cubic centimetre of soil may contain 1 km of mycorrhizal fungal hyphae,[386] with a fungal surface area of 300 cm^2 interfacing with the soil. Through this increased surface area, the fungus actively and selectively absorbs minerals that the plant needs and transfers them to the plant, while excluding minerals that the plant does not need. Mycorrhizal fungi also secrete growth factors that stimulate root growth and branching, as well as antibiotics that protect the root from pathogenic bacteria and fungi. Nutrients and water in the soil are limited, and each root is surrounded by competitive bacteria, fungi and animals (**nematodes**), making mycorrhizal fungi extremely important to the health, growth and function of roots. In return for their services, they receive carbohydrates from the host plant.

Mycorrhizal fungi can be **ectomycorrhizal**, forming a sheath around the root tip of the host plant and growing on the outer surface of the roots, or **endomycorrhizal**, growing inside the roots. Most fungi on conifers are ectomycorrhizal; western redcedar and bigleaf maple (*Acer macrophyllum*) have endomycorrhizal fungi. Recent research has shown that in clearcut openings, ectomycorrhizal abundance and diversity decreases with distance from a stand edge and is higher next to old-growth stands.[387]



The poisonous *Amanita muscaria* is mycorrhizal on the roots of many tree species.
PHOTO: COREY BUNNELL.

Status/threats in B.C. Decomposition proceeds almost unnoticed in the natural world at all times. However, this process is so fundamental that we will almost certainly notice if a significant change occurs. Climate change is causing temperature increases and changes in moisture availability, which will affect the rate of decomposition.[388] This in turn will affect the raw materials necessary for nutrient cycling. Acidification is another factor affecting organisms involved in decomposition.[389]

Data gaps: There is little information on decomposition and nutrient cycling in B.C. ecosystems. Many organisms and pathways involved in decomposition and nutrient cycling are poorly understood.

B. POLLINATION

What is it? Pollination is the transfer of pollen between plants by biological organisms or by abiotic factors such as wind.[390]

Why is it important? Flowering and seed-producing plants rely on pollination to reproduce. In natural and semi-natural habitats, 65–90% of plants rely on animals for pollination; the others rely on wind, water or splashing raindrops. Pollinating animals are rewarded, usually with food, often nectar. Vertebrates (mainly birds and bats) do some pollinating, but the majority of pollinators are insects: beetles, bees, wasps, flies, butterflies and moths. Insects pollinate more than three-quarters of all staple food crops; one of every three bites of food we take is a result of successful plant pollination by animals.[391] While many larger trees (e.g., conifers, aspens and cottonwoods [*Populus* spp.], birches [*Betula* spp.] and alders are wind-pollinated, most plant species rely on the more precise delivery of pollen by animals. Close to the forest floor, wind is less prominent and animals are a more reliable means of pollination. The loss of pollinators, and in turn, the plant species they pollinate, would have cascading ecological effects.[392,393] Insect pollinators are involved in food production for wildlife, and their larval stage is often an important prey item.[394]

Status/threats in B.C. We do not know the extent to which pollinators are of conservation concern in B.C. A study of the effects of landscape changes on bees in Garry oak ecosystems is currently underway.[395,396] In other parts of the world (e.g., Hawaii, eastern Canada, southern U.S.) there are examples of individual pollinators and their host plants being severely affected. In the United States, major declines in both managed and wild populations of pollinators have been reported.[397] A steady decline in insects has been associated with the overall decline in biodiversity as a result of ecosystem degradation.[398] European honeybees (*Apis mellifera*), which typically have been introduced and managed as crop pollinators, are declining in abundance due to a variety of diseases and the impact of other alien species (e.g., the honey bee mite [*Varroa jacobsoni*]).[399] Native bee communities can provide full pollination services where farms are located close to high value habitat. However, in areas where insecticides, herbicides and inorganic fertilizers are employed, where natural borders around agricultural fields are ploughed or where flood irrigation is used, agricultural intensification can reduce the diversity and abundance of native bees.[400] These practices reduce floral diversity and habitat. Climate change, disease and parasites have also had negative impacts on pollinators.[401] Ecosystems that are dependent on insect pollinators, such as alpine or subalpine meadows, are in more danger of decline than those that are primarily wind-pollinated such as grasslands.

Insects pollinate the majority of all flowering and seed-producing plants, including more than three-quarters of our staple food crops.
PHOTO: LAURE NEISH.

Data gaps: We know little about native pollinators in B.C., whether or not their abundance and diversity are declining, and whether they are being displaced by the less-effective European honeybee, as they have been elsewhere.

C. LARGE MAMMAL PREDATOR-PREY DYNAMICS

What are they? **Predator-prey systems** involve interactions between predators and their prey and occur at all scales, from interactions between invertebrates such as mites to those involving large mammals. Large predators do much to sustain the integrity, richness and productivity of terrestrial ecosystems.[402,403] Unlike the predator-prey systems of small organisms, those of large species are reasonably well documented. B.C. is exceptional among northern temperate regions in retaining these intact[a] or relatively intact[b] systems, which have been lost in many other jurisdictions owing to significant population declines of large carnivores and ungulates (see also Section 2.5.2.2-B, p. 144). One important example of a predator-prey system in B.C. involves the grey wolf (*Canis lupus*) and ungulates such as deer, moose (*Alces americanus*) and elk.

Why are they important? Top carnivores often shape the structure and function of ecosystems by influencing the number, distribution and behaviour of their prey, including large **herbivores**, as well as the number, distribution and behaviour of smaller, generalist predators.[404] Large herbivores shape the structure and species composition of plant communities, mainly as a result of foraging.[405] Ungulate **herbivory** regulates the populations of their food plants and in turn, the stand-level structure of ecosystems. The grey wolf is one well-studied example of a top predator that has the potential to regulate prey communities of ungulates.[406,407] Because wolves have the ability to increase rapidly, their populations can have significant impacts on the rest of the ecological community.

Changes in predator populations can shift prey population densities, prey community diversity and the distribution and abundance of ungulate forage vegetation. For example, the extirpation of wolves from Yellowstone National Park in the U.S. around 1925 (together with restrictions on the hunting of ungulates) is thought to have resulted in landscape simplification, such as the loss of riparian habitat caused by over-browsing by deer, elk and moose, and the loss of trembling aspen from the forest canopy. The reintroduction of wolves to the Yellowstone ecosystem has caused a cascade of effects, including the recovery of aspen due to a reduction in browsing by elk. [408,409] In the Yellowstone ecosystem, high moose densities resulting from the extirpation

[a] An intact predator-prey system is one in which all of the native species are present, and with no alien species that plays a role as either predator or prey relative to the others.
[b] A relatively intact predator-prey system is one that is missing only one species, and with no alien species that plays a role as either predator or prey relative to the others, and where the loss of the species has not substantially altered the importance of predator-prey interactions to the populations of the remaining species.

of both wolves and grizzly bears decreased bird species richness and nesting density through the reduction in riparian plants such as willows.[410, 411]

In areas of B.C. where large carnivore densities are reduced by either disturbance or direct human-caused mortality, ungulate herbivory often exceeds sustainable levels and has deleterious effects on ecosystems and on other species. In the Rocky Mountain Trench, intensive ungulate herbivory in the relative absence of predators has contributed to overgrazing, which in turn has created opportunities for the spread of invasive alien species.[412] Black-tailed deer, introduced to Haida Gwaii/Queen Charlotte Islands, where wolves are not found, have had major impacts on other species and resulted in the simplification of the forest ecosystem.[413,414] Similarly, fallow deer (*Dama dama*) on Sidney Island near Vancouver Island have significantly affected the structure of the forest, creating a visible 'browse line' below which there is little evidence of palatable plant species. An overabundance of ungulates can also affect nutrient cycling, net **primary production** and **fire regimes**.[415,416,417]

Status/threats in B.C. Predator-prey systems cover most of B.C. and have only been lost entirely from areas of ecosystem conversion (see Section 3, p. 155). However, these systems have been directly impacted by: disturbance and fragmentation associated with motorized access,[418] including off-road vehicles; killing of large carnivores as a result of, or with the intention of preventing, livestock-related conflicts with humans; predator control intended to increase ungulate populations; and/or hunting and trapping of large carnivores and ungulates. Predator-prey systems have also been indirectly impacted by the increase in young forests resulting from forest harvesting, which has increased moose and deer densities in some areas and, by extension, wolf densities.[419]

Data gaps: Interactions between some large mammal predators and prey species have been relatively well studied, but the dynamics of predator-prey systems are not as well understood. We know little about the indirect ways that human activities may influence these systems by creating advantages and disadvantages for individual species. For example, we do not fully understand the complex relationships between mountain caribou – a species of conservation concern – and other large mammals, but there is some evidence to suggest that landscape-level changes in forest structure (see Section 3.3.3, p. 194) are resulting in higher moose populations, which lead in turn to higher wolf populations and higher predation rates on mountain caribou (see Text box 13, p. 85).[420,421,422]

D. SUCCESSION/DISTURBANCE

What is it? **Succession** is a series of dynamic changes in ecosystem structure, function, and species composition over time, as a result of which one group of organisms succeeds another through stages leading to a potential natural community or climax stage.[423] This natural process occurs constantly in the environment. Organisms have an optimal environmental range for growth and development. As they become established on a site, they produce changes in soil conditions, micro-climatic conditions and physical space. [424] As conditions change, other species whose requirements are more suited for the new conditions will flourish. Each successional stage is dominated by a different combination of organisms. While the **seral stages** of vegetation can be broken into convenient units, the process is actually a continuum. A series of disturbances will result in an ecosystem that is generally composed of numerous patches of various sizes at different stages of successional development.[425]

A disturbance, whether natural or human-generated, can reset the successional process. Disturbance mechanisms such as fire, insect infestation, wind storms, landslides, flooding and logging are agents or enablers of succession and can interact together to influence succession. For instance, fire may make vegetation more susceptible to disease, while infestations of insects such as mountain pine beetle may increase fuel loads, making the area more susceptible to higher-intensity fires, resulting in significant changes to the existing successional regime.

Disturbance affects communities at various spatial and temporal scales. Disturbance agents and the frequency of disturbance can be recognized in the history of some ecosystems. Frequent fires in B.C.'s interior have resulted in open grassland savannahs with scattered large, fire-resistant trees. Lack of fire in moist-climate ecosystems has created a very different forest, with thousand-year-old trees growing next to young saplings. In these forests, the primary disturbance event is an old tree falling and creating a patch of sun. On floodplains, frequent flooding creates a constantly shifting mosaic of sediment islands and young trees and shrubs. Some species survive the disturbance and others quickly colonize the disturbed area.

Fire

Fire is a key disturbance agent, controlling forest and grassland ecosystem composition, structure and function.[426,427,428,429] The way fire acts in an environment, referred to as the fire regime, has a major effect on the successional patterns of ecosystems.[430,431,432,433] Where fire is suppressed, even in semi-desert ecosystems in British Columbia, conifers can invade grasslands.[434]

Fire regime is characterized by fire size, type, intensity and frequency, with each factor playing a role in ecosystem response to the disturbance event.[435, 436] Figure 26 shows the variability of fire-return intervals in British Columbia. Four general **natural disturbance** types (NDTs) have been identified in relation to intensity and frequency of fires: rare or infrequent stand-initiating or crown fires (NDTs 1 and 2); frequent stand-initiating fires (NDT 3); and frequent surface fires (NDT 4). The fifth category on the map (NDT 5) shows non-forested areas that do not rely on fire to maintain that condition. At a more site-specific level, studies have shown considerable variability within these broad zones.[437] Some wet coastal forests have been completely replaced through small gap-creating events during their thousands of years of existence in the absence of fire.[438]

The characteristics of a fire depend on many factors, including vegetation, fuels, weather and topography. For instance, grasses and conifer needles on the forest floor are important vectors for fire spread, while larger fuels and **duff** contribute to longer, more intense fire. Areas of high precipitation are less likely than arid areas to burn, and wind can direct the spread and duration of fire events. Steep, south-facing slopes and ridgelines are more prone to fire than shallow slopes or valley bottoms.[439,440]

Tree stand age also plays a role in fire regime, since a stand's fuel load, including the number of dead and down trees, generally increases with stand age. There are also important seasonal effects on fire type and vegetative response to fire.[441]

Fire regimes can determine the age structure of tree species within stands, which will, in turn, determine the types of plants and animals a community can support.[442] Although some ecosystems, such as alpine ecosystems, have evolved largely in the absence of fire, others require fire to survive in their present form. Grassland and dry forest types have historically experienced frequent stand-maintaining fires.[443] Wetter

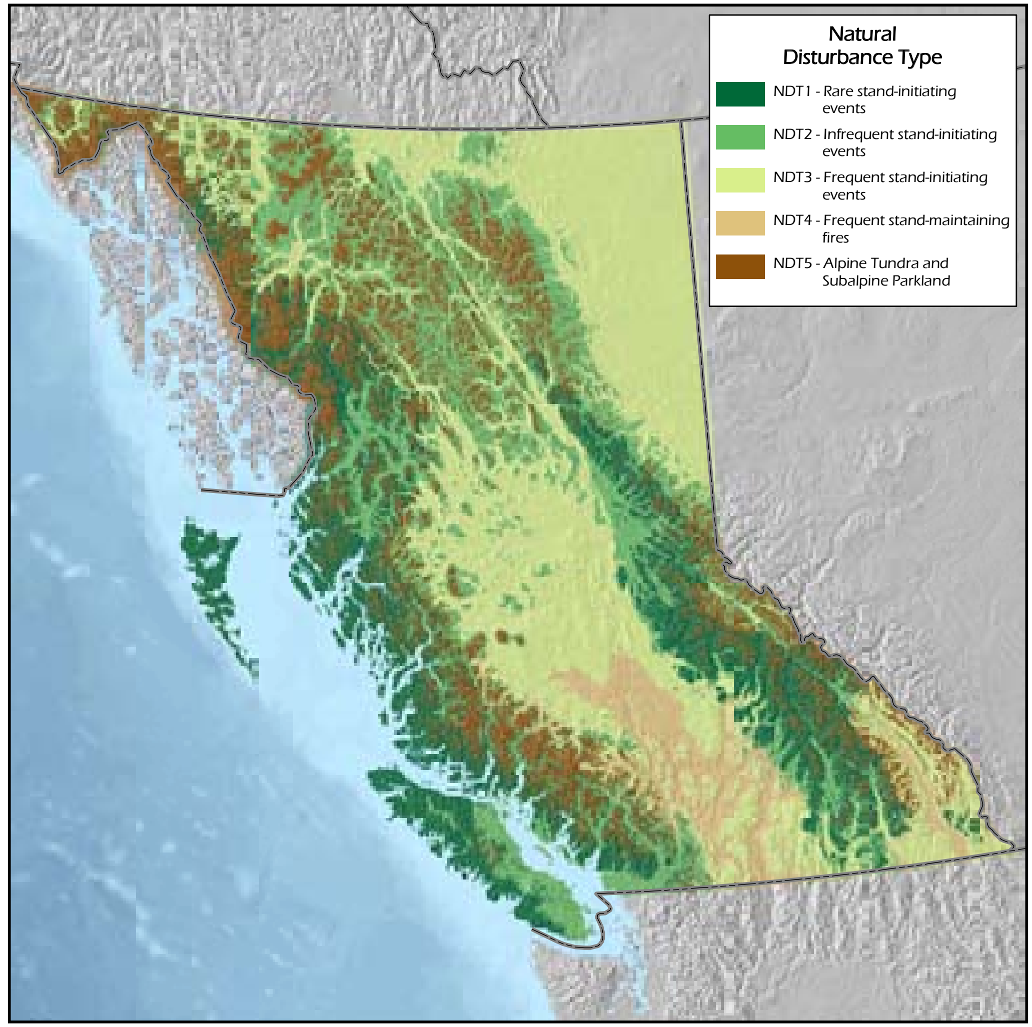


FIGURE 26: **Distribution of natural disturbance types in B.C.**
SOURCE: B.C. Ministry of Forests and Range.

ecosystems experience infrequent, stand-replacing fires.[444] Some individual organisms also depend on fire to fulfill a requirement within their life cycle.[445] Depending on severity, fire can increase soil nutrient availability or sterilize the soil and destroy the successional seed stock.[446]

Insects

Insects can have a significant impact on succession. Various species of bark beetles[a] collectively destroy more standing timber in western coniferous forests than all other insects combined. Pines, spruces, firs (*Abies* spp.) and hemlocks (*Tsuga* spp.) suffer most of the attack, in the order named.[447]

Adult bark beetles bore through the bark of conifers, making a tunnel between the bark and wood, in which to lay eggs. As the **cambium**-mining larvae grow, they create tunnels on the inner surface of the bark. Bark beetles are present in virtually all mature forests. However, under conditions favourable to the insects, major outbreaks can develop. Outbreaks that continue for many years can destroy trees over extensive areas. The most aggressive bark beetles are the pine beetles (*Dendroctonus* spp.)[448] (See Text box 16, p. 105).

The longhorned beetles[b] include some bark-boring species that can kill live trees or that may breed in the bark of felled, fire-killed or wind-thrown trees.

Why is it important? Disturbances such as fire and insect attack have a major effect on successional patterns and the structure and composition of ecosystems. When patterns of disturbance change because of either direct human activities or climate change, the resultant ecosystems may not function as expected.

Status/threats in B.C. Forestry practices, including fire suppression and salvage logging, have altered successional patterns.[449,450,451] As a result of all these changes, forests are becoming less diverse, and therefore less resilient, and grasslands are declining.[452,453,454,455] Climate change will further modify disturbance regimes (e.g., by increasing insect outbreaks) and cause large, sudden changes in vegetation.[456]

[a] Family Curculionidae, subfamily Scolytinae.
[b] Family Cerambycidae.

TEXT BOX 16. THE MOUNTAIN PINE BEETLE EPIDEMIC IN B.C.

The mountain pine beetle is a natural part of B.C.'s interior pine forest ecosystems, laying its eggs under the bark of mature pine trees. When the eggs hatch, the pine beetle larvae feed on the inner bark, cutting off the tree's nutrient supply.[457] The beetle also introduces a blue stain fungus into the sapwood, which prevents the tree from repelling the attacking beetles with pitch flow. A mountain pine beetle infestation can kill a host tree within a few weeks.[458]

B.C. is currently experiencing the largest mountain pine beetle infestation ever recorded in the province. The outbreak is due to two factors: the large amount of mature pine – the beetle's preferred host – present in B.C.'s interior forests as a result of past fire suppression and silvicultural practices; and the lack of sufficiently long periods of winter temperatures cold enough to kill overwintering beetles and keep the population in check.[459,460] Drought during the past several years has also made the trees less able to resist attack.[461]

As of 2006, 19% of B.C.'s forest had been affected by mountain pine beetle, with an additional 32% expected to be affected by 2018 (Figure 27). The resulting changes in forest structure have a number of ramifications. Pine **obligates**, such as the western pine elfin (*Callophrys eryphon*) and the pine subspecies of the red crossbill (*Loxia curvirostra stricklandi*) may suffer from the dramatic loss of pine in the province.[462] Loss of mature forest canopy reduces habitat quality and quantity for many bird and mammal species, and winter cover for ungulates, although the increase in standing and fallen dead trees will initially provide habitat for woodpeckers and cavity-nesting birds,[463] and new understory vegetation may benefit some species, such as grouse, deer and bears. Reduction in **transpiration** as a result of extensive tree death is expected to significantly change forest hydrology.[464] The resulting increased runoff will have short-term effects on stream systems, including erosion. The effects of increased logging levels aimed at salvaging beetle-killed trees may also be significant.[465,466,467,468] The risk of fire in beetle-killed forests is increasing. The effects of climate change have already expanded the amount of habitat suitable for mountain pine beetle by 75% in the past three decades, and the beetle has now moved into Alberta. This trend is expected to continue (Map 10).[469]

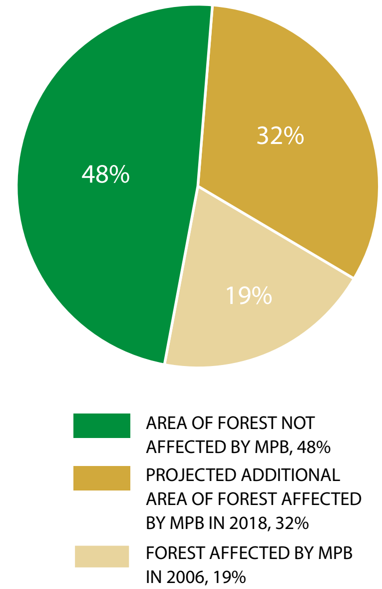
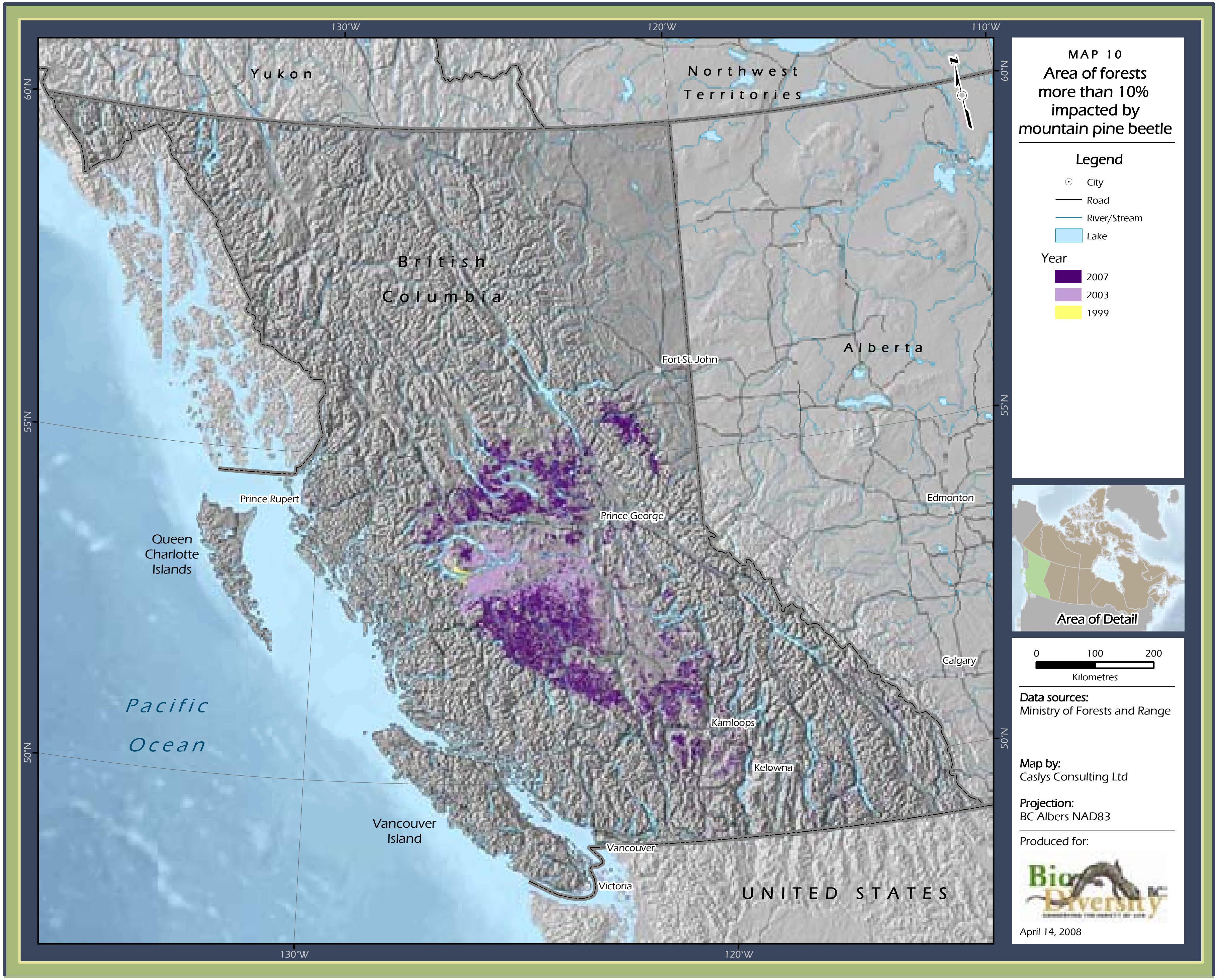


FIGURE 27: Forests in B.C. affected by mountain pine beetle (MPB), with projections to 2018.

SOURCE: Forest area is based on Baseline Thematic Mapping (BTM), Integrated Land Management Branch, from mid 1990s inventory data. Mountain pine beetle data are based on the Ministry of Forests and Range 1999 to 2006 Provincial Aerial Overview of Forest Health (www.for.gov.bc.ca/hfp/health/overview/overview.htm) and output from the BCMPB Projection Model (version 4) (www.for.gov.bc.ca/hre/BCMPB).


MAP 10
Area of forests more than 10% impacted by mountain pine beetle
Legend
City
Road
River/Stream
Lake
Year
2007
2003
1999
Area of Detail
0
100
200
Kilometres
Data sources:
Ministry of Forests and Range
Map by:
Caslys Consulting Ltd
Projection:
BC Albers NAD83
Produced for:
Bio Diversity BC
April 14, 2008
130°W
120°W
110°W
60°N
55°N
50°N
Yukon
Northwest Territories
British Columbia
Alberta
Fort St. John
Prince Rupert
Prince George
Edmonton
Queen Charlotte Islands
Calgary
Pacific Ocean
Kamloops
Kelowna
Vancouver Island
Vancouver
Victoria
UNITED STATES

Data gaps: Regional disturbance regimes have been characterized for only 45% of the 91 biogeoclimatic subzones in the province.[470] Most research has been focused on fire, with limited work on insects, wind or other disturbance agents. The lack of quantitative data is most likely related to the province's great diversity of ecosystems, which creates a much more complex system than is characterized by the four forested natural disturbance types described for B.C. This system is based on disturbance intervals and does not consider disturbance severity.[471]

Because insects that cause infestations in forests have large economic impacts they have been studied more than other insects. However, with increasing temperatures, particularly in the winter, the range of many species is changing. Monitoring these range changes will be important for predicting large-scale disturbances in the future.

E. SOUTHERN RED-BACKED VOLES

What are they? The southern red-backed vole is an herbivorous rodent distributed throughout much of B.C.

Why are they important? Southern red-backed voles play a number of functional roles in older forest communities, with influences on both their predators and their prey.[472,473] They are prey for many species, including medium-sized mammals, forest hawks and owls. They facilitate nutrient cycling, including the decomposition of **coarse woody debris**, by dispersing a significant volume and diversity of fungal species (in one study more than 23 genera of fungi),[474] many of which are mycorrhizal (see Text box 15, p.98). They aerate the soil by digging tunnels and they can influence local tree mortality by foraging on the roots of saplings and small trees, resulting in an increased mix of tree species in a stand and thus enhancing the number of niches available for other species. This can potentially contribute to the overall 'old-growth' quality of a stand.[475] This species is known to be associated with stands that have higher densities of large pieces of coarse woody debris and of 'truffles' (edible underground fungi).[476]

Status/threats in B.C. Although the southern red-backed vole is not a species of conservation concern in the province, the subspecies *occidentalis* is critically imperilled and the subspecies *galei* is vulnerable. Southern red-backed voles are primarily associated with old-growth and mature forests,[477] which are being reduced in distribution in many areas of B.C. Populations of these voles decline significantly with clearcutting.[478] This species may be affected as old-growth forest is replaced by young seral forest and, over the long term, as the size and abundance of coarse woody debris declines across the landscape.[479]

Data gaps: We do not know to what extent this species' functions are replicated by other small mammals in younger seral stages, or how southern red-backed vole population cycles affect the dependence of any particular community on this species' functions. The loss of coarse woody debris across the landscape will intensify as more older stands become part of managed forests with short harvesting rotations. The ability of forest stands

Some tree decay fungi create rot pockets surrounded by a sound outer shell, ideal for woodpeckers and other cavity users.
PHOTO: ISTOCK.

to maintain populations of the southern red-backed vole and associated species under those conditions is not known. No provincial population status information exists for this species.

F. WILDLIFE TREES

What are they? Wildlife trees are standing dead or living trees with special characteristics that provide nesting, denning, feeding, roosting or perching sites for wildlife species. The characteristics of wildlife trees include large trunks (sometimes hollow), large branches, deformed or broken tops, internal decay and sloughing bark.[480] The interactions between fungi attempting to decompose living trees and the trees' defences produce different decay patterns, as the tree attempts to seal off the pathogenic fungi. Wildlife trees usually develop over a long time and the most important are usually large, old, damaged, diseased or decaying trees.

Why are they important? Many vertebrates profit from the pockets of rot inside a living tree resulting from the work of fungi. Wildlife trees provide habitat for at least 90 species in B.C.[481] Some bird and mammal species rely on wildlife trees. Large platforms created by branches are used as nesting sites for large birds. Dead tops are used as hunting perches and nest sites. Trees with softened trunks are used by primary cavity nesters (those that build their own nesting cavity) and the abandoned holes are used by many other mammals and birds (secondary cavity nesters). This close community relationship between wildlife trees and primary and secondary cavity nesters has been described as a nest web.[482] Some birds nest and bats roost under loose bark. Insects attracted to these trees feed a variety of birds. Black bears den in hollow trunks. Wildlife trees are especially valuable in grasslands, riparian areas and wetlands and along shorelines.

Status/threats in B.C. Wildlife trees are becoming increasingly scarce as old forests are harvested for forest products or cleared for agriculture and other types of land development. Forest harvesting rotation periods of 40 to 120 years do not allow enough time for wildlife trees or their diverse invertebrate communities to develop.[483] Wildlife trees are sometimes classified as 'danger' trees and cut down for worker safety and are also often taken during salvage or firewood logging.[484]

Data gaps: Relatively little is known about the biology and ecology of many wildlife tree-dependent species, including the American three-toed woodpecker (*Picoides dorsalis*), black-backed woodpecker (*P. arcticus*), white-headed woodpecker (*P. albolarvatus*), Lewis's woodpecker, Williamson's sapsucker (*Sphyrapicus thyroideus*), flammulated owl (*Otus flammeolus*), western screech owl (*Megascops kennicottii*), northern hawk owl (*Surnia ulula*), northern pygmy-owl (*Glaucidium gnoma*) and northern saw-whet owl (*Aegolius acadicus*). Associations between wildlife trees and both lichens and invertebrates are very poorly documented. These gaps make it difficult to determine the effects of the loss of wildlife trees from ecosystems and to monitor the effectiveness of wildlife tree retention practices.

G. BROADLEAF TREES

What are they? A broadleaf tree is one with relatively wide, flat leaves (as opposed to the needle-like leaves of conifers); in B.C., most broadleaf trees are deciduous, shedding their leaves in autumn. There are at least 17 species of broadleaf trees in B.C. and many more shrubs with similar characteristics. Some of the more common ones are red alder, trembling aspen, paper birch (*Betula papyrifera*), bigleaf maple and the province's only cottonwood – a subspecies of balsam poplar known as black cottonwood. Broadleaf trees are distributed in groups or singly throughout the forested zones of B.C. and, depending on the species, may be associated with riparian ecosystems.

Broadleaf trees, such as trembling aspen (*Populus tremuloides*) provide valuable breeding and foraging habitat for many birds, mammals and invertebrates.
PHOTO: JARED HOBBS.

Why are they important? Despite covering less area in B.C. than conifers, broadleaf trees are used for breeding habitat by more species, including a wider range of birds and mammals. They also provide important foraging habitat for many birds and mammals, and therefore presumably for a wide diversity of invertebrate species.

Trembling aspen and paper birch, as well as other trees, shrubs and herbs, are associated with soil microbes and ectomycorrhizae, which colonize the roots of plants and form a network of fungal hyphae linking the broadleaf trees with neighbouring conifers in mixed forests (see Text box 15, p. 98). When deciduous species are present, carbon transfer and nitrogen fixation in conifers increases, suggesting that the broadleaf species are an essential component for maintaining longer-term ecosystem productivity.[485,486]

Broadleaf trees prevent the spread of the root disease *Armillaria ostoyae* among conifers[487] and reduce attack by weevils and spruce budworm. These species also directly increase productivity of soil by dropping large volumes of leaf and branch litter onto the forest floor every year.

Among the notable broadleaf tree communities in B.C. are black cottonwood ecosystems. Cottonwoods are important wildlife trees (see Section 2.5.1.2-F, p. 108) because they are prone to limb breakage, creating large natural cavities, and because many woodpeckers nest in them and are later followed by secondary cavity nesters. Cottonwood ecosystems are often, though not always, located adjacent to water bodies. They provide habitat for a wide diversity of animals, including species requiring large nesting trees close to water (e.g., great blue heron [*Ardea herodias*], bald eagle [*Haliaeetus leucocephalus*]), as well as black bears and many cavity-nesting ducks and owls. The large size and relatively short lifespan of cottonwoods means that they likely contribute significantly to riparian functioning, with leaf fall providing important organic matter, and inputs of large instream woody debris increasing habitat for fish spawning (and other aquatic breeding species) through pool development.

FIGURE 28: **Loss of black cottonwood / water birch riparian shrub ecosystem in the Okanagan since 1800.**
SOURCE: Prepared for this report with data from T. Lea.

Ecologically, floodplain cottonwood ecosystems tend to include a diversity of ecological communities that are uncommon in B.C., including some of conservation concern. These ecosystems contribute to the structural integrity of stream bank and lakeshore habitats. In many locations, cottonwood ecosystems exist within the flooding zone of streams, rivers and lakes. This species (along with trembling aspen) is thought to act as a nutrient pump in forested ecosystems, whereby nutrients transported by these species into the canopy are released and made available to support other species, such as certain lichens that are found in greater numbers in areas where nutrients are made available by this 'drip zone' effect.[488]

Status/threats in B.C. In some areas, certain forest management practices (e.g., extensive brushing and chemical removal of deciduous species, fire suppression across the broader landscape) have resulted in there being too few young broadleaf trees, both within and outside the managed forest landscape, to replace existing mature broadleaf trees that are close to their natural lifespan of 100 to 150 years.[489]

In the short term, the loss of a mature component of broadleaf species will result in significant reduction of habitat for a diversity of species, including woodpeckers and associated secondary cavity nesters. In the longer term, loss of these trees from regenerating forests, both managed and natural, may have significant productivity impacts due to reduced nitrogen fixation from the loss of mycorrhizal fungi.[490]

Across the province, many cottonwood ecosystems are of conservation concern.[491, 492] The B.C. Conservation Data Centre lists 12 ecological communities of conservation concern that include black cottonwood.[493] Historic losses of cottonwood ecosystems have been significant in some areas. For example, in the Okanagan, 63% of the black cottonwood / water birch riparian shrub forest has been lost since 1800 (Figure 28).[494] Losses are due to a number of factors. Damming of rivers has flooded areas historically dominated by cottonwood ecosystems. Single trees and whole ecosystems are also affected by rural or recreational development and agriculture. In addition, regeneration of the species, and therefore the ecosystem, has been reduced in many areas because of reduced water levels and reduced flooding potential around many lakes (e.g., around the West Arm of Kootenay Lake),[495] since black cottonwoods primarily regenerate after flooding. Climate change also has the potential to influence the distribution of the species through the expected significant increase in frequency of low water flows and reduction in peak flows.

Data gaps: Inventory of broadleaf trees, which have typically been considered non-commercial, is limited. The last inventory in the province was undertaken in the early 1990s, although a new inventory is underway. Black cottonwood is mapped on forest cover maps, but the distribution of the broader riparian ecosystem is not systematically monitored in B.C. No systematic mapping is available for cottonwood ecosystems located on private land, which may be significant. Current forest inventory sometimes omits small occurrences of broadleaf trees.

H. SOIL

What is it? Soil is the naturally occurring, unconsolidated mineral or organic material at the surface of the earth that is capable of supporting plant growth.[496] Different soil types across B.C. are the result of the five factors of soil formation: parent material, climate, organisms, topography and time. Variations in soil properties, such as texture, thickness and mineralogy, are inherited from the parent material; other properties, such as organic content, depth of the weathering zone, and the development of horizons (layers), are the result of soil-forming processes. The four major soil-forming processes – additions, losses, translocations and transformations[497] – are primarily influenced by temperature, precipitation and organisms. Soils are classified by their properties, many of which reflect how the soils are formed. The type and variety of soils found across the landscape both influence, and are influenced by, biodiversity.

Soil layers are formed as a result of several factors and can be a determinant of the vegetation on a site. Drawn lines depict three soil layers above bedrock.
PHOTO: BOB MAXWELL.

Why is it important? Soil represents the dynamic interface between the living organisms, air, water and rock. It supports plant growth and is fundamental to terrestrial ecosystems, including wetlands. Soil consists of mineral material originating from the parent material and organic matter formed by the decomposition of organisms and their by-products. Organic matter provides nutrients to plants, enhances the ability of the soil to hold water and enhances soil structure. It also provides aeration and drainage, promotes long-term site productivity and stores carbon.[498] Soil is created by, and provides habitat for, highly complex bacterial and fungal communities, which are instrumental in decomposition and nutrient cycling (see Text box 15, p. 98), as well as diverse communities of invertebrates (e.g., nematodes, roundworms and arthropods), which act as **detritivores** and provide a food source for ground-foraging vertebrates such as shrews (*Sorex* spp.). Soil also influences larger animals, whose uses of soil include burrowing, nesting, travelling, cooling and obtaining minerals from mineral licks.

Soil is critical to future ecological response to climate change. Enduring landscape features such as parent material and topography will remain essentially the same as climate, biota and disturbance regimes change. Soils change over a longer time scale than individual plants and animals and retain characteristics and clues to past ecology and disturbance (e.g., floods, charcoal from forest fires, excavation, landslides, volcanic deposits and pollen). Different soil types may also act to buffer or amplify climatic, anthropogenic and ecological changes.

Status/threats in B.C. From a global perspective, soils in B.C. are generally believed to be in good condition, as impacts tend to be localized. The human activities that have had the largest impacts on soil are urban development, mining, forestry, grazing, creation of reservoirs and oil and gas development. Rural development and agriculture convert ecosystems, and the soil that remains tends to have much reduced value to biodiversity.

Forestry is one of the most widespread human activities affecting soil in B.C. The primary impacts from forestry are compaction through the construction and use of roads and landings, loss of soil material due to destabilization and hydrological processes, the resulting increased sedimentation in streams, and the reduction of organic matter inputs. Most organic material taken to a landing or mill is material that eventually would have become part of the soil. Grazing can also result in soil compaction and/or erosion, especially in riparian areas. Oil and gas development results in compaction through the construction and use of roads, well sites, pipelines and other facilities, as well as environmental contamination of soils in localized areas. Oil and gas drilling waste includes petroleum hydrocarbons.[499]

Also impacted by livestock trampling is a unique and rare type of soil cover known as the cryptogamic crust (also known as the microbial, microfloral, microphytic or cryobiotic crust) – a thin layer of lichens, mosses, liverworts, algae, fungi and bacteria that is found in undisturbed semi-arid ecosystems. It can be found on either soil or non-soil surfaces. The cryptogamic crust layer is important to water retention in the arid parts of the province.[500] The cryptogamic crust in grassland communities in low-elevation areas of B.C. has mostly disappeared as a result of ecosystem conversion. In the isolated pockets where the cryptogamic crust still occurs and livestock have access, they can trample the crust and break it up.[501]

Data gaps: Because soil organisms are often microscopic or out of sight, there is widespread lack of information about them (See Text box 14, p.88). Some of the most obvious gaps are: knowledge of basic biodiversity found in soils, including inventories for single-celled organisms, fungi and microfauna; lack of taxonomic expertise to carry out these inventories; knowledge of specific functions of soil organisms, including how they are involved in maintaining specific physical and chemical conditions and how they contribute to ecosystem resilience and stability; knowledge of how climate change will affect the redistribution of soil organisms and the resulting impacts on soil processes; and knowledge of impacts of large-scale human disturbances (e.g., forest harvesting, fertilization, urban and rural development) on soil biodiversity and related functions.

Soils inventory mapping covers less than 50% of the province. For provincial-level modelling, 100% coverage would be desirable. Provincial soils data were collected between the 1930s and the early 1990s. Soils data are not easily accessible and are in a variety of formats.

Shallow soils on rocky terrain are associated with distinctive ecosystems and are widespread within B.C. These soils have not been well studied or described.

I. COARSE WOODY DEBRIS / LARGE WOODY DEBRIS

What is it? Coarse woody debris (CWD) is large pieces of wood, generally greater than 10 cm in diameter, on or near the forest floor, and includes sound or rotting logs, stumps and large branches that have fallen or been cut (standing dead trees are discussed in Section 2.5.1.2-F, p. 108).[502] In aquatic environments, this material is called large woody debris (LWD) or large organic debris.

Why is it important? Coarse woody debris is important in both forest and aquatic ecosystems for several reasons.[503,504] CWD contributes to stand-level diversity in old-growth and mature forests, providing habitat for feeding, reproduction and shelter for many organisms including invertebrates, small mammals and amphibians. It provides nutrients and habitat for various bacteria and fungi (see also Section 2.5.1.2-A, p. 97), as well as saprophytic plants,[a] lichens and mosses that are important for decomposition and nutrient and water cycling. It also acts as a refugium for displaced species where it persists during and after disturbances, can buffer microclimates for the establishment of seedlings, and it stores carbon.

In aquatic and riparian ecosystems, LWD shapes and stabilizes streambanks and prevents erosion.[505] When it falls into streams, it disperses stream energy and enhances fish habitat by creating pools, gradual steps, gravel bars and riffles. Large woody debris releases nutrients and increases the retention of organic debris from upland sources, which is then decomposed by stream organisms.

Status/threats in B.C. In the aquatic environment, the absence of LWD has a negative effect on the stability of stream structure and on the species that use it as habitat. Removal of wood from large rivers can result in altered channel structure and have long-term effects.[506] Long and large-diameter pieces of CWD take longer to decay than smaller pieces and therefore add structure over a longer time period. They are rarer in harvested sites compared to natural areas.[507,508]

Data gaps: There are still many unanswered questions about the role of CWD in forested ecosystems and the ability of these functions to be maintained in systems with diminished piece size. In freshwater systems, particularly large rivers, there is a lack of information on the life cycle of LWD and its effect on fish habitat.[509]

2.5.1.3 FRESHWATER ELEMENTS

A. WETLANDS

What are they? Freshwater wetlands are areas where fresh water is at or near the surface for most of the year. They include bogs, **fens**, swamps and marshes. Temporary wetlands provide habitat for a number of extremely rare taxa.[510]

[a] Plants that grow on, and derive their nourishment from, dead or decaying organic matter.

Wetlands host a disproportionately high number of species for their size.
PHOTO: BRUCE HARRISON.

Why are they important? Wetlands provide habitat for many species and fulfill a broad range of ecological functions. The largest wetland complexes in B.C., such as the Columbia Valley wetlands (see Section 2.5.2.3-A, p. 145), are internationally significant. The province's more numerous small wetlands make major contributions to biodiversity;[511] they cumulatively create wetland complexes (which are important features in many landscapes) and may be interconnected.[512] Temporary wetlands (seasonally flooded wetlands that have both a wet and a dry regime, which vary in timing, frequency and duration) are important for amphibians[513] and invertebrates,[514] as well as for zooplankton and plant species.[515]

Wetlands buffer environmental extremes by absorbing and filtering sediments, pollutants and excess nutrients, recharging groundwater, maintaining stream flows, controlling runoff, storing flood waters, reducing erosion and stabilizing shorelines. They also help regulate atmospheric gases and climate cycles. In brief, wetlands absorb water quickly and release it slowly, with its quality improved.

The contribution of wetlands to biodiversity and to ecological functions maintaining both terrestrial and freshwater systems is disproportionate to their size. Wetlands are areas of high species richness. A large proportion of B.C.'s terrestrial vertebrate species rely on wetlands to meet some of their needs or use wetland habitat at some point in their life cycle, and more than 30% of the province's species of conservation concern are wetland-dependent.[516]

Status/threats in B.C. Wetlands are estimated to comprise about 7% of the province's area, but are decreasing rapidly. Because they tend to occur in low-lying areas suitable for agriculture and settlement, wetlands are among the most heavily impacted ecosystems worldwide. They are subject to many impacts that reduce their suitability as habitat, including removal of water, siltation, pollution, water diversion, ecosystem conversion to urban and agricultural uses, and general human disturbance.

The Okanagan River is almost completely channellized, contributing to the loss of about 85% of the original wetlands in the south Okanagan.[517] Many of the wetlands in the lower Fraser Valley have also disappeared, with the diking and drainage of 85% of the wetlands in the Fraser River delta[518] (see Text box 7, p. 43) and the complete eradication of the once-rich Sumas Lake wetlands. Between 1989 and 1999, approximately 20% of the wetlands in the Fraser Valley between Hope and Vancouver were impacted by urbanization or agriculture,[519] including peatland drainage in the Fraser River delta. On the east coast of Vancouver Island, there was a loss of approximately 32% of salt and estuarine marshes between the early 1900s and 1988,[520] and a loss of 2% of freshwater wetlands between early 1990s and 2002.[521] Agricultural reclamation of wetlands in the Cariboo-Chilcotin has contributed to ecosystem conversion and degradation in that region.[522]

Climate change could jeopardize shallow wetlands and their contributions in the B.C. interior, and rising sea levels could inundate coastal wetlands.[523,524]

Data gaps: Although the wetland and riparian ecosystem classification of British Columbia is well developed,[525] not all of the province has been surveyed. Smaller wetlands are not well surveyed or inventoried. Temporary wetlands are not included in any surveys.

B. SPHAGNUM

What is it? *Sphagnum* mosses (commonly known as peat mosses) are bryophytes that inhabit and distinguish wetland ecosystems characterized by their acidic environment and an accumulation of organic matter (peat). In B.C., significant *Sphagnum* ecosystems are found in the boreal forests of the northeast and along the coast.[526] Burns Bog is a well known *Sphagnum*-dominated bog found in southwestern British Columbia (see Section 2.5.2.3-A, p. 145).[527,528]

Why is it important? The morphological, chemical and physical properties of *Sphagnum* species contribute to the development of the wet, nutrient-poor, acidic environments in which they flourish.[529] By raising the peat surface, acidifying its environment and absorbing 10 to 20 times its dry weight in moisture, *Sphagnum* has a disproportionate impact on its surrounding environment and plays a significant role in wetland succession.[530] *Sphagnum* is required to fix the acidity of the bog ecosystem to allow the succession of other wetland species.[531]

Acidic and nutrient-poor environments created by peat mosses are unique ecosystems in which only a few specialized species are able to thrive. These ecosystems contain rare species such as the subarctic darner (*Aeshna subarctica*) and Pacific water shrew.[532,533] Environments created by *Sphagnum* also provide habitat for waterfowl.

Peat bogs created by *Sphagnum* are of international significance for their role in mitigating the effects of climate change by trapping greenhouse gases such as CO_2 and methane, which otherwise would be released during decomposition processes.[534] *Sphagnum* environments control run-off, act as catchment areas and provide repositories for natural and anthropological history preserved in organic layers.

Status/threats in B.C. Ecosystem conversion, predominantly through peat mining, is the main threat to coastal *Sphagnum*. Sites are generally small and therefore susceptible to disturbance. Clearing the top layers, such as for agriculture, releases methane, contributing to climate change. Flooding destroys the habitat. Adjacent agricultural development also has the potential to introduce chemicals, altering the environment and species succession.

Drainage allows other species to become established, and once bogs have been drained, natural regeneration of *Sphagnum* is difficult. Harvest is a threat to *Sphagnum* located near urban environments. Although these plants can cope with seasonal and daily surface temperature fluctuations and periodic drought, *Sphagnum* species are susceptible to long-term changes due to climate change. Repeated burning is not favourable to their survival. Oil and gas development is a threat to *Sphagnum* ecosystems in northeastern B.C.[535]

Data Gaps: There are significant gaps in knowledge of life history strategies, including dispersal, of *Sphagnum* species.[536] Although they are found in locations with regular fire occurrence, the influence of fire on these plants is poorly understood.[537] There is no systematic inventory of *Sphagnum*.

C. LAKE-LEVEL PATTERNS

What are they? Many lakes are characterized by predictable temporal water-level patterns.[538] The regular pattern of lake levels is affected by several aspects of climate (e.g., precipitation, temperature, humidity) and by physical setting (e.g., geology, basin shape, basin size). Natural lake-level patterns vary considerably among geographic regions of the province. Many natural lakes in B.C. have water licenses allowing drawdown and others have been modified by the addition of weirs to manage lake levels. These changes create water bodies that are part natural lake and part reservoir. This key element includes these modified lakes, but does not include the entirely artificial water bodies created by dams.

Why are they important? Emergent and submerged aquatic **macrophytes** (large aquatic plants) are the dominant structural component of shoreline habitats. They provide food and shelter for a wide variety of invertebrate, fish and wildlife species. Vegetation responds to strong gradients between the terrestrial and aquatic interface and under most natural conditions there is strong zonation of vegetation along this gradient from forest and shrub thicket to wet meadow to marsh to aquatic.[539] The wet meadow and marsh zones are found solely within the area affected by fluctuating water levels.

Fluctuating water levels are considered the most important factor determining vegetation patterns on lakeshores, although other factors, such as wave exposure, soil or sediment type, and species interactions are also influential. Under most natural conditions, water level fluctuations occur due to seasonal changes in precipitation and surface/groundwater inflows, as well as discharge and evaporation. Climate will influence precipitation and temperature (evaporation), while the physical setting will influence surface and subsurface flows.

As a lake's water level drops, wetted areas are exposed and the zone where light levels are sufficient for plant growth (the photic zone) shifts deeper in the lake basin.[540] The frequency, duration and magnitude of drops in the lake level determine the effect on vegetation and some animal species. For example, lake sockeye salmon need stable lake levels for successful reproduction.[541,542]

Status/threats in B.C. Humans affect lake levels through dams, water diversions and extractions, and land use changes. We do not know the extent of these impacts and they may increase in response to climate change. Climate change is already having noticeable effects on streamflow patterns in some areas of B.C., which will likely affect lake levels.

Altered lake levels affect the quantity and quality of shoreline and riparian habitats, and the abundance and distribution of aquatic and riparian organisms.[543] As water level fluctuations increase in magnitude, there is often a decrease in the extent of the shoreline zone as high-elevation areas are inundated insufficiently to support emergent species and too frequently to support upland vegetation. Low-elevation areas are unproductive because the photic zone does not extend to these areas for enough time to allow establishment of submerged macrophytes.

Lake drawdowns of 5–7 m can completely remove macrophytes from the shoreline zone.[544,545,546,547] Relatively minor shifts in average annual water levels (plus or minus 10 cm) or in water level fluctuations can produce substantial changes in the vegetation community, and species changes are common even after a single drawdown.[a,548,549] Stabilized water levels are also capable of significant effects on the diversity of macrophytes in the shoreline zone.[550]

It has also been suggested that drawdowns in lakes can cause algal blooms (visible aggregations of algae in or on the surface layer of a water body) when nutrients are released from exposed shoreline areas, causing a subsequent limited uptake of nutrients in shoreline habitats.[551,552] Shoreline zone invertebrate populations can be severely reduced by drawdown and many studies have shown correlations between fish abundance and diversity and altered lake-level patterns.[553,554,555]

Data gaps: The effect of water level and drawdown on macrophyte distribution and abundance has been fairly well studied, though results have been variable due to differences among studies in lake geology and physical characteristics, species affected and differences in drawdown scenarios.[556]

D. HEADWATER STREAMS

What are they? Headwater streams are found at the top end of stream systems. They are often steep streams dominated by bedrock sills and influenced by landslides that deliver boulders and other sediment to the channel. Headwater streams can represent half of the total length of a river system.[557]

Steep headwater streams provide habitat for many aquatic invertebrates and some specialized amphibians.
PHOTO: TORY STEVENS.

[a] The magnitude of fluctuations is one of the primary differences between reservoirs and natural lakes, and causes extirpation of shoreline vegetation from most hydropower reservoirs.

Why are they important? These small streams are critical for input of water and sediments, for nutrient dynamics and for the addition of most of the coarse particulate organic matter[a] in stream systems. Most (70–90%) of the coarse organic particulates are transported downstream,[558] where they provide a food source for stream invertebrates that in turn feed larger organisms. Headwater streams are strongly linked to adjacent slopes. Landslides account for most of the sediment in headwater channels.[559]

While steep headwater streams tend to be fishless, they provide habitat for many aquatic invertebrates, and low-gradient headwater streams are among the most productive environments in a river system because of the retention of organic material. For solely aquatic species (e.g., fish), headwaters can be geographically isolated from one watershed to the next. This means that they are also genetically isolated, which accounts for the genetic variability within these species between headwater systems.[560]

Status/threats in B.C. Although headwater streams make up more than half the length of a stream system, they are often so small that they are not mapped or considered in resource management, which puts them at greater risk than other streams.[561] This is particularly true if they are not fish-bearing.

Much of the structure and many of the processes within streams, including headwater streams, are determined by relationships with adjacent ecosystems, particularly the riparian zone. The status of adjacent riparian systems affects:

- microclimate (light, temperature and humidity);
- nutrient input from hill slopes (riparian zones modify amount, form and timing of nutrient export from watersheds);
- contribution of large woody debris (see Section 2.5.1.2-I, p. 113);
- contribution of organic matter (much of the food base for stream ecosystems comes from adjacent terrestrial sources); and
- retention of inputs to LWD jams and smaller organic debris accumulations.

Data gaps: The importance of headwater streams to downstream ecosystems is not well known. There is no measure of the amount of headwater area that has been degraded by roads, timber harvesting, mineral exploration and mining in B.C.

[a] Coarse particulate organic matter is particles of organic matter (leaves, wood, etc.) that are >1mm in size.

E. GROUNDWATER

What is it? Surface waters in the form of rivers, lakes and wetlands are the most readily apparent component of the hydrologic cycle, but in most areas of B.C. there is a strong interaction between surface flows and groundwater (see also Section 2.5.1.1-B, p. 94). This interaction is apparent when surface flows in perennial streams continue long after precipitation or snowmelt runoff events. Groundwater is recharged by infiltration from precipitation and surface flow and, depending on the depth of the water table and subsurface geology, groundwater may be subsequently released as surface flow.[562,563] The release of groundwater to surface water provides most of the base flow for many streams through periods of no precipitation, or during winter when precipitation is locked up as snow or ice.

Bull trout (*Salvelinus confluentus*) sometimes use cool groundwater upwelling sites for spawning and incubation.
PHOTO: JEFF STRAUSS.

Why is it important? A minimum flow is important to organisms such as fish, not only as a constant medium in which to live, but also because of the ameliorating effects on extreme temperatures by groundwater inputs.[564,565] In winter, groundwater releases are typically warmer than ambient surface water and may prevent freezing conditions in spawning and rearing areas.[566,567] In summer, groundwater is often cooler than the ambient temperature, which can help keep stream temperatures within the thermal tolerance limits of cold-water fish species.[568] Many fish congregate near groundwater sources at different times of year. For example, bull trout sometimes use groundwater upwelling sites for spawning, and incubation at these sites is considerably more successful than in adjacent non-upwelling sites.[569] Similar results have been reported for spawning salmon in lakes, streams and reservoirs.[570, 571,572,573] Migrating adult chinook salmon sometimes take advantage of cool groundwater upwelling sites at times when many nearby stream locations are beyond their physiological thermal limits.[574,575]

The hyporheic zone is thought to be a critical refuge for surface-dwelling invertebrates, and most insect families and other groups that live in surface waters have also been collected from the hyporheic zone.[576,577] Nutrients released to surface waters from the hyporheic zone influence surface water quality and productivity, to the point of creating productivity hot spots in some instances.[578,579]

Changes to groundwater resources have varying impacts on biodiversity, depending on the physical and ecological setting. Some species in the diverse hyporheic community, such as bull trout, depend directly on groundwater resources.[580] Other species and communities are less dependent, but large and measurable adverse consequences are nevertheless likely. For the many species of fish that use groundwater upwelling areas as spawning habitat or holding habitats during migrations, loss of these features could reduce incubation success and raise physiological stress levels; both could potentially decrease the abundance of adult and juvenile fish and lead to replacement by more thermally tolerant species. Lower water tables can have profound effects on riparian and floodplain vegetation, with cascading effects on local biodiversity and physical effects, such as lower streambank stability.

Status/threats in B.C. Overall, groundwater resources are of considerable concern in a number of locales in B.C., particularly in the southern portion of the province where agricultural, municipal and industrial demands for groundwater are highest. Approximately 25% of B.C. residents obtain drinking water from groundwater sources.[581] Thirty-five aquifers were designated as 'heavily used' in 2001, up from 17 in 1996.[582] Monitoring data indicate that groundwater levels are declining in areas where groundwater withdrawal and urban development are most intensive.[583]

Groundwater and surface water can be influenced directly by a number of factors, including climate, land use, water use and industrial activities. How each of these act within a particular watershed is rarely straightforward, but there are many examples linking human activities to changes in quality and quantity of groundwater and surface water, and interactions between the two water sources. These include the following:

- When groundwater is removed for human use there can be direct, measurable influences on stream flow.[584,585]
- Changes to water table levels can significantly influence riparian vegetation.[586]
- Surface changes, such as river regulation, sediment inputs or eutrophication, have a direct impact on water table levels by altering infiltration and exfiltration rates.[587]
- Release of contaminants into surface waters can infiltrate and alter groundwater quality.[588]
- Groundwater recharge rates are closely linked to temperature and precipitation, which are expected to change due to climate change.[589,590]
- Impervious surfaces, such as pavement, can have a large influence on runoff and groundwater recharge, with effects on minimum and peak stream flows.[591,592]
- In agricultural settings, changes in land cover, drainage and irrigation can have severe impacts on stream flows.[593,594,595]

Data gaps: There are large uncertainties about where groundwater is, how it moves, locations and rates of groundwater–surface water exchange, aquifer recharge rates, and impacts of land use, water use and climate change. In B.C., work is underway on hydrologic modelling and measurement of some high-value aquifers, and stream and lake ecologists are starting to incorporate knowledge of groundwater dynamics into their studies.

F. ANADROMOUS SALMONIDS AND NUTRIENT CYCLING

What is it? Fish that breed in fresh water and spend at least part of their adult life in a marine environment (i.e., anadromous fish) play a significant role in nutrient cycling bringing marine nutrients to terrestrial and freshwater ecosystems. Anadromous salmonids found in B.C. are chinook, chum, coho, pink and sockeye salmon, and steelhead. Some other species are partially anadromous and are not included in this discussion.

Anadromous populations are found throughout the Fraser River system and almost all coastal systems. Historically, anadromous salmon reached Columbia Lake in the headwaters of the Columbia River, but they have been extirpated from the upper Columbia River due to impassable dams in the U.S. Anadromous populations are absent from the Kootenay River system due to natural barriers. They are also absent from the Peace River drainage, which drains east into the Mackenzie River system.

Why is it important? The majority of freshwater systems in B.C. are oligotrophic (i.e., nutrient-poor). This means that the inherent productivity of these water bodies is low and the abundance and biomass of fish that can be supported is also low. Anadromous salmonids act as a nutrient pump, bringing nutrients from the ocean to nutrient-poor interior waters. They hatch in freshwater streams (and occasionally in lakeshore areas) and migrate to the ocean after a variable amount of time in freshwater. After growing and accumulating most of their body tissue in the ocean, they return to their natal streams and lakes to reproduce and then die. Anadromous salmon may return in large numbers, and this returning biomass brings marine-derived nutrients into freshwater ecosystems and supports many terrestrial and freshwater species. They are a limiting food resource for a wide variety of vertebrates and invertebrates, including both predators and scavengers.[596]

Many adults are caught and consumed en route to or on the spawning grounds, eggs are eaten by birds and fish, and the carcasses of spawned-out salmon provide a substantial input of nutrients to many freshwater and terrestrial systems (Figure 29).[597,598] When the young hatch the following spring and summer, they are the prey base for many more species. Stream- and lake-rearing juveniles are often the dominant component of the fish community.

There is some evidence of positive feedback between present and future salmon runs due to the profound nutrient inputs provided by returning adults.[599,600] The nutrients from the adults increase **macroalgae** production in estuaries, boosting the productivity of crustaceans, which become prey for salmon smolts. Lower returns lead to lower nutrient levels in lakes and rivers, which reduces the carrying capacity of these water bodies and thus the ability to support fish. Lower abundance or loss of this element would lead to lower abundance of many terrestrial

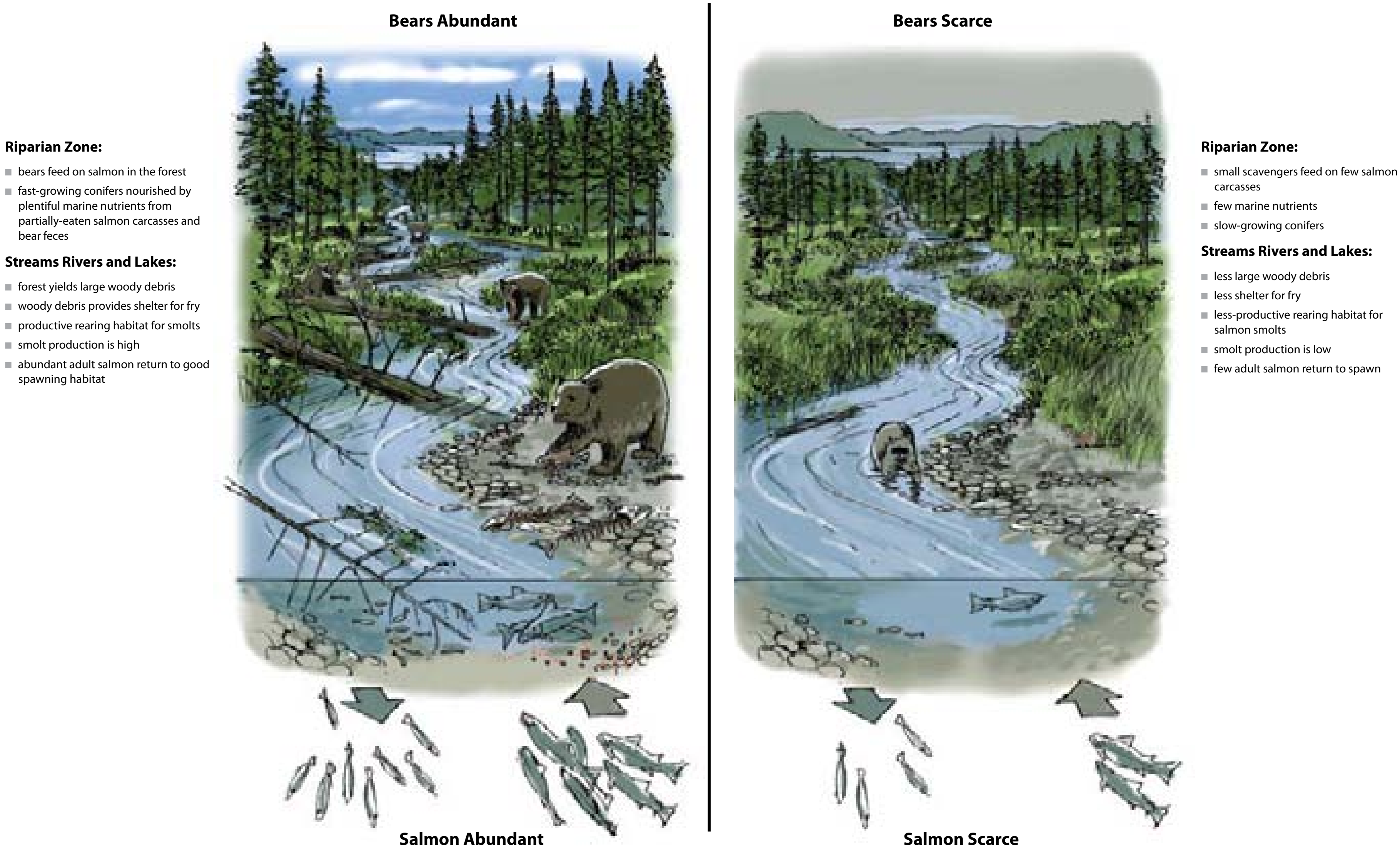


FIGURE 29: **The relationship between salmon returns, bears, riparian forests and future salmon productivity.**
ILLUSTRATION: Soren Henrich

and freshwater species and lower overall productivity in many freshwater bodies. Conversely, there is evidence that smolts returning to the ocean can represent a potential loss of nutrients from the freshwater system to the marine.[601,602]

Status/threats in B.C. The approximate number of populations for each species is: chinook salmon (780), chum salmon (1,450), coho salmon (2,400), pink salmon (2,100), sockeye salmon (900) and steelhead (850).[603] In the mid 1990s, 5,487 British Columbia and Yukon anadromous salmonid populations were assessed; 19.6% of these were of conservation concern (i.e., high conservation concern, moderate conservation concern or special concern) or extirpated.[604] Although the rest of the assessed populations were not below a threshold for conservation concern, many are likely below historic abundance levels. Many of the populations of conservation concern are small. Most of the populations that were not assessed are also small and are therefore likely to be of conservation concern. Many of the ecosystems with smaller populations may be becoming progressively oligotrophic due to declining inputs of marine-derived nutrient inputs.[605]

In the late 1990s, the sockeye salmon runs in the Owikeno Lake system of the central coast collapsed, with returns reaching a 50-year low in 1999.[606] That fall there was a dramatic increase in the number of conflicts between humans and grizzly bears at the nearby community of Rivers Inlet. Ten grizzly bears were destroyed and three more were translocated.[607] Monitoring from 1998 to 2002 documented a decline in grizzly bear use of salmon streams in the area and indicated that switching to alternative food sources such as berries is not a viable option for most bears when salmon abundance is low. These results suggest that the population declined in response to the dramatic reduction in this critical food source.[608]

Because of their complex life histories, anadromous salmonids are vulnerable to changes in biophysical processes or disturbance regimes that occur throughout the watersheds they inhabit. During the freshwater part of their life cycle, they are affected by harvesting, land and water use, pollution, alien species and climate change. Impacts such as riparian ecosystem conversion or degradation, alteration of drainage patterns and pollution are additive and may produce a large incremental effect if combined with other activities.[609] Sources of ecosystem degradation include construction of dams and stream crossings, water **impoundment**, land clearing (related to urban development, agriculture or logging), mining and gravel removal. Increased runoff increases nutrient levels, erosion, and sedimentation in streams. Removal of riparian vegetation raises water temperature.[610]

Climate change is expected to have severe impacts on freshwater fish distributions in B.C. through effects on precipitation,[611] streamflow[612] and water temperatures,[613] and range changes in native and non-native species.[614,615,616,617,618] Pacific salmon are highly vulnerable to the effects of changes in freshwater flows and temperature. Low water flows in the late summer can block access to spawning grounds, while winter flooding can wash eggs out of the gravel. Rising water temperatures in the Fraser River are expected to delay sockeye salmon migration and reduce enroute survival. Thirty-two areas, centered in southwestern B.C. and the southern and central interior, have been identified as being uniquely vulnerable because they have water temperatures or low/high freshwater flows that currently affect salmon survival.[619]

Within the marine realm, B.C. salmon are affected by a number of impacts and threats, including harvesting, aquaculture and climate change. Harvest rates vary over time and among populations, but can exceed 50% for targeted populations.[620] Harvest rates can be unsustainably high for populations of conservation concern that are harvested incidentally.[621,622,623] Known and suspected impacts of marine aquaculture operations on wild salmon include competition from, and interbreeding with, escaped farm fish, and the spread of diseases or parasites such as salmon lice (*Lepeophtheirus salmonis*).[624] Climate change is expected to influence several environmental variables that may affect salmon during the marine portion of their life cycle; of these, sea surface temperature is likely to be the most significant.[625]

Data gaps: The ecology of anadromous salmonids is well known and commercially harvested populations are well studied. However, there is limited information on smaller populations. The effects of land and fisheries resource management practices on salmonids and nutrient cycling are not well understood.[626] There are also uncertainties regarding the nature and strength of interactions with other species and with ecosystems.

G. WILLOWS

What are they? Willows are deciduous trees and shrubs in the genus Salix that grow in moist habitats from the high Arctic to the tropics.[627] B.C.'s more than 48 native willow species range in height from tall trees to low, carpet-forming shrubs, and grow in habitats ranging from upland forest and alpine tundra to the full spectrum of wetland types.

Why are they important? Willows are common within riparian areas and swamps. They provide structure, reduce water flows, stabilize stream banks and are a food source for species such as American beavers (*Castor canadensis*), moose, snowshoe hares (*Lepus americanus*) and grouse (e.g., willow ptarmigan [*Lagopus lagopus*]).[628] The specialized root system of willows allows them to thrive in conditions that are potentially limiting to other woody plants, such as the high water table in swamps. Willows grow prolifically in a variety of nutrient-poor ecosystems and have the ability to grow from broken branches.

Status/threats in B.C. Nine species and one subspecies are of conservation concern. All of the province's native willows are at the geographic margins of their ranges in B.C., with the core of their ranges to the north, east or south, so some species could be expected to be rare in the province. However, some may be more common than is recorded, since willows are difficult to identify and some occur in remote places. Glabrous dwarf willow (*S. reticulata* ssp. *glabellicarpa*) is only found in B.C. and Alaska, and is of global conservation concern.[629]

An introduced weevil, the poplar and willow borer (*Cryptorhynchus lapathi*), has spread widely in the past 30 years and has been killing willows at low elevations and latitudes.[630] It is spreading north along highways and logging roads and is expected to extend its range north and to higher elevations with climate change. In B.C., this species primarily attacks young willow stems, which are often killed by larval feeding.[631]

Data gaps: The spatial distribution of willow species is not documented. The tendency of willows to hybridize creates complications in tracking species.

H. BEAVERS

What are they? The American beaver, North America's largest rodent, is a keystone species that plays a large number of functional roles in freshwater ecosystems and riparian forests. Because of their profound influence on the physical structure of the ecosystems they inhabit, beavers are sometimes called ecological engineers.

American beavers (*Castor canadensis*) are sometimes called ecological engineers because their presence in an ecosystem has such a dramatic effect on the physical environment.
PHOTO: JEFFREY HOCHSTRASSER.

Why are they important? The beaver is the only non-human species that impounds water by constructing dams that flood or maintain flooding in significant areas. By cutting down large numbers of trees and shrubs, beavers change the course of succession and vastly influence ecosystems and species.[632, 633] Impoundment by beavers can create wetlands and wet meadows, and, in the process, create habitat for other species. The subsequent flooding and killing of standing trees provides habitat for many cavity-nesting species and foragers. Over the long term, wetlands silt up to form highly productive meadows and riparian habitat. The process of damming reduces channel scouring and erosion, changes sediment loading and flow regimes downstream, recharges groundwater levels, regulates water flow and can create cold springs, resulting in better conditions for cold-water fish species such as trout. Beaver dams may also form warm-water pools.[634]

The removal or addition of beavers in a particular area will often profoundly change local habitat types. Removing beavers generally results in the loss of beaver dams in the short term (unless they have been established for significant periods and are maintained by stream processes) and subsequent loss of standing water, removal of habitat for associated freshwater and terrestrial species, and significant changes in downstream hydrology.[635] This process will influence habitat availability for other animals, including terrestrial birds, mammals and amphibians and many aquatic species.[636]

Status/threats in B.C. In B.C., the estimated beaver population is 400,000 to 600,000 and this species is not of conservation concern.[637] However, the habitats of the beaver – wetlands and free-flowing rivers – have been extensively impacted throughout lower elevations, particularly in the province's southern regions. Hydroelectric impoundment, rural and agricultural development, and forestry activities have affected historic habitat, and local populations have likely been impacted in these areas.[638] Localized changes to beaver populations due to trapping have been observed, and habitat changes have resulted in local extirpation.[639]

Beavers are not native to Haida Gwaii/Queen Charlotte Islands and their introduction to these islands has caused significant habitat degradation, to the extent that water flow has been reversed across parts of Graham Island.

Data gaps: There are no significant data gaps. However, the potential impacts of small-scale hydro projects on beavers and their associated habitats are unknown.

I. WATERFOWL HERBIVORY OF AQUATIC PLANTS

What is it? In aquatic habitats, waterfowl forage on plants that are emergent (leaves above the water surface), submergent (below the surface) and floating.

Why is it important? Since waterfowl herbivory changes the competitive hierarchy of plant communities within a wetland, it affects species abundance and the composition of plant communities.[640,641] A reciprocal relationship also exists, as the abundance and distribution of plants provides an important food source for waterfowl and, therefore, their abundance and species composition. In particular, waterfowl herbivory can be a regulating factor in submerged aquatic plant populations in shallow sheltered areas.[642]

Herbivory was only recently identified as an important factor affecting the community structure of macrophytes.[643] Traditionally, the breakdown of aquatic plants into detritus was assumed to be the most important mechanism for bringing this plant material into the food web. It is now thought that waterfowl grazing plays major role.[644]

Status/threats in B.C. There is uncertainty about the relationship between waterfowl herbivory and the loss of freshwater ecosystems. The main threats are the loss of wetlands and the potential local overpopulation of some waterfowl species.

Data gaps: There is a lack of information about the magnitude of the effect of waterfowl herbivory on aquatic plants, and about spatial and temporal differences in these plants and waterfowl species in different parts of B.C.

2.5.1.4 MARINE OVERLAP ELEMENTS

A. MACROALGAE

What are they? Macroalgae are commonly known as seaweeds and include numerous species, such as those that constitute kelp beds or 'forests' (e.g., *Nereocystis luetkeana*, commonly known as bull kelp or bladder kelp). Kelp forests are usually found in a 100-m-wide band along the shore and are components of the intertidal zone in B.C.

Why are they important? Macroalgae provide habitat, particularly nursery areas for juvenile fish and invertebrates, and are the major primary producer in the shallow ocean margins.[645] Organisms graze on them directly, they break apart and become detritus, and eventually become part of the ocean environment as dissolved components. They are also an important source of nutrients when they wash up on beaches.[646] Kelp forests are large, three-dimensional structures that provide habitat and a significant source of food to marine ecosystems from the detritus of the abundant drift algae associated with kelp forests, thus supporting a large variety of invertebrates and fish.[647,648,649,650,651] Kelp forests dampen wave heights and tidal currents, and can influence dispersal, settlement rates and recruitment of benthic invertebrates and rockfish.[652]

Status/threats in B.C. Macroalgae populations in B.C. are generally stable, but some changes in local distribution and abundance have been observed.[653] The recovery of sea otter (*Enhydra lutris*) populations and climate change will influence macroalgae populations.[654]

Data gaps: Mapping of macroalgae on the B.C. coast is incomplete.

B. CALIFORNIA MUSSELS

What are they? The California mussel (*Mytilus californianus*) is a large **bivalve** mollusc that forms extensive aggregations attached to bedrock on exposed intertidal shores (and is also subtidal at high-current sites). The California mussel is found from Alaska to Baja California.

Why are they important? This mussel, particularly when it forms extensive mussel beds, is critical to intertidal ecosystems as a **primary consumer**, prey for a number of species and provider of habitat for a large community of species. More than 300 other species inhabit the interstices of established California mussel beds.[655]

Status/threats in B.C. For the most part, California mussel populations in B.C. are stable and near historic levels. Across their range, mussels have declined in both number and size in association with proximity to human settlement, due to recreational harvesting. Declines of extensive beds of large mussels have been documented

Well-established California mussel (*Mytilus californianus*) beds provide habitat for many other species, which inhabit the spaces between the mussels.
PHOTO: PHIL BAILEY.

on the west coast of Vancouver Island, with a shift toward scattered patches of small individuals and an associated decline of predators and community abundance.[656] As California mussels generally recruit to established beds, recovery from disturbance is slow.[657] Ocean acidification is a threat to California mussels (Text box 17). Climate change may already be affecting populations in some areas outside B.C.[658]

Data gaps: Mapping of California mussels on the B.C. coast is incomplete.

C. SEA OTTERS

What are they? Sea otters are marine members of the weasel family that use the intertidal zone when it is inundated. Sea otters live in cold oceanic water, but have no body fat. They survive through a combination of a very high metabolic rate and highly insulative fur. Their metabolic rate is such that they consume between 23 and 33% of their body weight per day.[659] Sea urchins (*Strongylocentrotus* spp.), where available, make up much of their diet, particularly where sea otters have been recently reintroduced and the sea urchin population is high.

Why are they important? Sea otters are a prime example of a keystone species.[660] Where sea otters occur, sea urchin populations are small and confined to cracks in the substrate or under boulders.[661] From these protected locations, sea urchins switch their feeding strategy from actively grazing kelp to passively feeding on the abundant drift algae associated with kelp forests.[662] In the absence of sea otters, sea urchins suppress kelp forests with cascading ecological effects.

Status/threats in B.C. The sea otter is a species of conservation concern in B.C. Once abundant along much of the B.C. coast, sea otters were extirpated from B.C. by the early 1900s. Relocations from Alaska between 1968 and 1972 successfully established colonies in Checleset Bay (now protected as an ecological reserve) and Hakai Luxvbalis Conservancy Area.[663] The sea otter has since repopulated 25–33% of its historic range in B.C., but is not yet considered secure, as populations are small (less than 3,500).[664]

Sea otters are threatened by oil spills, disease and parasites, low genetic variability, marine biotoxins, contaminants, entanglement in fishing gear, collisions with vessels, poaching and human disturbance.[665] Of these, oil spills are the most significant risk.

Data gaps: There has not been a complete population count in B.C. since 1995. Little is known about the interchange between individuals in different populations and about habitat use. It would be helpful to clarify the importance of threats other than oil, such as disease, predation and entanglement in fishing gear.

TEXT BOX 17. OCEAN ACIDIFICATION

Increased CO_2 in the atmosphere is having impacts beyond climate change. The ocean acts as a sink for CO_2, but this affects the acidity of seawater.[666] If global emissions continue to follow current trends, the average acidity could rise to a level higher than it has been for hundreds of thousands of years, representing a rate of change 100 times greater than at any time during this period. It could take tens of thousands of years to return to conditions similar to pre-industrial times.

Increasing seawater acidity gradually depletes the concentration of carbonate ions, which many sea creatures use to build shells and other types of exoskeletons. Recent research predicts that large parts of the ocean may lack this essential nutrient within a few decades and that by 2050 there could be too few carbonate ions in surface waters for shell formation.[667] This trend is expected to continue and the effect will be most pronounced at higher latitudes.[668]

The effects on intertidal areas could be profound. Echinoderms (e.g., sea stars and sea urchins) have calcite structures containing magnesium, which dissolves very readily under more acidic conditions.[669] These organisms often function as keystone species, grazing on algae and kelp. Mussels, oysters, copepods and crabs, which are all elements of intertidal ecosystems, are also affected.

D. CRUSTACEANS

What are they? Crustaceans are a large group within the phylum Arthropoda (animals with external skeletons) and are second only to insects in their diversity of species.[670] Barnacles, shrimps, crabs, amphipods (beach hoppers) and isopods (aquatic sow bugs) are among the types of crustaceans found in the intertidal zone. These animals are generally small to very small, with five or more pairs of legs. They can live within or on beaches or, as is the case for barnacles, attached to rocks in the intertidal zone. Crustacean life cycles vary, but most include a free-swimming larval stage that at times dominates the nearshore zooplankton community.

Why are they important? Intertidal crustaceans play two critical roles in coastal ecosystems.[671] They recycle organic matter washed up on beaches and they provide a large, diverse prey base, which supports complex food webs that in turn promote ecosystem stability and resiliency.[672]

Intertidal crustaceans are decomposers, primary consumers or predators, and sometimes all three. Crustaceans, in general, occupy lower **trophic** levels. Species at lower trophic levels develop large populations, which

Barnacles (*Balanus* spp.) recycle organic matter and are a food source for other organisms in some intertidal ecosystems.
PHOTO: RAE MURPHY.

ultimately support higher-level predators that are economically important to B.C. Amphipods and isopods are detritivores that recycle dead plant and animal material. An isopod commonly called the gribble is one of the few animals that can consume wood. Barnacles strain the planktonic 'soup' that flows over and past them, consuming a great variety of microscopic and slightly larger food items. Crabs are both decomposers and predators.

Without functioning crustacean populations in the intertidal zone, the role of organic recycling becomes dominated by microscopic organisms. This becomes a cascading situation leading to anoxic (low oxygen) conditions, production of hydrogen sulphides, further degradation of environmental conditions and, as a result, the inability of the environment to support complex marine communities.[673,674]

Species at higher trophic levels that depend on crustacean productivity include salmon and shorebirds. Salmon smolts depend on a variety of crustacean prey, many of which are larvae of intertidal species. The timing of smolt migration coincides with major spawning and planktonic larval stages of crustaceans. Estuaries provide prey for grey whales (*Eschrichtius robustus*), including blue mud shrimp (*Upogebia pugettensis*), ghost shrimp (*Callianassa californiensis*) and larval intertidal crabs.[675] Migrating shorebirds depend on feeding grounds along the coast of B.C., where they pause to feed on biofilm[676] and a wide variety of crustaceans living on and in beaches.[677]

Status/threats in B.C. Generally, B.C. crustacean populations are stable, although declines in the diversity of species have been noted in some locations.[678] Ocean acidification is a threat to all crustaceans (Text box 17).

Data gaps: There is no formal inventory for non-commercial species of crustaceans.

E. SEAGRASS MEADOWS

What are they? Seagrasses are flowering plants that have adapted to the marine environment.[679] Seagrasses have similar structure to terrestrial grasses: rhizomal roots, long narrow leaves with obvious internal (vascular) structure and flowering stems. There are only a few species of closely related marine grasses in the genera *Zostera* (seagrasses, also known as eel-grasses) and *Phyllospadix* (surf-grasses). Along shorelines, where conditions are suitable, abundant growth of marine grasses forms ecosystems called seagrass meadows.

Why are they important? Seagrass meadows play an important role in primary production, carbon sequestration (processes that remove carbon from the atmosphere), habitat structure, shoreline stabilization and water quality maintenance.[680] The productivity of a number of other important species is directly linked to healthy seagrass meadows. Pacific herring (*Clupea pallasi*), salmon and brant (*Branta bernicla*) are among the B.C. species that depend on seagrass meadows.

Status/threats in B.C. Seagrass meadows have been highly impacted by human activities. There are no accurate estimates of the pre-industrial range of seagrass meadows in B.C.,[681] but Puget Sound, Washington, has lost an estimated 33% of its seagrass meadows since they were first inventoried.[682] Extensive seagrass meadows develop in the same areas that humans find useful: estuaries and sandy shorelines with low wave action. Threats to seagrass meadows include log handling, vessel traffic, dredging, upland erosion and construction activities, shoreline structures, increased water temperature, pollutants, excessive nutrients, herbicides and invasive alien species.[683]

Data gaps: There are few science-based inventories of B.C. seagrass meadows. We do not know the ecological significance of specific populations and, in many cases, the reasons for declines are unknown.

Seagrasses grow along B.C. shorelines where conditions are suitable.
PHOTO: AMANDA COTTON.

F. UPLAND SEDIMENTS AND LARGE WOODY DEBRIS IN THE INTERTIDAL

What is it? Estuaries, tidal flats, salt marshes, sand dune complexes, beaches and sand spits receive sediments and large woody debris (LWD) from upstream areas, either directly from streams and rivers or indirectly via the ocean.[684] Floods, storms and tides often later relocate these elements, contributing to the constantly changing nature of these ecosystems. In general, estuaries and coastal wetlands are net depositional environments for sediments.[685]

Sediments found in estuarine ecosystems are typically composed of animal and plant matter, as well as inorganic material such as mud or sand. Sources of large woody debris include woody vegetation from upstream riparian areas and drift logs that have broken free from log booms.

Why is it important? Estuarine ecosystems, both vegetated and unvegetated, are critical transition zones that link terrestrial, freshwater and marine habitats and perform many essential ecological functions, including nutrient cycling. Sediment-associated organisms – including bacteria, fungi, single-celled animals and sediment-dwelling invertebrates (e.g., nematodes, copepods, annelids, molluscs and peracarid crustaceans) and vascular plants – are integral to these functions. Sediment-associated plants also contribute to structural complexity in estuarine ecosystems, providing important habitat for a wide variety of species.[686]

Large woody debris plays numerous ecological roles in estuarine ecosystems. These include providing habitat and food for wood-degrading organisms such as wood-boring isopods (e.g., *Limnoria lignorum*) and shipworms (e.g., *Bankia setacea*), inputs into detrital food webs, shelter for fish from high current velocities and predators, egg attachment sites for fish such as Pacific herring, perches or nest sites for birds such as bald eagles, great blue herons, gulls (*Larus* spp.) and purple martins (*Progne subis*), haulout sites for harbour seals and colonization sites for woody vegetation. In estuarine marshes, LWD can have opposing influences on successional processes:

Large woody debris in the intertidal zone.
PHOTO: JOEL BLIT.

stable pieces of wood act as nurse logs for trees and shrubs, while mobile pieces can keep the forest edge from advancing by battering against trees and the upper marsh shoreline.[687,688]

Status/threats in B.C. The main threats to estuarine ecosystems in relation to upland sediments and LWD are ecosystem conversion and degradation. Agriculture, urban development and the construction of port facilities and roads have all impacted estuarine ecosystems in parts of B.C., particularly around southern Vancouver Island and along the lower mainland coast.[689] Human activities in inland areas have also affected these ecosystems. Since the mid 1800s there has been a dramatic reduction in the volume and size of LWD in coastal ecosystems in the Pacific Northwest states;[690,691] this trend likely also applies to B.C. The amount of LWD in estuarine ecosystems, especially large and long pieces of wood, has declined as riparian forests have been logged and as dams in some river systems have interrupted the downstream movement of LWD. Removal of logs and stumps to maintain channel navigability, diking, marsh filling and channelization have decreased the retention of LWD in estuarine ecosystems.[692]

Predicted impacts of climate change on estuarine ecosystems include erosion and/or sedimentation, coastal flooding and permanent inundation of low-gradient, intertidal areas. Unvegetated tidal flats are vulnerable to increased submergence and more extensive and rapid erosion. However, increased upland erosion and flooding associated with increased winter precipitation and more frequent winter storm and surge events, plus increased river flow due to glacial melt, may result in sufficient sedimentation to offset coastal erosion and submergence.[693]

There is evidence that estuarine marshes can adapt to sea-level rise provided there is sufficient sedimentation and internal biomass production and room for the entire wetland to move to higher ground or farther inland. If barriers to wetland migration are not removed, it is highly likely that climate change will result in significant shrinkage and eventual disappearance of salt marshes along the extensively diked Squamish, Nanaimo and Fraser rivers.[694]

Data gaps: There have been few scientific studies done to confirm or further characterize hypothesized ecological functions of estuarine LWD; this lack is in marked contrast to the extensive research on LWD in riverine and terrestrial ecosystems.[695] There are also important gaps in knowledge of estuarine sediment-associated organisms and their functions. For example, we do not know whether rates of organic matter decomposition and nutrient recycling in estuaries depends on the diversity of species of microbes. We know more about the links between biodiversity and function for larger plants and animals, but many questions remain unanswered.[696]

G. ESTUARIES

What are they? An estuary is a partially enclosed body of water where sea water is measurably diluted by mixing with river runoff (see Section 2.2.3.2, p. 47).[697] Estuaries can be classified as salt wedge (large river runoff with little mixing between the fresh water above and salt water below), partially mixed (greater tidal action and lower river runoff causing mixing, e.g., inlets, sounds) or well mixed (strong tidal action with low river runoff, resulting in water that is nearly homogeneous; typical of small bays near turbulent areas). Estuarine ecosystems have similar characteristics to wetland ecosystems, but also have daily fluctuations in the water table and variations in salinity.[698]

Estuaries are affected by several physical processes that are largely independent of human activities (e.g., tides, wind, rain, sunlight, evaporation, differences in water density). Human activities can affect estuaries by influencing the volume of water released by a river (e.g., through dams or water diversions), modifying the estuary opening through dredging, changing the runoff from surrounding land (e.g., by creating **impervious areas**) or releasing environmental contaminants.[699]

An estuary system can be subdivided into three areas: tidal river; zone of mixed fresh and salt water; and nearshore zone.[700] As a result, an estuary includes the lower reaches of a river and the surrounding terrestrial land that is inundated infrequently (i.e., only at the highest tides), the intertidal zone (which is subject to daily tidal inundation) and the zone below the lowest tide (which is always covered by water).

B.C.'s two largest estuaries, those of the Fraser River and the Skeena River, have the second and fourth largest annual mean freshwater inflow from rivers, relative to all estuaries along the west coast of North America.[701]

Why are they important? Both organic and inorganic nutrients from rivers collect in estuaries to create biologically active areas where large populations of mammals, birds and marine organisms congregate,[702] with primary production rivalling tropical rainforests.[703] Estuaries are transition areas that provide connectivity for many aquatic migrating species, such as salmon, as they travel between the ocean and the upstream river. Estuaries fulfill ecological roles such as filtering water, decomposing organic matter and providing feeding habitat.[704,705] Within estuaries, habitats such as seagrass meadows and wetlands are recognized as 'nurseries' (i.e., rearing areas), particularly for fish and invertebrates.[706]

Estuaries overlap with a number of other key elements in B.C., including riparian areas, stream systems, anadromous salmonids, waterfowl herbivory and crustaceans. Depending on geography, they may also contain macroalgae, seagrass meadows and willows. In B.C., hundreds of thousands of wintering waterfowl depend on estuaries.[707] The Fraser River estuary supports the highest concentration of wintering birds (shorebirds, waterfowl and raptors) in Canada.[708] Sometimes more than a million birds can be found in the Fraser River estuary on a single day and 20 million salmon pass through annually during a period of a few weeks.[709]

Status/threats in B.C. In the Georgia Basin, approximately 23% of the nearshore has been urbanized.[710] The human population adjacent to the Fraser River estuary is similar in scale to that of other estuary sites along the west coast of North America, such as San Francisco Bay and Puget Sound. Key threats to west coast estuaries include ecosystem conversion and degradation, diverted fresh water flows, marine sediment contamination and alien species introductions.[711] As a result, loss of estuarine habitat is substantial in the Fraser River delta (70%)[712] and on the east coast of Vancouver Island (32%),[713] with much of this area converted to fertile agricultural land through diking. Estuarine ecosystems are also threatened by sea-level rise resulting from climate change. Particularly vulnerable are those adjacent to dikes, which will prevent them from migrating to higher elevations.

With approximately 2.3% of B.C.'s rugged coastline classified as estuary, these ecosystems are considered rare.[714] Estuaries in B.C. have been mapped at various regional scales (in 1984,[715,716] 1993[717] and 2000[718]), as well as at a provincial scale (in 1985[719] and 2007[720]). The 2007 estuary mapping defined intertidal polygons for over 440 estuaries in B.C., calculated the total intertidal area (75,000 ha) and ranked them for biological importance to water birds. In 1999, a large-scale mapping framework for describing the physical and biological character of estuaries was prepared for B.C.[721]

Data gaps: Intertidal areas of estuaries at the mouths of fourth-order rivers have not been mapped at a scale of 1:50,000 and the 1999 mapping framework for estuaries has not been applied to all B.C. estuaries. The condition of estuaries at regional and provincial scales is unknown. Knowledge of wildlife use of many estuaries is incomplete and knowledge of **cumulative impacts** on estuarine functions is limited.

2.5.2 SPECIAL ELEMENTS

B.C. has several elements of biodiversity that are of global significance either because they are important habitat for seasonal concentrations of species or because they are uncommon or even unique globally (Table 24).[722] These elements are among the things that make B.C. special. They relate to geography, geology and the relatively undisturbed character of large areas of the province. Like many of the key elements described in Section 2.5.1, the special elements are subject to numerous threats that can potentially decrease the resilience of B.C.'s biodiversity. This list of special features is not intended to be all-inclusive, but rather to highlight some uncommon B.C. species, communities and ecosystems of ecological significance.

TABLE 24. SELECTED SPECIAL ELEMENTS OF BIODIVERSITY IN B.C.

REALM	SPECIAL ELEMENT	DESCRIPTION	STATUS	THREATS
Seasonal Concentrations of Species	**Important bird areas**	B.C. has globally significant seasonal concentrations of birds.	Most sites are not protected	Concentrations of species are vulnerable to catastrophic events. Other threats: loss of intertidal habitat from ecosystem conversion, sea level rise, pollution and direct disturbance.
	Steller sea lion rookeries/ haulouts	Rookeries are rocky islands used for breeding. Haulouts are non-breeding areas.	Species is of conservation concern in B.C. Two of three rookeries are protected.	Steller sea lions are vulnerable to catastrophic events at rookeries and haulouts, and threatened by shooting and entanglement in fishing gear.
	Major salmon spawning sites	Major salmon populations have escapements above a species-specific level defined in the text.	Nearly 20% of B.C. and Yukon populations were of conservation concern in the 1990s. Trend is increasing.	Most mortality occurs in the marine realm, but freshwater and terrestrial threats include changing hydrology, sedimentation, artificial stream barriers, loss of estuaries and warming water.
Special Communities	**Old-growth temperate rainforests**	Temperate rainforests are typically associated with coastal mountain ranges. Also occur in interior B.C.	Much of the low-lying, highly productive areas have been logged and/ or converted to high human density areas or agriculture, or flooded by hydroelectric dams.	Remaining low-elevation forests are often highly fragmented by roads and forest harvesting.
	Intact large mammal predator-prey systems	Predator-prey systems in which all of the native large carnivores and ungulates are present.	28% of B.C. has intact systems.	Loss of large mammals is due to direct mortality and ecosystem conversion and degradation.
Specific Features	**Large wetlands (Freshwater)**	Large wetlands are centres of both freshwater and terrestrial biodiversity. One example, Burns Bog, hosts organisms absent or rare elsewhere and is the largest raised bog in coastal North and South America.	Partially protected.	Large wetlands are threatened by pollution from agricultural and urban activities; motorized recreation; ecosystem conversion; and artificially managed water levels.

CONTINUED ON PAGE 136

TABLE 24. CONTINUED

REALM	SPECIAL ELEMENT	DESCRIPTION	STATUS	THREATS
Specific Features	**Karst**	Karst is a unique landscape created from soluble bedrock, particularly in areas of high rainfall. Karst supports rare species and communities, but is easily damaged.	More than one-quarter of the B.C. land area potentially underlain by karst has been modified through timber harvest and road building. Less than 20% of the province's karst is protected.	Road building and forest harvesting activities can directly damage karst structures. Indirect threats include soil loss and sedimentation.
	Hot springs	Hot springs are unique, self-contained habitats created by very hot water from deep within the earth.	Many are heavily used for recreation.	Vulnerable to pollution, disturbance and ecosystem conversion.
	Glacially influenced watersheds	Watersheds that have more than 5% of their area covered in glaciers are defined as glacially influenced.	Increasing temperatures over the past century have resulted in loss of glacial volume.	Continuing increases in temperature and changes in precipitation will affect glaciers in the future. Many smaller glaciers have already melted. Lower-elevation glaciers are most affected.
	Serpentine soils	Formed from bedrock with high toxicity from heavy metals, these soils provide harsh growing conditions and tend to support specifically adapted, unique plant communities.	Unknown.	Serpentine soils are treated as waste lands because of their lack of productivity. They are threatened by mineral exploration and sometimes by urban development.
	Saline lakes	Lakes or ponds with no outlet and a very high salt content. Home to invertebrate species not found in other water bodies.	Some are protected.	Saline lakes are often found in dry climates with agricultural pressures. They are especially vulnerable to climate change because most lack tall vegetation to buffer them against air temperature change.
	Fishless lakes	Lakes that are historically fishless and have never been stocked and contain unique communities that are not affected by the presence of fish.	Few low-elevation examples remain and most are unprotected.	Biggest threat is the introduction of fish.
	Microbialites	Fossilized mats formed by microbes, primarily cyanobacteria. Freshwater examples are globally rare, with two examples known in B.C.	Only one site is protected. Both are in fairly good condition.	Microbialites are subject to damage by recreational users of the lakes.

NOTE: Elements in this table are just a small sample of the special elements of biodiversity in B.C. They are used for illustrative purposes.

2.5.2.1 SEASONAL CONCENTRATIONS OF SPECIES

A. IMPORTANT BIRD AREAS

What are they? Eighty-four sites in B.C., many of which provide important habitat for concentrations of breeding, wintering and/or migrating birds, are recognized as Important Bird Areas (IBAs).[723] These sites occur primarily along the coast, particularly around the lower mainland and Vancouver Island, and secondarily through the central interior and along the southern border with the U.S. (Map 11A). Examples of IBAs in B.C. include: the Scott Island Group off the northwest tip of Vancouver Island, which hosts 12 seabird species totalling more than two million breeding birds; Fraser Lake in central B.C., which is a globally significant site for wintering trumpeter swans; and the Skookumchuck Prairie, a small area of native grassland in the Rocky Mountain Trench that provides habitat for about 22 pairs of long-billed curlew (*Numenius americanus*), a species of conservation concern. One of the most important areas in B.C. for bird concentrations is the Fraser River estuary, which includes coastal wetlands, mudflats and intertidal marshes and provides habitat for a high diversity and biomass of birds.

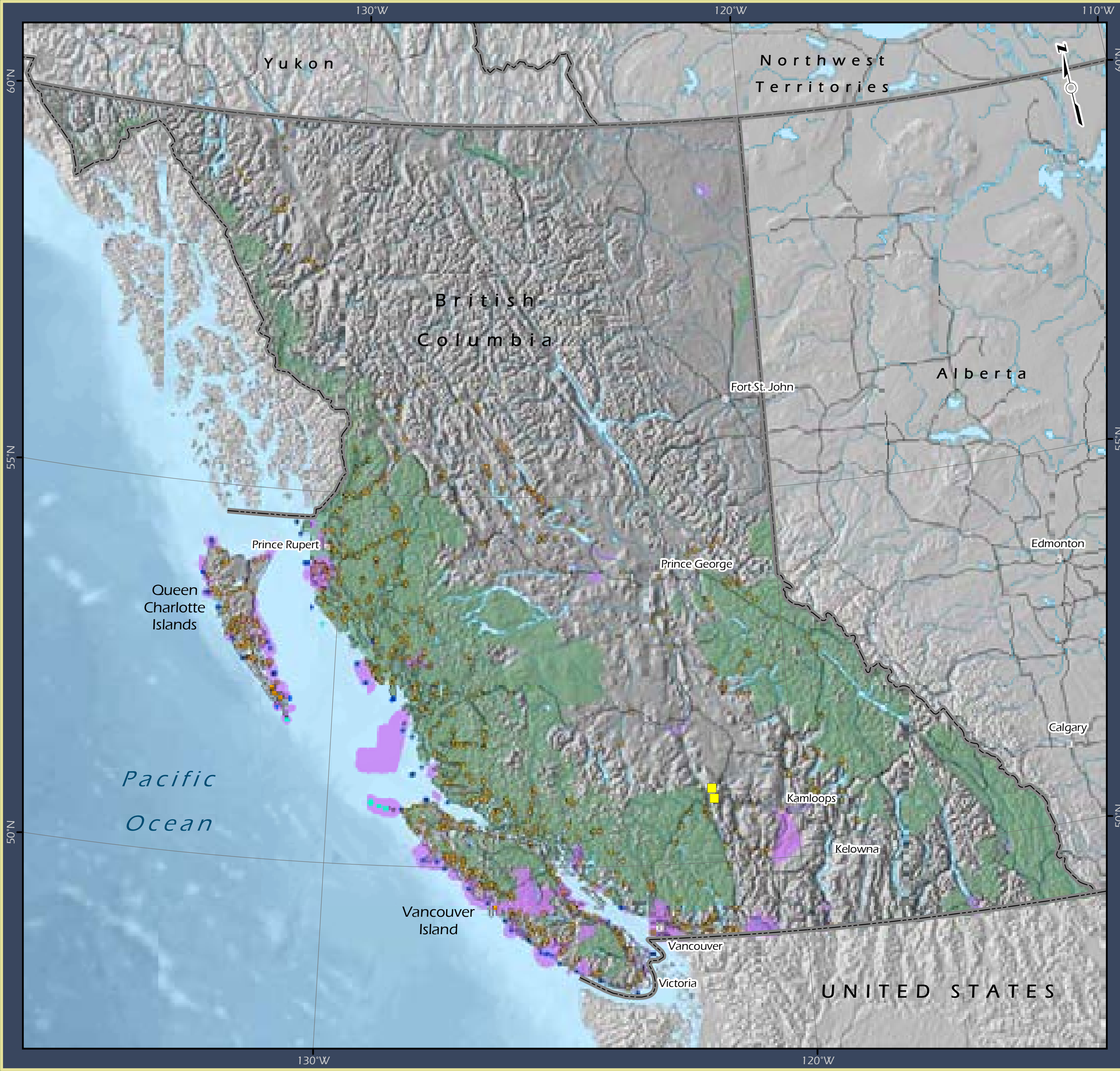
Why are they important? B.C. provides important habitat for seasonal concentrations of many species of birds for breeding, wintering, and/or migrating, particularly along the Pacific Flyway (see also Section 2.3.4.3, p. 69). These sites are critical to key life stages for large portions of the total continental populations of these species.

Status/threats in B.C. Species occurring in localized high densities become vulnerable to outside threats. Most IBAs in B.C. are not protected. Current threats to the most significant IBA, the Fraser River estuary, include loss of intertidal habitat through planned industrial port expansion, intensification of agriculture (e.g., greenhouse development adjacent to the intertidal zone, berry and nursery crops) and pollution from the mouth of the Fraser River. Disturbance has grown in recent years (e.g., bird control at nearby Vancouver International Airport, increasing boat traffic, hikers and beach walkers), with potentially detrimental impacts on bird habitat and populations. Sea level rise resulting from climate change could reduce intertidal habitat.[724] On some coastal islands, introduced mammals (e.g., mink [*Neovison vison*] and raccoon [*Procyon lotor*] on Cox and Lanz Islands in the Scott Island Group) are having detrimental impacts on ground-nesting seabirds.[725]

Data gaps: Many of these areas where birds congregate are surrounded by increasing development. We do not know the thresholds in terms of water quality and shoreline development for trumpeter swan populations that winter on Fraser Lake, or how much human disturbance populations on the coast can be subjected to without showing declines in reproductive success. Other unknowns are the impacts of fisheries on seabird colonies and how climate change will affect food resources.

MAP 11A

Special elements: species



Legend

- City
- Road
- River/Stream
- Lake

Special elements

- Major salmon spawning sites*
- Steller sea lion haulouts
- Steller sea lion rookeries
- Microbialites
- Important bird areas
- Intact large mammal predator-prey system (all native large mammals present, no alien large mammals)**

* Defined as those with spawning populations above a specific level (i.e., >20,000 pink, >10,000 chum, >5,000 lake -type sockeye, >2,000 coho, >500 chinook and >500 river-type sockeye) in two or more years.

** Large is defined as >20 kg average body mass.

0 100 200

Kilometres

Data sources:
Ministry of Environment, Fisheries and Oceans Canada, Canadian Wildlife Service, Conservation Data Centre

Map by:
Caslys Consulting Ltd

Projection:
BC Albers NAD83

Produced for:

BioDiversity BC

June 12, 2008

B. STELLER SEA LION ROOKERIES AND HAULOUTS

What are they? The Steller sea lion is the largest species of sea lion and the only one that lives year-round and breeds in B.C. waters. Steller sea lions prefer exposed rocky shorelines and wave-cut platforms for haulout sites and breeding areas (rookeries), returning to the same sites year after year.[726] There are three main breeding areas in B.C.: the Scott Islands (including Beresford, Sartine and Triangle islands) off the northwest tip of Vancouver Island, the Kerouard Islands off the southern tip of Haida Gwaii/Queen Charlotte Islands, and North Danger rocks off the northern mainland coast (Map 11A).[727]

Why are they important? Two of B.C.'s rookeries are the largest breeding aggregations in the world.

Status/threats in B.C. Both breeding and non-breeding populations of the Steller sea lion are of conservation concern in B.C.[728] Locations for haulouts and rookeries are mapped. Two of the three rookeries – those on the Kerouard Islands and the Scott Islands – are protected. Steller sea lions are vulnerable to shooting, incidental take in fishing gear, entanglement in debris, catastrophic events, environmental contaminants and displacement from, or degradation, of their habitat.

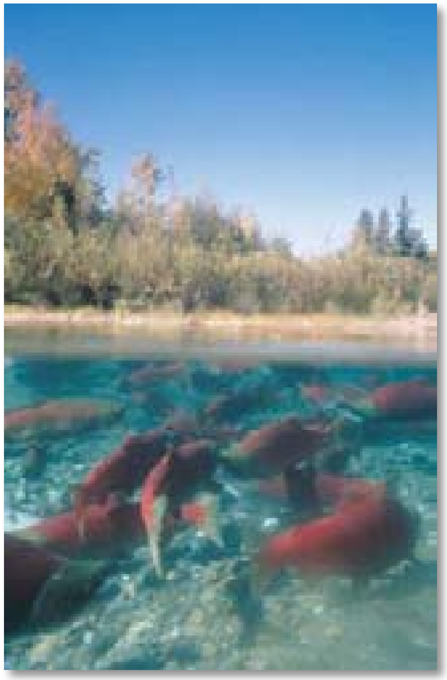
Thousands of Steller sea lions were culled, killed for research or killed for commercial reasons in the first half of the 20th century. This was very disruptive and caused the loss of at least one rookery. Populations have not fully recovered in most areas in spite of receiving full protection under the *Fisheries Act* in 1970. Currently, about 8,900 sea lions are found on rookeries in B.C., which represents about 65% of the number present prior to the large-scale kills. The total B.C. population inhabiting coastal waters during the breeding season is estimated at 18,400 to 19,700 individuals, including non-breeding animals associated with rookeries in southeast Alaska.[729]

Data gaps: More information is needed on rates of disturbance at haulout sites (e.g., by aircraft, boats, pedestrians, construction or fishing activities).[730] The population-level impacts of oil spills are not well established.[731]

Steller sea lions (*Eumetopias jubatus*) return annually to favoured breeding and haul-out sites. Two of B.C.'s sea lion rookeries are among the world's largest.
PHOTO: JARED HOBBS.

C. MAJOR SALMON SPAWNING SITES

What are they? Native anadromous salmonids in B.C. include chinook, chum, coho, pink and sockeye salmon, and steelhead (see Section 2.5.1.3-F, p. 121). High levels of habitat diversity, variable environmental conditions and the strong tendency for salmon to return to their rivers of origin have combined to promote rapid, post-glacial evolution of these species, resulting in many thousands of unique spawning populations specifically adapted to local conditions.[732]



Salmon species such as sockeye salmon (*Oncorhynchus nerka*) spawn in many of B.C.'s rivers.
PHOTO: BC PARKS.

Major salmon spawning sites (Map 11A) are located where spawning populations exceed a defined number of individuals in two or more years (i.e., >20,000 pink salmon, >10,000 chum salmon, >5,000 lake-type sockeye salmon, >2,000 coho salmon, >500 chinook salmon, >500 river-type sockeye salmon).[733,734]

Why are they important? A disproportionate number of B.C. salmon come from major spawning sites. These populations exhibit considerable genetic diversity below the species level, reflecting the evolution of local adaptations that especially suit them to occupy a given geographic locale.[735] In addition to being important to biodiversity, major salmon spawning sites are culturally significant to First Nations (see Text box 2, p. 13).

Status/threats in B.C. The number of major spawning sites for each species is: 189 for chum salmon, 183 for coho salmon, 89 for even-year runs of pink salmon, 65 for odd-year runs of pink salmon, 125 for both odd- and even-year runs of pink salmon (i.e., sites where both thresholds are met), 55 for chinook salmon and 46 for sockeye salmon.[736]

The greatest threats to major salmon spawning sites are climate change and conversion or degradation of spawning and rearing habitat (see Section 2.5.1.3-F, p. 121). The seasonal concentration of salmon populations during certain parts of their life cycle contributes to their vulnerability to catastrophic events. For example, on August 5, 2005, a train derailment resulted in a spill of approximately 45,000 L of sodium hydroxide solution into the Cheakamus River. Nearly all free-swimming fish occupying the Cheakamus River mainstem were killed, with mortality estimated at more than 500,000 fish from 10 species. The only survivors were those fish that were still in the gravel as developing young or were residing in tributary streams or back channels, and those that had not yet returned to the Cheakamus River.[737]

Data gaps: Major salmon populations and spawning sites are well studied. The effects of climate change on the future use of these sites are not known.

2.5.2.2 SPECIAL COMMUNITIES

A. OLD-GROWTH TEMPERATE RAINFORESTS

What are they? Temperate rainforests occur in mid latitudes and are typically associated with the ocean and coastal mountain ranges, which promote high rainfall. B.C. has coastal rainforest along its entire coast and on its offshore islands, as well as inland rainforest located between 51°N and 54°N along the windward slopes of the Columbia and Rocky mountains.[738] Another definition of the inland temperate rainforest gives a larger range, extending from south of the U.S. border to Prince George.[739] In B.C., the coastal temperate rainforest is largely described by the Coastal Western Hemlock and Mountain Hemlock biogeoclimatic zones and the inland temperate rainforest by the Interior Cedar–Hemlock zone. Old-growth temperate rainforest is defined as more than 250 years old (Map 11B).

Temperate rainforests are primarily dominated by a disturbance regime called gap dynamics, meaning that, in general, single trees die, creating gaps, and are replaced by trees growing up from the understory, rather than entire stands being replaced at once. This results in forests that are very old and complex, with multiple layers of trees. Forest stands are often older than the individual trees within them and may not have been disturbed for many thousands of years. Such stands have been called 'antique' forests.[740] On the west coast of Vancouver Island, stands have been aged as having existed for more than 3,000 years since the last disturbance.[741,742] In B.C.'s inland temperate rainforest, researchers have found trees greater than 1,400 years old and stands that have survived through multiple generations of trees.[743]

Old-growth temperate rainforest in the Carmanah Valley.
PHOTO: JARED HOBBS.

Some temperate rainforest areas are influenced by disturbances such as large-scale windthrow (e.g., northern Vancouver Island and exposed parts of the outer coast), large-scale fire (e.g., the south coast and the drier zones of the Interior Cedar–Hemlock zone) and flooding (e.g., riparian areas).

The coastal rainforest grows some of the world's largest trees, with some Sitka spruce exceeding 90 m in height and western redcedars reaching more than 15 m in circumference.[744] Although inland rainforest trees typically do not achieve these dimensions, they are regionally exceptional for their size. In contrast to the large-structured forest, parts of the coastal temperate rainforest consists of woodland bog forest, characterized by widely spaced, small, stunted trees and little woody debris or other structure. Riparian forests are also prevalent in both coastal and inland temperate rainforests.

Why are they important? B.C.'s old-growth rainforests contain high biodiversity. Their large structures (i.e., standing trees and coarse woody debris) and multiple layers provide habitat niches for many species. This

MAP 11B

Special elements: ecosystems

Legend

- City
- Road
- River/Stream
- Lake

Special elements

- Hot springs
- Saline lakes
- Burns Bog
- Creston Valley Wetlands
- Columbia Valley Wetlands
- Glacially influenced watersheds (>5% of area covered by glaciers)
- Old growth temperate rainforest (>250 years old in the Coastal Western Hemlock, Mountain Hemlock and Interior Douglas-fir biogeoclimatic zones)

0 100 200

Kilometres

Data sources:
Dr. G. Scudder, Ministry of Environment, Ministry of Energy Mines and Petroleum Resources, Ministry of Agriculture and Lands

Map by:
Caslys Consulting Ltd

Projection:
BC Albers NAD83

Produced for:

April 14, 2008

complexity combined with the great age of many of these forests affords time and opportunity for speciation. The high diversity of non-vertebrate species inhabiting these forests is particularly notable. For example, in coastal rainforests, more than 300 species of previously unknown arthropods have been identified in the Sitka spruce canopy, none of which have been found in young regenerating forests,[745] and 83 species of oribatid mites have been found in the canopy and in areas of the forest floor associated with western redcedars.[746] Both coastal and inland old-growth rainforests support a high diversity of lichens and fungi.[747,748]

Bog forest ecosystems within the coastal rainforest are typically nutrient-poor, which tends to result in relatively high plant diversity due to the inability of single species to dominate these sites.

There are 242 species of provincial conservation concern in the Coastal Western Hemlock zone, 45 in the Mountain Hemlock zone and 170 in the Interior Cedar–Hemlock zone (see Table 4, p. 34). Some of these species occur in more than one of these zones.

Status/threats in B.C. Researchers estimate that 56% of the world's coastal temperate rainforest has been logged or converted to non-forest uses. In North America, the only remaining large, unlogged watersheds are in British Columbia (mainly on the central and north coasts) and Alaska.[749] The world's largest area of intact coastal temperate rainforest (321,120 ha) is encompassed by the Kitlope Heritage Conservancy Protected Area on B.C.'s mainland coast.[750]

Much of B.C.'s remaining old-growth coastal temperate rainforest is fragmented by roads, other access routes and forest harvesting. Almost half (47%) is in small, unfragmented areas that are less than 20,000 ha in size. Approximately one-third is in unfragmented areas of greater than 50,000 ha.[751] Development has been concentrated in low-lying, high-productivity areas and very little old forest remains in these sites.[752,753,754]

Depending on how the inland temperate rainforest is defined, either all or most of this ecosystem occurs in B.C. All of the province's old-growth inland rainforest is highly vulnerable to the impacts of roads, logging and flooding by hydroelectric dams. Much of this ecosystem has already disappeared and the remaining stands are highly fragmented.[755]

Data gaps: The mapping of old-growth temperate rainforests in B.C. is out of date and incomplete for some areas. The ecology of these forests is not well understood. Recovery times for different rainforest elements and the overall recovery ability of these forests are unknown, particularly in the context of climate change.

B. INTACT LARGE MAMMAL PREDATOR-PREY SYSTEMS

What are they? British Columbia is home to four species of large carnivores (i.e., with body mass greater than 20 kg): grey wolf, cougar, American black bear and grizzly bear. Large herbivores historically or currently preyed on by this suite of predators include all of the province's native ungulate species: plains and wood bison (*Bos bison bison* and *B.b. athabascae*), mountain goat, bighorn and thinhorn sheep (*Ovis canadensis* and *O. dalli*), moose, elk, mule and white-tailed deer (*Odocoileus hemionus* and *O. virginianus*) and caribou.

An intact large mammal predator-prey system is one in which all of the native species are present, with no alien species that plays a role as either predator or prey relative to the others. These systems are vital elements in many natural communities (see Section 2.5.1.2-C, p. 100).

The loss of one or more species from a large mammal predator-prey system can result in a variety of ecosystem impacts. The absence of top predators can lead to an artificially high abundance of herbivores and smaller, generalist predators, whose influence can ripple through the ecosystem, producing impacts such as overgrazing, overbrowsing, declines in populations of ground-nesting birds and spread of alien species.[756]

Why are they important? B.C. is globally significant for the fact that 28% of the province has intact large mammal predator-prey ecosystems and these systems are unusually rich in temperate-zone, large carnivore and ungulate species. Many of these species have undergone significant range contractions in other jurisdictions, which increases the significance of their presence in B.C. Worldwide, less than 21% of the earth's land base retains all of the large mammal species that were historically found in each area.[757]

The presence or absence of intact large mammal assemblages, including the full historical complement of large carnivores and ungulates, is a useful ecologically based measurement of human impacts on biodiversity. In general, areas with intact large mammal assemblages are more likely to be ecologically functional than those that are missing one or more species.[758]

Status/threats in B.C. Large mammals are particularly vulnerable to local extirpation due to direct mortality (depending on the species, they may be killed for meat or trophies or as a population-control or protective measure) and the sensitivity of some of these species to disturbance and habitat fragmentation.[759] A continent-wide analysis of sensitive species (i.e., those that have undergone significant range contractions) of carnivores and ungulates in North America shows B.C. to be one of the areas with the highest number of these species, both historically and currently. Species richness for sensitive carnivores and ungulates is particularly high in the northern Rocky Mountains from Colorado to the Yukon, but is also high in parts of B.C. outside the Rockies

(Figure 30).[760] B.C.'s large mammal fauna is intact along the mainland coast, but there are gaps elsewhere in the coastal region (see Map 11A, p.138). Specifically, Dawson caribou, known only from Haida Gwaii/Queen Charlotte Islands, are extinct, and Roosevelt elk (*Cervus canadensis roosevelti*) have been extirpated from parts of Vancouver Island, the Sunshine Coast and the lower mainland.

In most of the rest of B.C., one or more large mammal species have been extirpated since the time of European contact. Wood bison are missing from most of northern B.C. and grizzlies from much of the central and southern interior. The other species most frequently missing from predator-prey systems in areas of B.C. are wolves, plains bison, elk and caribou. The primary reason for these losses is historical unregulated direct killing.[761]

Attempts to reintroduce extirpated large mammals into their former range have been made in B.C. Experience elsewhere has proven that such reintroductions can have dramatic, positive ecological effects.[762]

Data gaps: The mapping of historic and current distributions of some large carnivores and ungulates is incomplete (e.g., historic distribution of wood bison, current distribution of grey wolf).

2.5.2.3 SPECIAL FEATURES

A. LARGE WETLANDS (FRESHWATER)

In B.C., wetlands tend to be small, isolated features. Three exceptions in the province are: Burns Bog, the largest raised bog in coastal North and South America; and two internationally recognized wetland complexes in the Kootenays – the Creston Valley Wildlife Management Area and the Columbia Valley Wetlands Wildlife Management Area (see Map 11B, p. 142).

Creston Valley Wetlands

What is it? The Creston Valley wetland complex is a large area (approximately 7,000 ha) at the south end of Kootenay Lake. It consists of Duck Lake (1,500 ha), 17 marshes and a portion of the Kootenay River.

Why is it important? The area provides habitat to more than 265 bird species, 50 mammal species and 30 fish species, as well as reptiles, amphibians and thousands of invertebrate and plant species. It is an important stopover site for tundra swans (*Cygnus columbianus*), greater white-fronted geese (*Anser albifrons*) and many other waterfowl. It is also a regionally important site for birds of prey wintering in the B.C. interior and home to the northern leopard frog (*Rana pipiens*), a species of conservation concern. The marshes are a valuable link in a chain of wetlands stretching from the Arctic Ocean to California.

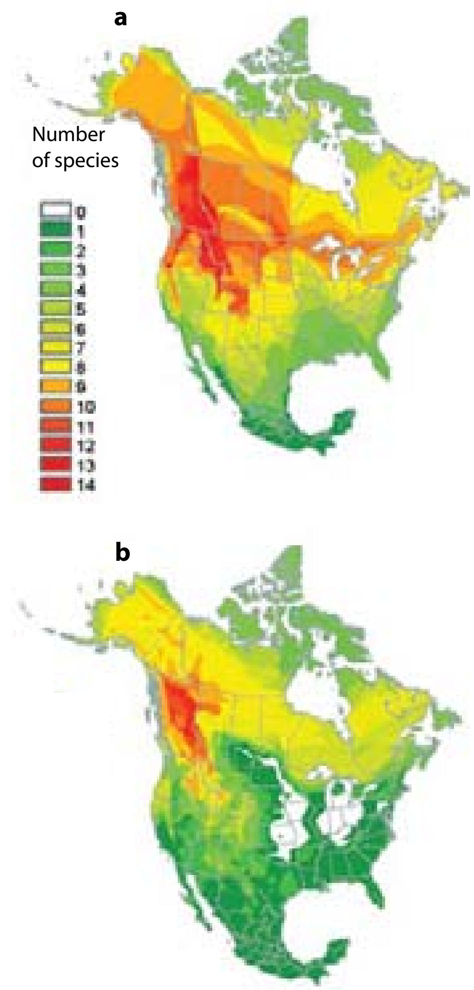


FIGURE 30: **Historic (a) and current (b) species richness for 17 carnivore and ungulate species that have undergone significant range contractions in North America.**
SOURCE: Laliberte, A.S. and W.J. Ripple. 2004. Range contractions of North American carnivores and ungulates. Bioscience 54(2): 123-138.

Status/threats in B.C. Most of the complex is managed under the *Creston Valley Wildlife Management Area Act*. Threats to the Creston Valley wetlands include continued ecosystem conversion, runoff from surrounding agricultural and urban areas and the requirement for continuous management to maintain the current artificial water levels that maintain wetland productivity. The wetland complex is also intersected by highway and railway corridors.

Columbia Valley Wetlands

What is it? The Columbia Valley wetland complex in the East Kootenay Trench is the longest contiguous network of wetlands in North America, covering more than 26,000 ha.

Why is it important? These wetlands host more than 260 resident and migratory bird species, including some that are rare within the province (e.g., prairie falcon [*Falco mexicanus*], short-eared owl [*Asio flammeus*] and American avocet [*Recurvirostra americana*]).

Status/threats in B.C. Much of this complex is managed within several Wildlife Management Areas. Threats to the Columbia Valley wetlands include runoff from pesticides and fertilizers used in surrounding areas, which affects wetland function, and increasing recreational impacts. Motorized recreation using power boats and jet skis is of particular concern because it can result in erosion and destruction of nesting habitat through increased wave action, and can also cause nest desertion.

Burns Bog[763]

What is it? Burns Bog, in the Fraser River delta, is a type of wetland known as a raised bog, which typically develops on top of a fen. In a raised bog, the supply of mineral-rich groundwater is cut off as the bog rises, leaving nutrient-poor precipitation as the bog's only source of moisture and nutrients. Raised bogs are characterized by acidic, nutrient-poor water, two-layered peat deposits and communities dominated by plants that can survive in these conditions, such as *Sphagnum* and heaths (Ericaceae).[764]

Why is it important? Although relatively common in the North America's boreal and eastern regions, raised bogs are less common in western North America, where blanket bogs or fens predominate. Burns Bog is the largest raised bog on the west coast of the Americas, covering 4,000 ha, and is at the southern limit of some northern species.[765] Raised bogs host uncommon collections of species, including unusual numbers of carnivorous plants, an apparent adaptation to lack of nutrients. Plant species in Burns Bog that are uncommon to the region include the carnivorous great sundew (*Drosera anglica*), as well as few-flowered sedge (*Carex pauciflora*) and crowberry (*Empetrum nigrum*). The bog is also home to animals of provincial conservation concern, including sandhill cranes and the *occidentalis* subspecies of the southern red-backed vole. A new species, the Olympic shrew, was recently confirmed from Burns Bog.[766]

Like other peatlands, raised bogs sequester greenhouse gases (both methane and CO_2), thus acting as a buffer against climate change. Disturbance of the bog surface increases emission of these gases.

Status/threats in B.C. About half of this wetland (2,042 ha) is protected as the Burns Bog Ecological Conservancy Area, but it is threatened by incursion of 'non-bog' water that is not favourable to the bog flora and fauna. Much of the remainder of the bog is privately owned and is occupied by a large landfill.

Large wetlands data gaps: Burns Bog and the two Kootenays wetland complexes are well mapped. However, the impacts of land uses in surrounding areas are not well known. The ecological and hydrological processes of Burns Bog, and bogs in general, are not well understood,[767] particularly the requirements for succession and recovery.[768]

The great sundew (*Drosera anglica*), survives in acidic and nutrient-poor waters usually found in bogs. Sundews are insect-eating plants, an adaptation to the lack of nutrients.
PHOTO: ISTOCK.

B. KARST

What is it? Karst is a landscape derived from soluble bedrock – typically limestone, but also dolomite, marble and gypsum. With time, water dissolves the bedrock and creates caves, sinkholes, vertical shafts, convoluted rock surfaces and disappearing and reappearing streams. Approximately 11% of British Columbia is potentially underlain by karst, including the Rocky Mountains (particularly in the south) and the temperate rainforests of Vancouver Island and the Queen Charlotte Islands; there are also smaller, more isolated patches on the north coast, in the Purcell Mountains, in the northwest along the Stikine and Taku rivers, in the northeast near Chetwynd and Prince George, and near Chilliwack in the Cariboo.[769,770] The province appears to have the most diverse examples of karst in Canada.[771]

Why is it important? Some habitats formed from karst are naturally isolated and therefore tend to host rare or unique species. Karst caves in B.C. are inhabited by species found nowhere else and are important as bat hibernacula.[772] Above ground, the complex physical structures formed in karst stream beds provide sites for fish to rest, breed and avoid predation. Terrestrial ecosystems on karst also tend to be very productive because of high levels of dissolved minerals, fractured bedrock and well-drained soils, all of which encourage deep rooting and high growth rates of associated plants and trees. Their chemistry is basic rather than acidic, allowing colonization by plant species (including bryophytes, ferns and rooted plants) that are rare or absent on more acidic substrates such as granite. This chemistry, plus their productivity, encourages high species richness. Karst sites in B.C. are recognized for their rare plant species and cave fauna, including some endemic species.[773,774]

Processes in karst ecosystems occur underground (as pictured here) and on the surface. Many uniquely adapted species make use of these special environments.
PHOTO: MARTIN DAVIS.

For example, caves on Vancouver Island host at least 10 species of invertebrates found nowhere else and others that are extremely rare.[775]

In Alaska, karst landscapes have been shown to increase the productivity of adjacent salmon streams by producing cool, stable streams with ideal properties for fish spawning[776] and by leaching of calcium carbonate, which buffers acidic streams; aquatic insect populations tend to be more diverse within karst-fed streams. Beyond their contributions to biodiversity, karst ecosystems are often of cultural value to First Nations, including as burial sites,[777] and are important repositories for historical evidence of climate change (sediments and formations) and extinct species.[778,779]

Status/threats in B.C. Karst ecosystems in B.C. are highly vulnerable to disturbance particularly those found in the wet, mountainous coastal regions of the province. Karst located in the interior is generally less susceptible to surface development due to the protection provided by deep soils and surficial materials deposited through glaciation. Road building and logging can cause direct physical damage, soil erosion and sediment transfer, and can interrupt natural surface and subsurface drainage patterns and collapse caves, potentially causing the collapse of the entire karst ecosystem.[780]

Because karst is highly productive, associated forests are sought after for timber harvesting. However, the geological characteristics that encourage productivity also encourage soil loss and site degradation once vegetation cover is disturbed. Indirect damage, such as sedimentation from fine-textured soils and blockages caused by debris, can also affect the functioning of karst ecosystems. Just over half of the B.C. landscape that is potentially karst is forested and, of that, 55% has been logged.[781]

In some areas there is high recreational use by cavers.

Data gaps: Provincial mapping of karst sites is incomplete and relatively little assessment of karst-associated species has been done.[782] It is also unlikely that all noteworthy sites are known.

C. HOT SPRINGS

What are they? Hot springs are habitats created by pools of very hot, sometimes near boiling, water that is heated from deep within the earth. Hot springs occur on every continent. Within Canada, they occur in the mountainous regions of B.C. (see Map 11B, p. 142), Alberta, the Northwest Territories, Yukon and Nunavut.

Why are they important? Because of the uncommon conditions in hot springs (very high temperatures, little or no oxygen and large amounts of dissolved minerals), hot springs habitat is very different from surrounding habitats. Hot springs are highly localized and isolated from each other and tend to host very simple but unique ecosystems and species. Only one species in B.C. is reported to be restricted to hot springs: the hotwater physa (*Physella wrighti*) is a critically imperilled freshwater snail that occurs only in the Liard Hot Springs[783] (i.e., it is endemic to B.C. and to that particular site). In B.C., the southern maiden hair fern (*Adiantum capillus-veneris*) is reported only from the Fairmont Hot Springs but also occurs on five continents and is sufficiently secure in some areas that it is harvested by florists. Other plants sometimes occurring near hot springs in B.C. are the giant helleborine (*Epipactis gigantea)* and marsh muhly (*Muhlenbergia glomerata*), which have limited distributions in the province. Both are relatively widespread in North America, but giant helleborine is localized and often threatened. There undoubtedly are smaller organisms, such as microbes and possibly invertebrates, restricted to B.C. hot springs.

Status/threats in B.C. Locations of hot springs within British Columbia are known. Most larger and accessible ones are privately owned and developed. Several occur within provincial parks. Among the best known are Liard River Hot Springs Provincial Park, Ahousat Hot Springs (Gibson Marine Provincial Park) and Hot Springs Cove (Maquinna Provincial Marine Park). All attract visitors. Their small size, isolation and attractiveness to humans make hot springs especially vulnerable to human activities.

Data gaps: Most hot springs have not been surveyed for their contributions to biodiversity, particularly for smaller organisms.

D. GLACIALLY INFLUENCED STREAMS

What are they? Glaciers cover approximately 4% of B.C.'s land area (see Figure 7, p. 25). They serve as frozen reservoirs of water that feed lakes and rivers during the late summer and fall when runoff from seasonal snow cover is depleted. Almost half of the gauged rivers in the province have at least one glacier in their basin.[784] Glacially influenced watersheds are defined here as those with more than 5% of their area covered by glaciers, and streams within these watersheds are considered to be glacially influenced.[785] Glacially influenced watersheds cover 20% of the province (Map 11B, p. 142).

In glacier-fed rivers, the highest flows tend to occur in early or mid summer, depending on latitude, and glacier runoff can account for a significant portion of the available water supply.[786] Daily flow patterns are also distinctive. Near its source, the volume of a glacial river can have as much variation during a single summer day as over the course of an entire summer. Glacial rivers run high in the late afternoon and early evening in summer, with peak water levels on hot summer days sometimes reaching as high as during spring thaw. After sunset, melting slows, and by morning, water flow is greatly reduced.[787]

Why are they important? In late summer and fall, glacier melt maintains stream flow during dry weather, providing a reliable water supply and valuable aquatic habitat in downstream waterways and associated riparian and estuarine ecosystems. Glaciers can also affect stream temperature and may be important to cold-water specialists such as bull trout.

Status/threats in B.C. Glaciers in B.C. are generally shrinking due to climate change and glacially influenced streams are threatened by the resulting changes in glacier melt. Initially, receding glaciers discharge more water into some streams and rivers. While higher flows may benefit some aquatic species, potential negative impacts include increased stream turbidity and damage to fish habitat and riparian areas. In the longer term, glacier retreat will mean reduced water volume, and possibly temperature change, in glacier-fed streams and rivers, especially during the summer months.[788]

A recent study of August stream flow in 236 basins in B.C. showed significantly more negative trends for glacier-fed than for non-glacier-fed streams, supporting the hypothesis that retreating glaciers have exacerbated recent summer low flows. The negative stream flow trends in glacier-fed catchments suggest that summer stream flow in B.C. will decline if current climate change trends continue and glaciers continue to recede.[789]

Data gaps: There is no complete listing of species that are dependent on glacially influenced streams in B.C. There is a lack of stream monitoring data to gauge changes in the rate of water flow and temperature.

E. SERPENTINE SOILS

What are they? Serpentine soils are derived from serpentine and other rocks typical of the earth's mantle. These rocks contain high levels of magnesium, chromium, manganese, cobalt and nickel, which make the soils toxic to many plants. Serpentine soils also are characterized by a low calcium/magnesium ratio and low levels of potassium and phosphorus – minerals important for plant growth. The resulting vegetation is sometimes termed 'serpentine barrens.' Forests are absent or stunted, shrubs are usually sparse, and species adapted to serpentine soils are typically slow-growing.[790] Serpentine soils occur worldwide in areas of tectonic plate activity, but occupy less than 1% of the earth's surface, so are not common anywhere. In B.C., serpentine soils follow a line of tectonic activity through the centre of the province from Tulameen Lake in the south to Atlin in the northwest.

Why are they important? Plants that can tolerate the harsh environment of serpentine soils often cannot compete successfully with other species in less hostile environments, so are restricted to serpentine ecosystems. Examples in B.C. include Lemmon's holly fern (*Polystichum lemmonii*) found on Mount Baldy in the Okanagan and the mountain holly fern (*P. scopulinum*) from the Tulameen River valley. Both species are relatively widespread (though localized) and considered globally secure, but are rare in B.C. The presence of serpentine ecosystems increases the overall biodiversity in B.C. by providing a niche for these specialized plants.

Lemmon's holly fern (*Polystichum lemmonii*) can tolerate the harsh environment of serpentine soils, which are toxic to many other plants.
PHOTO: VIRGINIA SKILTON.

Status/threats in B.C. The overall status of serpentine soils is unknown. Because of their lack of productivity there is a tendency to treat areas of serpentine soils as wasteland. In B.C., the major threat is likely from mineral exploration and development, and possibly urbanization. Elsewhere, efforts to make serpentine ecosystems productive have involved massive intrusions that eliminate species adapted to these ecosystems.

Data gaps: No systematic, province-wide survey of these ecosystems has been undertaken.

F. SALINE LAKES

What are they? Saline or 'salt' lakes have been defined as those having more than 3g/L salt content, in contrast with 'freshwater' lakes, which have less than 3g/L of salt. The 'salts' include sodium, magnesium, carbonate, bicarbonate and sulphate. Salt lakes or ponds have no outlet. They are formed where evaporation exceeds rainfall and minerals become concentrated by evaporation during the summer. They often are alkaline, have extremely high nutrient levels, trace metals and low oxygen. Often by the end of summer, saline lakes are surrounded by crystalline salts, and some areas dry up completely, resulting in small salt flats. Maritime glasswort (*Salicornia maritima*) may add a red margin around some ponds, while alkali saltgrass (*Distichlis spicata* var. *stricta*) adds a yellow tint to some crystalline rings. The lakes typically have few or no submergent plants and few emergents.

Saline lakes occur on all continents and are widespread in dry environments. B.C.'s southern Interior Plateau, particularly in the Okanagan and Kamloops areas and throughout the Fraser Plateau, is dotted with small saline ponds that are mostly less than 1 km^2 in area (see Map 11B, p. 142).

Why are they important? The unique hydrology and species composition of saline lakes separates them from the surrounding habitat. Some species, including some dragonflies and midges (chironomids) and other invertebrates, such as brine shrimp (*Artemia* spp.), are specifically adapted to these conditions. For species that can maintain their internal chemical balance under these conditions, the lakes are secure and free of most potential predators. Adapted invertebrates can thus attain large numbers, resulting in ideal stopover and nesting sites for birds such as phalaropes (*Phalaropus* spp.) and plovers (*Charadrius* spp.).

A very few saline lakes, such as Mahoney Lake in the Okanagan, are meromictic, meaning the water layers do not turn over, so there is no mixing. In Mahoney Lake, this lack of mixing permits the densest population

Maritime glasswort (*Salicornia maritima*), growing at the edge of one of B.C.'s saline lakes, forms a distinct red margin.
PHOTO: SARMA LIEPINS.

Kliluk, also known as Spotted Lake, is a culturally significant site for the Okanagan Nation. As the lake dries up in summer, its high concentration of minerals forms shallow pools of white, pale yellow, green and blue mud.
PHOTO: ORVILLE DYER.

of phototrophic sulphur bacteria (dominated by the purple sulphur bacterium [*Amoebobacter purpureus*]) ever reported in a natural body of water. The sulphur bacteria form a thin but highly concentrated layer, called a sulphur bacterial plate, at the boundary between the layers of water with and without oxygen. This bacterial plate, in turn, supports a copepod (*Diaptomus connexus*) and a rotifer (*Brachionus plicatilis*).[791]

Some saline lakes, such as Spotted Lake in the Okanagan, are culturally significant to First Nations. The lake and surrounding land has been purchased by the Okanagan Nation Alliance for the purpose of conservation.

Status/threats in B.C. Some saline lakes, such as Mahoney Lake and Soap Lake, are protected within ecological reserves. Saline lakes are especially vulnerable because they occur in dry areas where agricultural and rural development are prevalent. Climate change poses a particular threat to saline lakes because they are typically shallow and distant from taller vegetation and consequently not buffered from air temperature change. Although the lakes are valuable to some species, it appears that little can be done to sustain many of them in the face of climate change. Pollution and the introduction of exotic species are also threats. In some areas, salt lakes are an economically important source of minerals such as halite, uranium, zeolites and borax.

Data gaps: Listing and mapping of saline lakes within the province is incomplete. Their small size means they are usually overlooked in broad-scale inventory.

G. FISHLESS LAKES

What are they? Fishless lake is a term applied to freshwater lakes that, because of their physical isolation from other water bodies, do not contain fish and have not been stocked with fish. They occur throughout B.C., but are particularly common in mountainous regions where access by downstream fish is prevented by waterfalls or canyons, and on plateaus where isolated lakes have no inflow or outflow.

Why are they important? Although historically common in B.C., fishless lakes are becoming increasingly rare in the province and elsewhere, and are a special element because they provide a unique environment. Prior to stocking, approximately 95% of an estimated

16,000 mountain lakes in the western United States were fishless. Now 60% of all of these lakes and 95% of the deeper (more than 3 m) and larger (more than 2 ha) lakes contain introduced trout.[792] Much the same has happened to accessible lakes at lower elevations in British Columbia.[793] Fishless lakes and headwaters are special in that resident species are not subject to predatory fish. The community composition in fishless lakes is therefore different from that found in lakes with fish, and includes species such as rare cladoceran crustaceans and the tiger salamander (*Ambystoma tigrinum*), a species of conservation concern. These communities may not be able to effectively withstand predation.

Status/threats in B.C. In much of the province, fewer than 5% of the low-elevation lakes remain natural,[794] and, even where habitats are protected, diversity may not be conserved.[795] Long-term studies on the effects of introduced fish show that even when the introduced fish populations are extirpated, their impacts on community structure may continue up to a decade after the last fish introduction. In other lakes, the fish successfully reproduce and become a permanent predator, even spreading to other previously fishless lakes in a watershed. The practice of introducing game fish into fishless lakes has effectively eliminated the fishless lake ecosystem from large areas of western North America.

Data gaps: There is no consolidated list or mapping of fishless lakes.

H. MICROBIALITES

What are they? Microbialites are fossilized mats formed by microbes, primarily cyanobacteria (previously known as blue-green algae).[796] Cyanobacteria create microbialites by trapping sedimentary grains, binding the grains with mucous, and cementing them with lime into thin layers. The bacteria extend the microbialites vertically to access sunlight necessary for photosynthesis. The resulting structures have a variety of shapes: columnar, conical, branching or stratiform. Over millennia, these structures became fossilized limestone, and microbialites today have a very definite laminated structure and appearance. Many examples date from the Precambrian era, but some microbialites are still home to living microbes. Two examples are found in B.C. in Pavilion Lake and Kelly Lake (see Map 11A, p. 138).

Why are they important? Cyanobacteria are among the earliest living organisms on the planet and likely the first to photosynthesize, using water, sunlight and carbon dioxide to yield oxygen and calcium dioxide (lime). Fossilized bacteria sometimes found in microbialites are evidence of some of the earliest life forms, dating from approximately 3.5 billion years ago, and may provide clues to the origins of life on earth.[797]

Status/threats in B.C. Microbialites are rare and vulnerable to disturbance due to their fragility. One of the two known occurrences of microbialites in B.C. is found in Pavilion Lake in Marble Canyon Provincial Park. The Pavilion Lake microbialites, which reach 2 m in height, are the largest known freshwater microbialites and contain both cyanobacteria and diatoms. In nearby Kelly Lake, the microbialites were thought to be only 1–2 cm in height.[798] Recently, however, much larger (>50 cm) structures have been measured.[799] Kelly Lake is adjacent to Downing Provincial Park, but is not itself protected.

Data gaps: Although all microbialite sites may have been found, extensive surveys in candidate lakes have not been undertaken.

3 Threats to Biodiversity in British Columbia

Biodiversity is under threat around the world. The 2005 Millenium Ecosystem Assessment estimated that 60% of the world's grasslands, forests, farmlands, rivers and lakes have been degraded, along with their ability to perform essential ecosystem functions and to support life.[800] Although the World Conservation Union (IUCN) monitors only a fraction of the world's 1.5 million scientifically described species, its assessment suggests that a significant proportion of species are of conservation concern. The global extinction rate is estimated at 100 to 1,000 times the natural background rate of extinction and may increase by 100-fold in the future.[801] Lost along with each species is its current and evolutionary potential to provide food, fuel, building materials, pollination, decomposition or other services essential to maintain life for all organisms, including humans.

Generally, ecosystem integrity in British Columbia has remained relatively high due to the province's short history of development and mountainous terrain. However, the current trends for both species and ecosystems are of major concern. Where biodiversity intersects with the ever-increasing human use of land and resources, species and ecosystems have suffered.[802] Within B.C., 43% of the assessed species are of provincial conservation concern (see Table 13, p. 54). Also of provincial conservation concern are four of the 16 biogeoclimatic zones (see Table 3, p. 32), four of the nine Major Drainage Areas (see Table 9, p.43) and 340 (56%) of the 611 described ecological communities (see Table 7, p. 38). The status of biodiversity at the genetic, species and ecosystem levels in B.C. indicates that all is not well.

The past 4,000 years of relative ecological stability was disrupted by the arrival of European and Asian settlers. Ecosystems that took thousands of years to develop have been disturbed, especially in the southern part of the province, by land conversion, widespread logging, dams and alien species. Not since the last ice age, 10,000 years ago, has such a change in biodiversity occurred in the province.

3.1 Approach

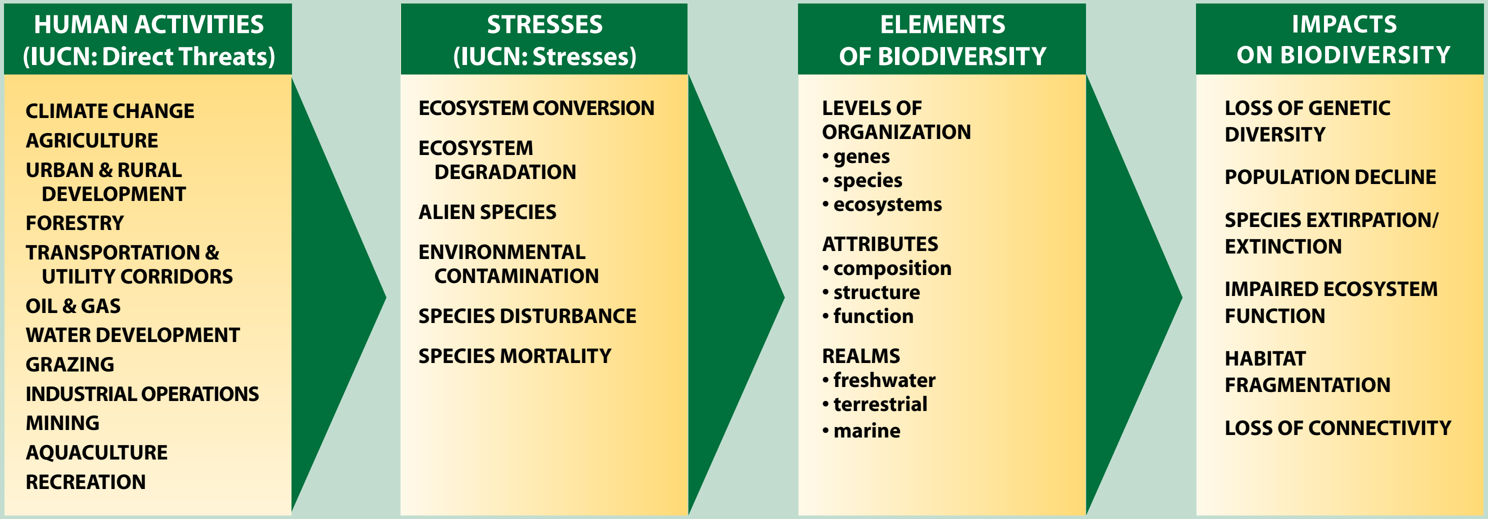
This section describes the impacts (past and current) and threats (future) to biodiversity in the freshwater and terrestrial realms and the overlap with the marine realm (estuaries and intertidal areas). A special emphasis is placed on climate change. Information on trends is presented where available. Where quantitative information was limited or not available, qualitative data based on professional judgements were incorporated into the assessment.

Since a consistent framework for measuring impacts in B.C. does not exist, a framework (Figure 31) was created based on input from a 2006 survey of 25 B.C. experts (referred to below as the 2006 biodiversity threats survey) and the IUCN classification of the major international threats to biodiversity.[803] The general concept underlying this framework is that there are multiple human activities (e.g., forestry, grazing) that culminate in a number of stresses (e.g., ecosystem conversion) and impact the elements of biodiversity, resulting in consequences such as loss of diversity or habitat fragmentation. Two main sources of information were used to determine the magnitude of, and relationship between, human activities and stresses. Both involved the observation of impacts as reported through opinion surveys and workshops: the 2006 biodiversity threats survey[804] and a 2003 assessment of threats.[805] Supplementary information was obtained from documents relating to impacts and threats to biodiversity in B.C.

Section 3 includes an examination of the main stresses (ecosystem conversion, ecosystem degradation and alien species) and the three lower-ranked stresses (environmental contamination, species disturbance and species mortality), followed by a discussion of the human activities that contribute to them. Most of the discussion (e.g., information and trends) focuses on the stresses and human activities that have the highest impact on biodiversity, according to the surveys.

3.2 Major Stresses on Biodiversity

Many of the declining trends presented in Section 2 are the result of two factors: ecosystem conversion and ecosystem degradation. For example, many streams in the Lower Fraser Valley have been lost to draining and culverting (see Text box 7, p. 43), grasslands have been converted to farms and urban centres (see Text box 5, p. 39),



HUMAN ACTIVITIES

Climate Change: Impacts due to changes in temperature, precipitation, wind, or other aspects of the earth's climate.
Agriculture: Infrastructure and activities associated with intensive agriculture cropping (e.g. vegetables, grass, nursery, silage etc.).
Urban & Rural Development: Infrastructure and activities associated with human use for the purposes of living (e.g. housing, buildings, sewage).
Forestry: Infrastructure and activities associated with harvest or management of trees.
Transportation & Utility Corridors: Infrastructure and activities associated with the movement of people, commodities or information (e.g. highways, ports, railways, power lines).
Oil & Gas: Infrastructure and activities associated with the extraction of petroleum or natural gas.
Water Development: Infrastructure and activities associated with diversion, storage, or pumping of water.
Grazing: Infrastructure and activities associated with extensive agriculture (i.e. grazing animals).
Industrial Operations: Infrastructure and activities associated with secondary industry or other primary industries not included in forestry, mining, oil & gas or water development.
Mining: Infrastructure and activities associated with the extraction of minerals or other geological materials.
Aquaculture: Infrastructure and activities associated with shellfish and finfish operations.
Recreation: Infrastructure or activities associated with motorized or non-motorized human uses for the purposes of recreation (e.g. hiking, swimming, hunting, fishing).

STRESSES

Ecosystem Conversion: Replacement of natural communities with human-dominated natural systems (e.g. intensive agriculture) or physical works (e.g. mines, urban areas).
Ecosystem Degradation: Direct change to the structure of natural systems (e.g. forest harvesting, water diversion).
Alien Species: Individuals or populations of a species when outside the natural range of the species (e.g. purple loosestrife, grey squirrels).
Environmental Contamination: The release of chemicals, including nutrients, to natural systems (e.g. sulphur oxides, treated sewage, fertilizers, pesticides).
Species Disturbance: The alteration of the behaviour of species (e.g. aircraft flying close to mountain goats, dogs chasing waterfowl).
Species Mortality: The direct killing of individuals (e.g. harvest, by-catch, road kills, intentional poisoning).

FIGURE 31: The biodiversity threat framework.

old-growth forests have been converted to early seral stages, and mountain caribou range in southern B.C. has been fragmented leading to substantial population declines and extirpations (see Text box 13, p. 85). Ecosystem conversion and degradation are prevalent in all four of the biogeoclimatic zones of conservation concern (see Table 3, p. 32).[806]

A third factor often cited for its effect on biodiversity is alien species invasion – often a secondary impact that follows ecosystem degradation.[807,808] Alien species are outcompeting many rare native plants in Garry oak ecosystems on Vancouver Island (see Text box 6, p. 40) and dominating grasslands in the Okanagan.[809] The number of alien species of vascular plants and freshwater fish in the province continues to increase,[810] with many of them having serious impacts on biodiversity.

The 2007 B.C. environmental trends report assessed six broad-scale stresses facing 179 of B.C.'s species of conservation concern and concluded that the top two were habitat loss (defined as a combination of habitat conversion and degradation) and alien species.[811] Similarly, the 2006 biodiversity threats survey identified the three major stresses on biodiversity in B.C. as ecosystem conversion, ecosystem degradation and alien species, based on the level of concern for genes, species and ecosystems in both the terrestrial and freshwater realms (Figure 32). Stresses rated as being of lesser concern were environmental contamination, species disturbance and species mortality. All of these can have consequences for biodiversity, such as loss of species, decreases in population size and distribution, loss of connectivity and ecosystem resilience, or compromised ecosystem processes and function.

The identification of ecosystem conversion, ecosystem degradation and alien species as the most significant stresses on biodiversity in B.C. is consistent with national and international findings. Ecosystem conversion and degradation have been identified by national and international studies as the most significant immediate stresses on biodiversity.[812,813,814,815] In addition, alien species have emerged as an increasing threat to native species and ecosystems around the world.[816]

Losses to biodiversity usually originate from more than one source. Multiple stresses can impact biodiversity at a magnitude greater than the sum of the individual stresses, can be cumulative over time and can trigger cascading impacts on other components of biodiversity. For example, B.C. is experiencing rapid climate change; we do not know the exact magnitude and extent of the threats to biodiversity, but impacts that have been observed already suggest that the stresses will be significant.[817,818] Climate change will have its greatest impact in areas of the province where biodiversity has already been affected by other factors such as ecosystem degradation or alien species. Future ecosystems may or may not re-assemble into the same form as in the past, and the speed at which plants and animals adapt to or move with changes in conditions will determine whether they thrive, decline or disappear.[819] Where the landscape has already been degraded and fragmented, habitat connectivity may be lost, resulting in species being unable to move in response to the changing climate. This may have a more significant impact on species that are restricted to freshwater ecosystems (e.g., fish), as they have fewer opportunities than terrestrial species for shifting their ranges.

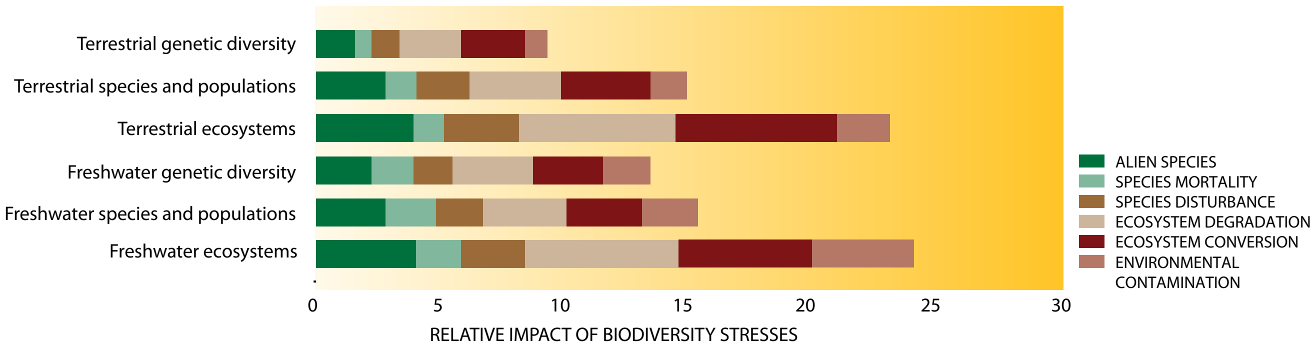


FIGURE 32: Impact of stresses on elements of biodiversity.
SOURCE: Long, G. 2007. Biodiversity Safety Net Gap Analysis. Biodiversity BC, Victoria, BC. 66pp. Available at: www.biodiversitybc.org.
NOTE: For this analysis, 25 B.C. experts identified the relative contribution of each of the six impacts by allocating 100 points amongst the six realm/level combinations.

In the 2006 biodiversity threats survey, the experts identified ecosystems as being of higher concern than species and genetic-level diversity in both realms, and expressed slightly higher concern for biodiversity in the freshwater realm than in the terrestrial realm.

3.2.1 ECOSYSTEM CONVERSION

Ecosystem conversion is one of the greatest stresses on biodiversity in B.C.[820] Ecosystem conversion is the direct and complete conversion of natural landscapes, such as forests, wetlands or grasslands, to landscapes for human uses (e.g., buildings, houses, parking lots, agricultural fields).[821] Ecosystem conversion or loss compromises or eliminates the ability of native species to survive in the new conditions and they either adapt, move or die. The result is reduced species richness and the loss of ecological functions such as air and water purification, pollination, soil building, climate regulation, and nutrient and water cycling. These functions performed by plant and animal species are essential for ecosystem health and for human well-being.

The magnitude of ecosystem conversion in B.C. varies spatially. In the terrestrial realm, there has been significant ecosystem conversion in the Coastal Douglas-fir biogeoclimatic zone on the southeast coast of Vancouver Island and in the Bunchgrass and Ponderosa Pine zones in the southern interior (Table 25), all three of which are of conservation concern (see Section 2.1.1.1, p. 30). Although only about 2% of the province's land base has been converted, the conversion is concentrated in these three rarest biogeoclimatic zones. In other parts of the province, the pattern of conversion follows the lower-elevation transportation corridors, with areas of loss concentrated around population centres. The province's mountainous topography has limited human activity and ecosystem conversion in high-elevation areas, but lower areas, such as valley bottoms and coastal

Downtown Vancouver is an urban area converted from old-growth temperate rainforest. Stanley Park, in the background, illustrates the natural condition.
PHOTO: ISTOCK.

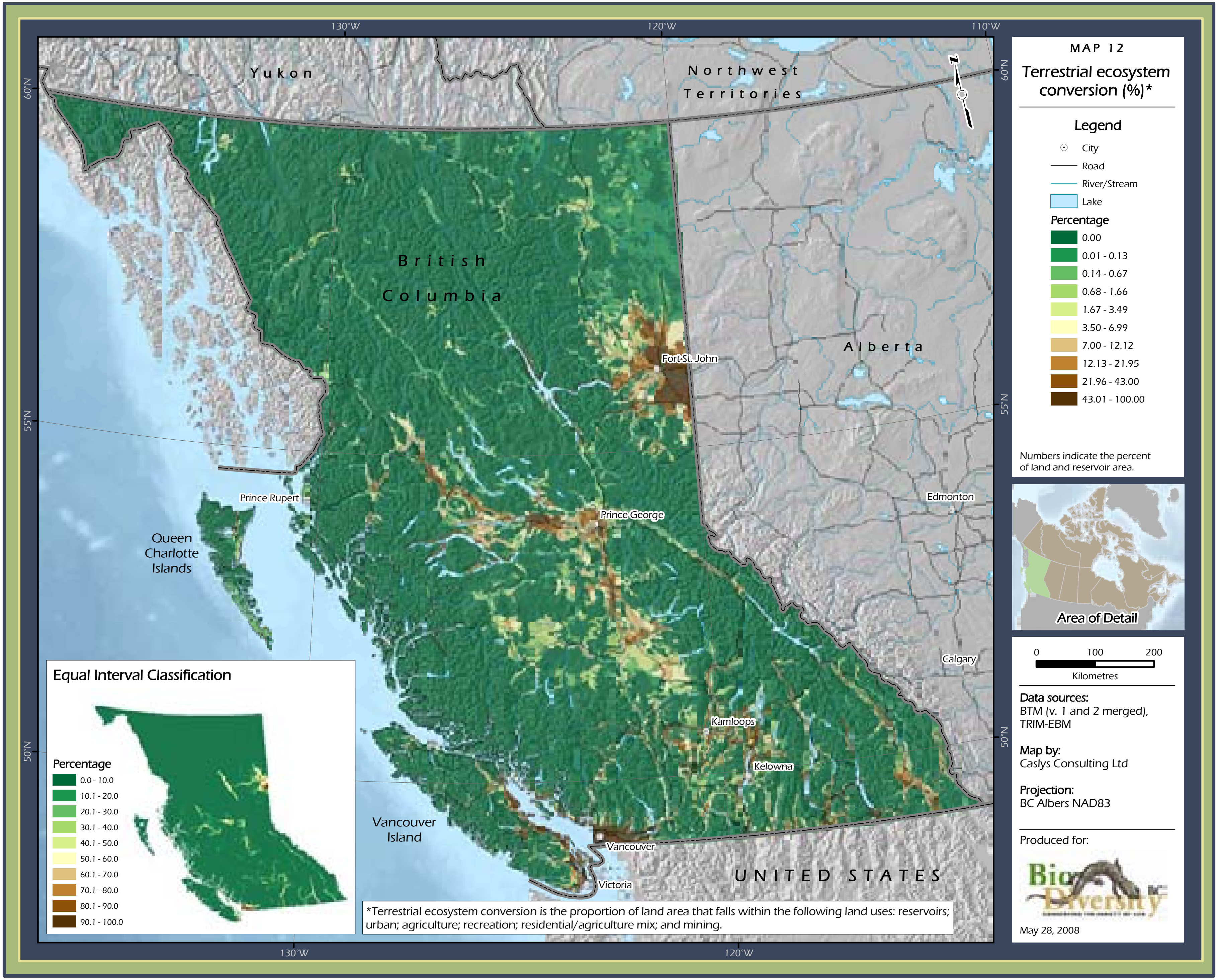
regions, have been significantly impacted; 94% of ecosystem conversion in B.C. has occurred below 1,000 m elevation (Map 12).

In the Okanagan Valley and Fraser River delta, more than 75% of the wetlands have been converted by agriculture, urbanization and commercial activities.[822,823] In the freshwater realm, extensive conversion also comes from reservoirs, which can eliminate natural ecosystems such as wetlands. Activities that result in ecosystem conversion in the overlap between the terrestrial and marine realms include shoreline armouring (e.g., retaining walls) and the diking, draining or filling of estuaries.

TABLE 25. AREA OF TERRESTRIAL ECOSYSTEM CONVERSION IN B.C. SINCE EUROPEAN CONTACT.

BIOGEOCLIMATIC ZONE	CONSERVATION STATUS	TOTAL LAND AREA BEFORE ECOSYSTEM CONVERSION (KM^2)	AREA OF ECOSYSTEM CONVERSION (KM^2)	AREA OF ECOSYSTEM REMAINING (KM^2)	PERCENT OF LAND AREA CONVERTED TO HUMAN USES
Coastal Douglas-fir	Imperilled (G2)	2,561	1,251	1,310	49%
Bunchgrass	Imperilled (G2)	2,579	531	2,048	21%
Ponderosa Pine	Imperilled/ vulnerable (G2/G3)	3,513	617	2,896	18%
Interior Douglas-fir	Vulnerable (G3)	42,721	2,302	40,419	5%
Boreal White and Black Spruce	Apparently secure (G4)	159,473	6,106	153,367	4%
Sub-boreal Spruce	Apparently secure (G4)	95,551	3,206	92,345	3%
Coastal Western Hemlock	Apparently secure (G4)	104,998	2,745	102,253	3%
Interior Cedar–Hemlock	Apparently secure (G4)	51,751	837	50,914	2%
Sub-boreal Pine–Spruce	Apparently secure (G4)	22,643	284	22,359	1%
Montane Spruce	Apparently secure (G4)	27,996	201	27,795	1%
Engelmann Spruce–Subalpine Fir	Secure (G5)	170,564	200	170,364	<1%
Mountain Hemlock	Apparently secure (G4)	36,590	18	36,572	<1%
Spruce–Willow–Birch	Apparently secure (G4)	80,131	30	80,101	<1%
Boreal Altai Fescue Alpine	Secure (G5)	76,828	17	76,811	<1%
Interior Mountain-heather Alpine	Secure (G5)	17,682	1	17,681	<1%
Coastal Mountain-heather Alpine	Secure (G5)	52,000	3	51,997	<1%
Provincial total		**947,581**	**18,349**	**929,232**	**2%**

SOURCE: Prepared for this report.
NOTE: Based on imagery taken between 1991 and 2001; ecosystem conversion that occurred after the images were taken is not included.



MAP 12
Terrestrial ecosystem conversion (%)*
Legend
City
Road
River/Stream
Lake
Percentage
0.00
0.01 - 0.13
0.14 - 0.67
0.68 - 1.66
1.67 - 3.49
3.50 - 6.99
7.00 - 12.12
12.13 - 21.95
21.96 - 43.00
43.01 - 100.00
Numbers indicate the percent of land and reservoir area.
Area of Detail
0 100 200
Kilometres
Data sources:
BTM (v. 1 and 2 merged), TRIM-EBM
Map by:
Caslys Consulting Ltd
Projection:
BC Albers NAD83
Produced for:
May 28, 2008
130°W
120°W
110°W
60°N
55°N
50°N
Yukon
Northwest Territories
British Columbia
Alberta
Fort St. John
Prince Rupert
Prince George
Edmonton
Queen Charlotte Islands
Calgary
Kamloops
Kelowna
Vancouver Island
Vancouver
Victoria
UNITED STATES
Equal Interval Classification
Percentage
0.0 - 10.0
10.1 - 20.0
20.1 - 30.0
30.1 - 40.0
40.1 - 50.0
50.1 - 60.0
60.1 - 70.0
70.1 - 80.0
80.1 - 90.0
90.1 - 100.0
*Terrestrial ecosystem conversion is the proportion of land area that falls within the following land uses: reservoirs; urban; agriculture; recreation; residential/agriculture mix; and mining.

3.2.2 ECOSYSTEM DEGRADATION

Ecosystem degradation is change to the structure of a natural system (e.g., through forest harvesting or water diversion), impacting an ecosystem's composition and function. This can take many forms, including habitat fragmentation, reduction in the quality or extent of habitat, or alteration of water flow.

The alteration of one component of biodiversity can set off a cascade of effects on other species and ecosystems. For example, fire suppression in an area of mixed forest and grassland allows the incursion of trees into the grassland, reducing the extent of the latter ecosystem.[824] At some point, the grassland may become too restricted for many of its species to survive. The increased forest encroachment could also modify the structure and composition of its predator community, resulting in increased predation on grassland species. In streams, an increase in the withdrawal of water can increase the temperature and reduce the ability of fish species to survive. The reduction in stream flow could delay the entry of salmon into the stream to spawn, exposing them to marine predators for a longer time and reducing the prey base for terrestrial predators and scavengers. Other causes of degradation include livestock grazing, damming of rivers, logging, installation of fences and road building. Degraded ecosystems are more vulnerable to invasion by alien species and to the spread of disease.[825]

Ecosystem degradation occurs throughout B.C. For example, the increasing allocation of water from streams for human uses (Figure 33) affects natural stream hydrology.[826] About 97% of water licensed in British Columbia is for power production, including storage. The remaining 3% is licensed for consumptive uses such as industrial,

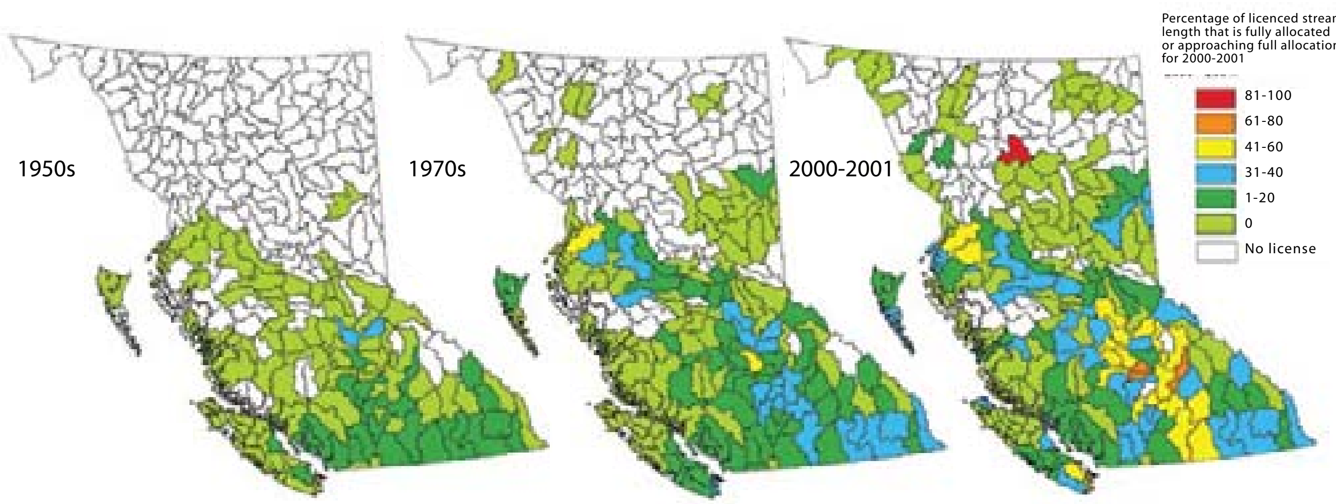


FIGURE 33: **Streams allocated to human uses, 1950s–2001.**
SOURCE: B.C. Ministry of Water, Land and Air Protection. 2002. Trends in Water Allocation Restrictions Across British Columbia. *In* Environmental Trends in British Columbia 2002. State of the Environment Reporting Office, Victoria, BC. Available at: www.env.gov.bc.ca/soerpt/8surfacewateruse/allocations.html.
NOTES: 0 = licenses present on the stream, but no restrictions. No licenses = no licences present on the stream. Values are the percentage of stream length fully allocated to human uses.

commercial and agricultural activities and drinking. The Bennett Dam on the Peace River, completed in 1967, created the largest body of fresh water in B.C., the Williston Reservoir.[827] It converted large parts of the Finlay and Parsnip rivers from a network of streams and rivers to a single water body, with devastating effects on Arctic grayling populations.[828] Within two years of the dam's completion there were impacts downstream, including reduced peak flows and a 28% decrease in the number of small lakes and wetlands. Also downstream, the Peace-Athabasca delta in northeastern Alberta, one of Canada's most productive and diverse marsh and wetland habitats, was significantly reduced in size, demonstrating the effects of actions in B.C. on biodiversity in other jurisdictions.[829]

Various stresses can combine to increase the magnitude of ecosystem degradation. This concept of cumulative impacts is based on the idea that while a single impact may not be notable, the combination of additional impacts can result in a significant stress on the system. In the face of multiple impacts, ecosystem resilience will decline until the ecosystem no longer has the ability to rebound and to provide the functions it once did.

The Nicola River case study (Text box 18) illustrates the cumulative impact of multiple stresses on one freshwater system. This situation is expected to become widespread in the Thompson and Okanagan areas, where licensed water use already removes a high percentage of the flow in many systems during the annual low-flow period and future water demand is expected to increase as a result of climate change and population growth.[830]

A portion of the water from the Salmon River is diverted through this concrete sluice into the upper Campbell River system to enhance the hydroelectric capacity of the John Hart Dam.
PHOTO: TIM ENNIS.

TEXT BOX 18. THE NICOLA RIVER: EXTREME PRESSURE ON WATER RESOURCES[831]

The Nicola River is a tributary of the Thompson River in the Fraser River drainage. The Nicola River drains 7,227 km^2 – an area equivalent to one-eighth of the Thompson River drainage – and is a major producer of chinook salmon, coho salmon and steelhead, supporting world-renowned runs of these species.[832] Water temperature is recognized as an extremely important variable that can affect the distribution, growth, behaviour, metabolism, disease resistance, survival and productivity of juvenile and adult salmonids.[833]

Water temperatures in the Thompson River are inherently susceptible to warming trends during the summer months due to regional climatic conditions.[834] Summers are characteristically hot and dry and air temperatures can exceed 40°C. Annual precipitation ranges from 250–500 mm per year.[835] High demand for water by the agricultural, industrial and domestic sectors exacerbates this natural susceptibility by decreasing flows and increasing extreme temperature fluctuations.[836] In addition, removal of riparian vegetation decreases shading and can increase channel width. Individually and collectively, these changes can elevate water temperatures in many situations.

Fisheries and Oceans Canada conducted temperature monitoring during 1994–1996 in the Nicola River watershed.[837,838,839] The study revealed temperatures frequently within the ranges considered unsuitable or lethal to salmonids. The preferred range for salmonid spawning is 4–14°C. Spawning ceases and disease increases at water temperatures above 16°C, and at 21–25°C, temperatures become lethal to salmonids. 1994 was the hottest year during the study, with average mid summer temperatures exceeding 21°C at almost all sites. At two sites on July 24, 1994, maximum recorded temperatures reached 29°C, well above the lethal tolerance range for Pacific salmonids. The total time above 25°C in 1994 ranged from 33 to 93 hours, with the maximum consecutive periods above 25°C ranging from 9 to 18 hours. While the temperatures measured in 1995 and 1996 were cooler, the temperatures were still stressful and even lethal to salmonids.

In addition to the commercial, recreational and First Nations fisheries supported by the Nicola River system, extensive forestry and agriculture takes place in the Nicola drainage. More than 26% of the watershed has been logged,[840] and agricultural activity is intensive and concentrated along the lower, more productive reaches. Upland areas are used for summer grazing and the valley bottoms are used for winter cattle feeding. There are at least 1,600 water licenses in the Nicola River watershed and 95 restrictions, many of them in place since as early as 1991.[841] More than 560 km of stream length in the watershed has been allocated to licenses and over 20% of that stream length has been restricted.[842] In addition, development is concentrated along the Coldwater River, a major tributary of the Nicola River.

The Nicola River situation highlights how a natural vulnerability – in this case, to temperature increases – can be severely exacerbated by a combination of climate change and resource development (e.g., loss of shade and water flow) to the point that ecosystem viability and the sustainability of major fish populations are seriously threatened.

3.2.3 ALIEN SPECIES

Alien species are those that occur outside their native range due to human introduction.[843] Alien species can be introduced intentionally (e.g., through agriculture, horticulture, forestry or the release of pets), accidentally (e.g., contamination on plants, species attached to equipment that is transported) or from captive or commercial cultivation (e.g., zoos, farmed animals, escapes from research facilities).[844] Species that are native to some parts of B.C. can be alien species when moved to other areas of the province (e.g., raccoons, beaver and deer are alien species on Haida Gwaii/Queen Charlotte Islands). For the purposes of this report, species that are native to neighbouring jurisdictions and shift their distributions due to climate or habitat change are not considered alien species.

Not all alien species are harmful because most cannot spread; invasive alien species are those species that threaten biodiversity. One estimate is that about 10% of alien species become invasive.[845] However, some species also exhibit a time lag between introduction and impact on biodiversity. For example, gorse (*Ulex europaeus*) was introduced to B.C. at least 90 years ago,[846] and was only recently recognized as an invasive alien species.[a] Invasive alien species alter forest fire cycles, nutrient cycling, hydrology and energy budgets in native ecosystems.[847] They displace native populations of plants and animals by occupying habitat and competing for resources.[848] Alien species can also affect native species through predation, displacement, habitat degradation (e.g., removal or replacement of vegetation), hybridization and the introduction of diseases, as well as by facilitating the spread of other non-native species.[849] Sometimes alien species are introduced to perform beneficial ecological roles, such as in the case of species introduced for biological control. For example, the beetle *Galerucella calmariensis* has been introduced to some areas to control purple loosestrife (*Lythrum salicaria*).

In B.C., some of the most vulnerable ecosystems include the grasslands of the interior, where invasive alien species such as purple loosestrife and European starlings (*Sturnus vulgaris*) reduce the abundance of native species, and grazing, road building and fire suppression have facilitated the spread of alien plant species such as cheatgrass (*Bromus tectorum*). On some of B.C.'s coastal islands, ecosystems have been degraded by alien species such as rats, racoons, deer and European rabbits (*Oryctolagus cuniculus*). In the urban areas of the lower mainland and Vancouver Island, the introduction of European herbaceous species, in conjunction with fire suppression, has altered the Garry oak ecosystem as well as many of the wetlands.[850] In streams, the release of species such as yellow perch (*Perca flavescens*) has reduced native trout populations through competi-

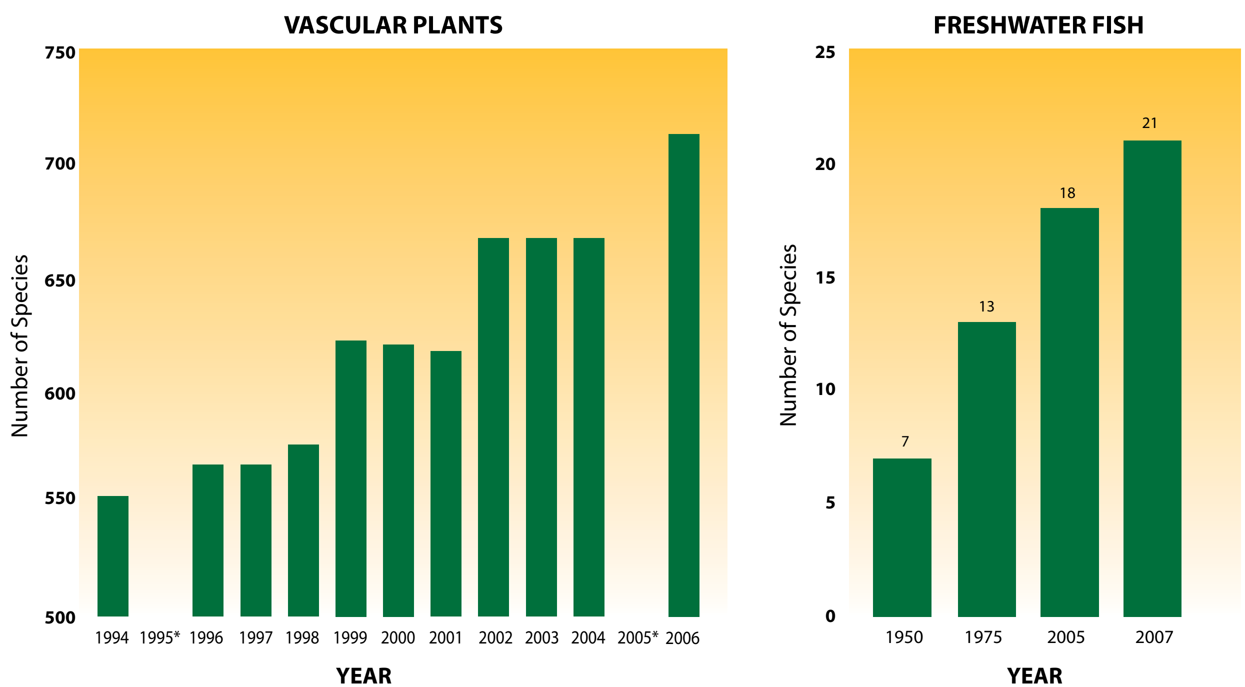
[a] Gorse was added to the provincial list of noxious weeds in 1996.

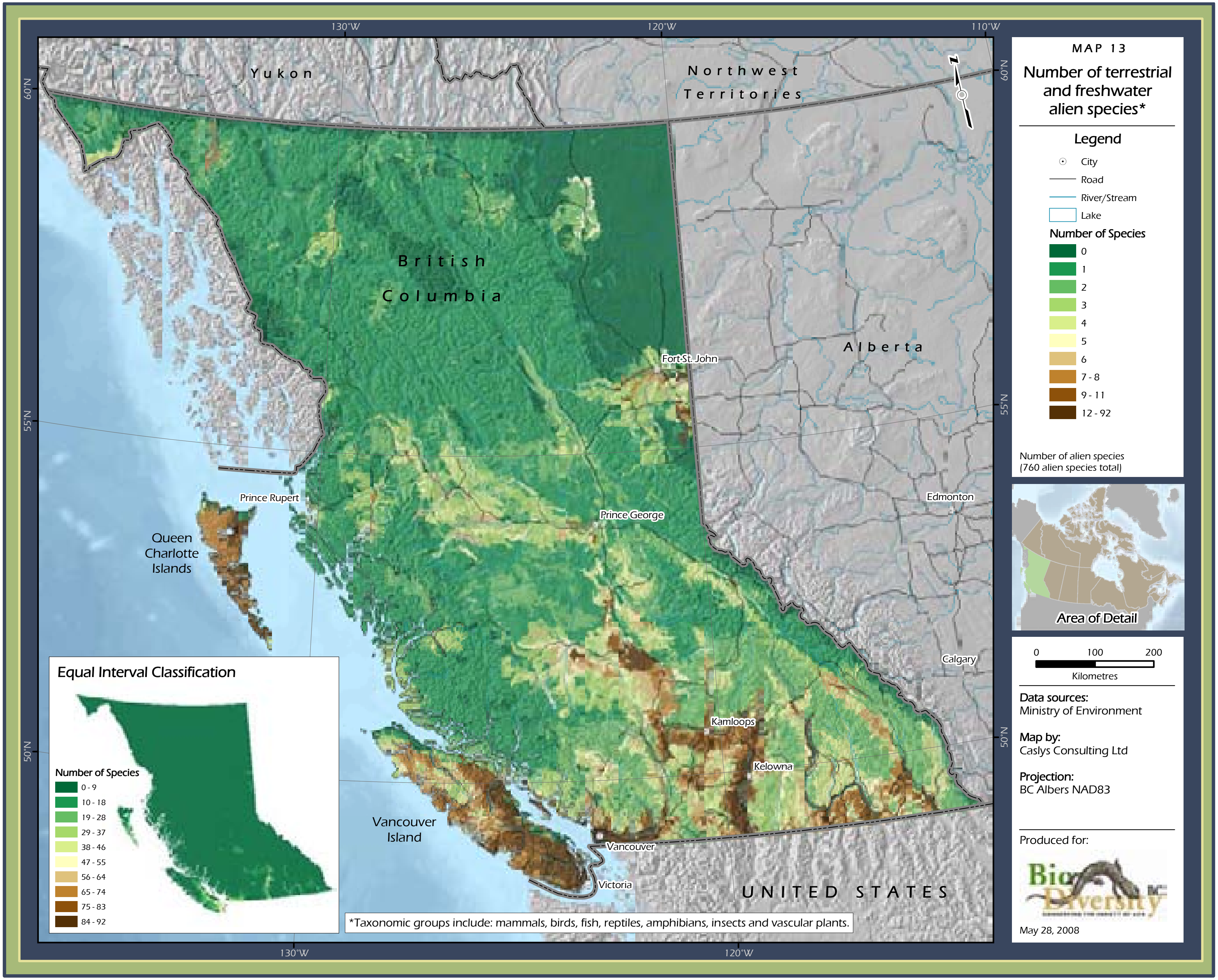
tion and predation.[851] Once established, invasive alien species can be extremely difficult and costly to control or eradicate, with knapweed (*Centaurea* spp.) being a good example of this problem in B.C.[852]

The B.C. Conservation Data Centre lists 809 alien species.[853] Most are vascular plants, but the inventory of many alien insects, such as beetles, true bugs and plant lice, is incomplete, and the abundance of alien insects in other areas already far exceeds that of alien vascular plants.[854,855,856] The number of alien vascular plants identified in B.C. increased by 29% between 1994 and 2006 (Figure 34).[857] Alien freshwater fish species increased by 300% between 1950 and 2007, rising from seven species to 21 (Figure 34),[858,859] and the number of water bodies hosting alien fish species increased from 28 to 625 between 1950 and 2005.[860] Note that the increase in detections of alien species is a function of both actual introductions and better information.

Map 13 shows the distribution of the 776 terrestrial and freshwater alien species of vertebrates, invertebrates and vascular plants for which location data were available.[861] The biogeoclimatic zones with the highest numbers of mapped alien species were the Coastal Western Hemlock (579 species), Coastal Douglas-fir (515) and Interior Douglas-fir (335) zones.

FIGURE 34: Alien vascular plant and freshwater fish species in B.C.
SOURCE: B.C. Ministry of Environment. 2007. Species Conservation. Technical Paper for Environmental Trends 2007. State of Environment Reporting Office, Victoria, BC. Available at: www.env.gov.bc.ca/soe/et07/07_species_conserv/technical_paper/species_conservation.pdf; and D. McPhail, University of British Columbia, Emeritus, personal communication.
NOTE:* Years with no data available.





MAP 13
Number of terrestrial and freshwater alien species*
Legend
City
Road
River/Stream
Lake
Number of Species
0
1
2
3
4
5
6
7 - 8
9 - 11
12 - 92
Number of alien species
(760 alien species total)
Area of Detail
0
100
200
Kilometres
Data sources:
Ministry of Environment
Map by:
Caslys Consulting Ltd
Projection:
BC Albers NAD83
Produced for:
May 28, 2008
Yukon
Northwest Territories
British Columbia
Alberta
UNITED STATES
Fort St. John
Prince Rupert
Prince George
Edmonton
Calgary
Kamloops
Kelowna
Vancouver
Victoria
Queen Charlotte Islands
Vancouver Island
130°W
120°W
110°W
60°N
55°N
50°N
Equal Interval Classification
Number of Species
0 - 9
10 - 18
19 - 28
29 - 37
38 - 46
47 - 55
56 - 64
65 - 74
75 - 83
84 - 92
*Taxonomic groups include: mammals, birds, fish, reptiles, amphibians, insects and vascular plants.

TEXT BOX 19. AQUACULTURE OF MANILA CLAMS IN INTERTIDAL AREAS[862]

The Manila clam (*Tapes philippinarum*) is an interesting example of an alien species that has become commercially important and is threatened by impacts on intertidal biodiversity, yet also potentially threatens intertidal biodiversity. Accidentally introduced into B.C. from Japan with the seed of the Pacific oyster (*Crassostrea gigas*) in the early 1900s, the Manila clam has become the most important commercial wild-harvested clam species in the province.[863] High concentrations of clam leases occur in some areas, such as Baynes Sound. There is a poor understanding of the cumulative effects of high densities of clam tenures combined with secondary impacts such as water quality changes, other alien species and climate change.

A number of approved activities associated with Manila clam production present threats to intertidal biodiversity.

- Substrate modification: Manila clams grow and survive best in a stable, loosely packed substrate of gravel, sand, mud and shell. To enhance natural substrate that is inadequate for Manila clam production, gravel or a combination of gravel and crushed oyster shell is spread on beaches, which likely affects the structure of benthic communities.
- Beach modification: To enhance substrate stability and protect clam pots from storm damage, predator-exclusion netting and berms are used to reduce wave energy. Other methods used to stabilize beaches for clam production include contouring the intertidal area and channelizing streams that flow through the plots. All of these practices may alter the natural patterns of waves and currents and result in impacts on the natural patterns of erosion and sedimentation in the intertidal zone.
- Predator control: Predation on clams by bottom fish, crabs, starfish and sea birds is controlled by the application of protective netting over seeded substrate. The removal and destruction of these predator species may shift the intertidal community to one primarily made up of clams.
- Maintenance: Terrestrial vehicles are sometimes used to spread gravel on beaches, move material into place or retrieve bags of clams or materials. Significant human activity takes place on beaches during site preparation and seeding, often at low tides. Vehicles compact substrate and alter drainage and sediments, impacting the intertidal vegetation and fauna such as

crustaceans and shallow-burrowing bivalves. Accidental discharge of oil and gasoline can contaminate intertidal fish and fish habitat. Boat propellers and the dragging of boats across beaches can damage eelgrass beds and intertidal vegetation. Nesting, roosting or foraging activities by coastal birds can be disrupted by human activities on the beach at certain times of year.

- Harvesting: Clams are harvested by hand-raking, with most harvesting taking place at night during low tides from October to March. The turning of sediments during raking can impact the spawning success of fish species that spawn in intertidal areas, such as longfin smelt, Pacific herring, sand lance (*Ammodytes* spp.) and rock sole (*Lepidopsetta bilineata*). Clam raking can also increase sediment in the water, and may bury some species and expose others.

3.2.4 ENVIRONMENTAL CONTAMINATION

Environmental contamination occurs when substances are released intentionally, accidentally or as a by-product, into natural systems. They may be transported through air, water or soil and can be emitted from specific sites (point source) or through more diffuse sources (nonpoint source), such as runoff from land. Contaminants can accumulate in various ways: within an organism (i.e., through ingestion); at progressively higher levels within a food web, as predators consume prey; or in particular geographic areas before being released into other ecosystems. For example, airborne contaminants can accumulate in the snow that feeds lakes in the Rocky Mountains, resulting in concentrations high enough to affect wildlife at the top of the food chain.[864]

Traditionally, the list of contaminants included metals (e.g., mercury, lead, copper, zinc), but more recent additions include: persistent organic pollutants (POPs), which include a wide range of chlorinated and other halogenated chemicals, such as dioxins, furans, polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs); fine particulate matter emitted from vehicles, factories and power plants; various types of pharmaceuticals, herbicides and pesticides; sewage effluent; and nitrogen, phosphorus or other nutrients from sources such as fertilizers.

The impact of a contaminant on a species or ecosystem depends on the amount of exposure and its toxicity and persistence. Effects may be lethal (i.e., the contaminant kills organisms) or sublethal[865] (e.g., it impairs reproduction or degrades ecosystems). Several POPs have been identified as endocrine-disruptors that interfere with hormones, resulting in feminization of male animals, masculinization of females, eggshell thinning in birds, and disruption of vitamin A and thyroid hormone physiology in mammals.[866] Sources of these substances have been found in sewage and pulp mill effluent and in pesticides.[867]

Shellfish beds in coastal B.C. are closed to harvesting when samples show contamination with bacteria (fecal coliforms) from human or animal wastes. Sources of contamination include urban runoff, sewage discharge and agricultural drainage. Closures of shellfish beds have increased since the 1970s owing to increases in human population and associated increases in the discharge of sewage (Figure 35). Increases in closures can be attributed to better monitoring for contamination, but also indicate increases in shoreline development. The sharp increase in 2001 resulted from a temporary closure in Clayoquot and Barkley sounds, likely the result of contamination from wildlife wastes that had been washed into the ocean by heavy rains. Closures to protect human health also indicate that there may be deleterious effects on other life forms.[868]

After the recognition of the impacts of POPs, many were banned or subject to stringent regulations, which have controlled their use and release since the 1970s. As a result, levels of many POPs have decreased substantially, but because of their low rate of decomposition, they remain in the environment and continue to circulate.[869] Levels of some other POPs have not decreased. PBDEs, which are used as flame retardants in consumer products, have generally increased. While one form used in polyurethane foam has decreased, many others used in the

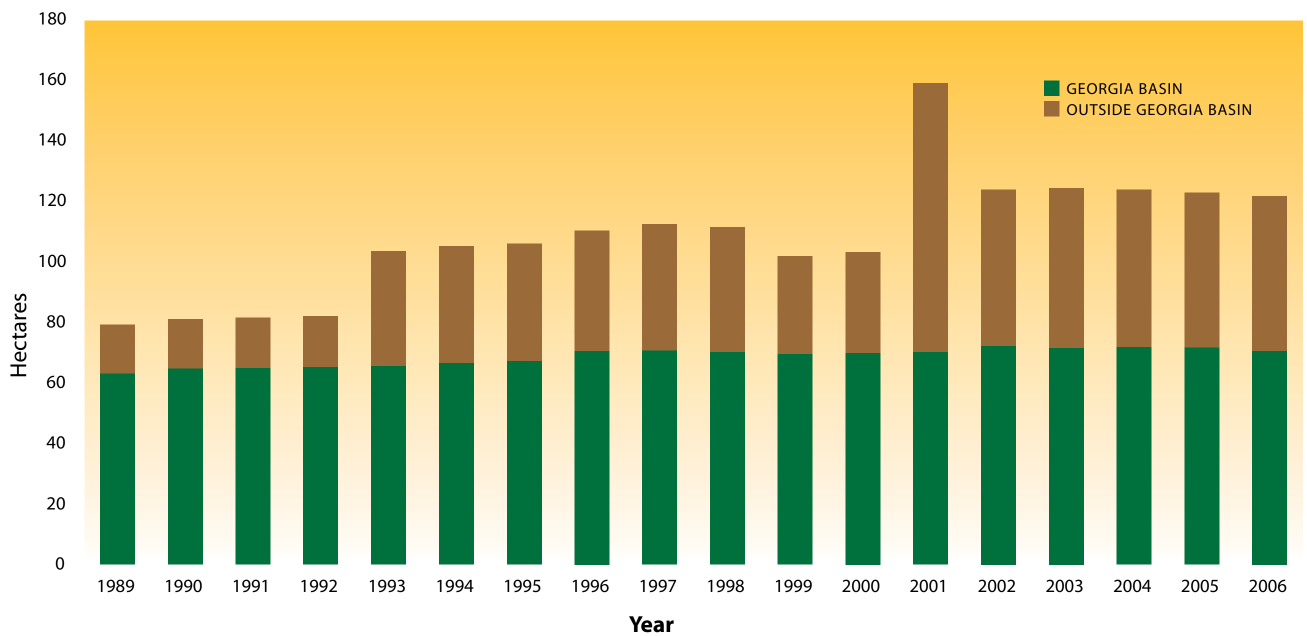


FIGURE 35: **Trends in shellfish beds closed to harvesting in British Columbia, 1989–2006.**
SOURCE: Environment Canada. 2005. Shellfish Closures: An Indicator of Contamination in Marine Ecosystems in BC. Ecosystem Information Section. Available at: www.ecoinfo.org/env_ind/region/shellfish/shellfish_e.cfm.

production of plastics (e.g., carpet backings, electrical insulation, computer and TV cases and other consumer goods) have increased.[870] This is reflected by an almost tenfold increase in the amount of PBDEs in the breast milk of Vancouver women between 1992 and 2002, from 3 ng/g to 20 ng/g.[871]

The amount of dioxins and furans emitted from pulp mills has decreased, but substantial amounts of sulphur compounds are still being emitted into the air.[872] While many metals are no longer emitted, there are still detectable levels in the environment from past events (see Section 3.3.11, p. 209).

3.2.5 SPECIES DISTURBANCE

Species disturbance is the alteration of the behaviour of species due to human activities, including those that result in the movement of physical objects or that create or alter sounds, sights, smells or other sensory stimuli. Examples include aircraft flying close to mountain goats, dogs chasing waterfowl, and power lines causing birds to modify flight patterns. Transportation and recreation are major causes of disturbance.

Disturbance can result in indirect mortality (increased risk of death), lowered productivity, or reduced use or abandonment of an area.[873] Some species may become habituated to disturbance (e.g., ungulates grazing near a highway), but their risk of mortality may increase through direct mortality or predation. Predation can increase when structures provide camouflage or better access via trails, such as when wolves follow packed-snow trails to gain access to mountain caribou herds.[874] In the intertidal zone, predator control nets used to reduce the loss of harvestable shellfish can have the unintended effect of excluding waterfowl from intertidal feeding habitats.[875]

In 2002, disturbance was rated as the seventh greatest threat (out of nine) to species of highest conservation concern in B.C.[876] Many species in B.C. are sensitive to human disturbance (e.g., wolverines, grizzly bears, mountain goats and mountain caribou.) For some species, disturbance is most significant at certain times of the year. One study of brant, which stage in intertidal areas at Parksville and Qualicum Beach during spring migration, rated human-associated disturbance (by people, dogs and boats) as the highest cause of disturbance at 39%, followed by natural disturbance by birds of prey at 33%.[877]

3.2.6 SPECIES MORTALITY

Species mortality is the direct killing of individuals either intentionally (e.g., harvesting, poisoning) or unintentionally (e.g., by-catch, road kill). In 2002, it was rated as the sixth greatest threat (out of nine) to species of highest conservation concern in B.C.[878] Though rated lower than other stresses on biodiversity, species mortality results in the direct reduction in population size. It can occur on a large scale (e.g., fishing, hunting) or on a smaller scale (e.g., pest removal). The direct loss of individuals at a large scale can reduce a species or population below a minimum population threshold, thus reducing its chance to maintain a viable population size. Some forms of species mortality (e.g., removal of plants) can create other stresses such as ecosystem degradation.

3.3 Human Activities Impacting Biodiversity

In Section 3.2, the major stresses on biodiversity in B.C. were identified as ecosystem conversion, ecosystem degradation and alien species. Section 3.3 examines the human activities in various economic sectors that contribute to these stresses. Note that it is not the sectors, but some specific practices undertaken within these sectors, that impact biodiversity.

People require products derived from nature such as food, water, wood, electrical power and soil to survive and to enjoy life. As populations increase, more natural resources are sought. Cities expand to house the increasing population, agriculture intensifies to grow enough food, more power generation is required to produce adequate electricity and more roads are built to transport goods and people. Because people and nature exist together on the same land, each of these human endeavours has the potential to contribute in a large or small way to those things that threaten biodiversity. Road construction can fragment habitat and increase access to wilderness areas; urban expansion can result in paving of riparian areas, draining of wetlands and polluting of streams; and agricultural practices can displace native species and divert water from sources used by aquatic species.

As illustrated in the Nicola River case study (see Text box 18, p. 164), stresses on biodiversity most often originate from multiple human activities with cumulative impacts that can have cascading effects.[879] Depending on the type of ecosystem, the climatic conditions or the particular aspect of biodiversity, the stresses can vary in geographical extent, magnitude, duration or persistence. A 2003 province-wide survey of almost 300 biodiversity experts identified which human activities were considered the most significant within the terrestrial and freshwater realms and the marine overlap with these two realms (Table 26).[880] In the terrestrial and freshwater realms, climate change was ranked highest, while harvest was considered the greatest threat to biodiversity in the overlap with the marine realm. The analysis also ranked forestry, agriculture, dams, rural and urban development, oil and gas, and recreation as being among the human activities that most impact biodiversity in B.C.[a]

[a] The 2003 survey used different terms and methods than the Biodiversity Threat Framework (see Figure 31, p. 157).

TABLE 26. 2003 PROVINCIAL OVERVIEW OF TOP 10 HUMAN ACTIVITIES IMPACTING BIODIVERSITY IN B.C.

TERRESTRIAL REALM	FRESHWATER REALM	MARINE OVERLAP
Climate change	Climate change	Harvest (commercial, recreational, illegal)
Forestry (Crown land)	Forestry (Crown land)	Climate change (sea level change, hydrological changes)
Alien species	Rural development	Alien species
Recreation	Dams	Aquaculture
Dams	Alien species	Transportation/corridors – ocean traffic
Forestry (private land)	Agriculture	Forestry – ocean/lake log handling
Oil and gas	Forestry (private land)	Rural development
Grazing	Transportation	Oil and gas
Harvest	Recreation	Urban development
Rural development	Harvest	Recreation

SOURCE: Holt, R.F., G. Utzig, M. Carver and J. Booth. 2003. Biodiversity Conservation in BC: An Assessment of Threats and Gaps. Unpublished report prepared for B.C. Ministry of Environment, Biodiversity Branch, Victoria, BC.

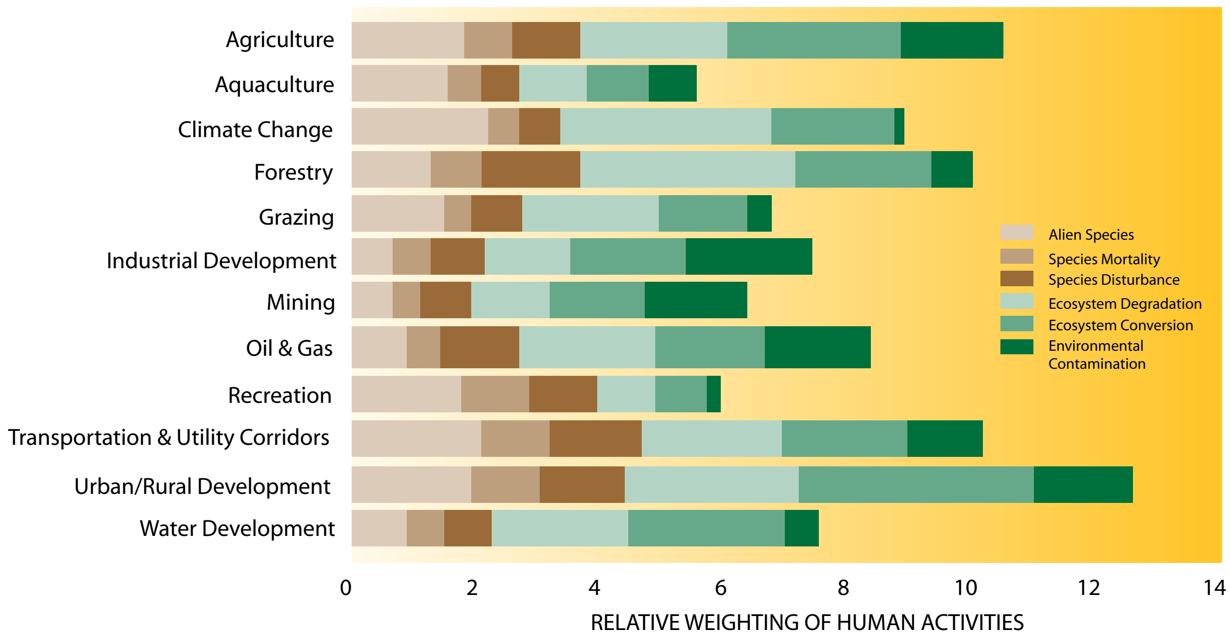
One of the criteria for the assessment of conservation status for biogeoclimatic zones presented in Section 2.2.1.1 (p. 30) was the level of impact to each zone from 11 different categories.[a,881] The results showed that climate change, residential development and agriculture are major contributors to ecosystem conversion and degradation in all four of the biogeoclimatic zones of conservation concern. Transportation, fire suppression, logging, energy and mines are also significant contributors to impacts in these zones.

Trends reported in Sections 2 and 3 also provide insights into the human activities impacting biodiversity in B.C. For example, the loss of Garry oak ecosystems on southern Vancouver Island (see Text box 6, p. 40) and grasslands in the Okanagan (see Text box 5, p. 39) are primarily the result of agriculture and urban and rural development. A systematic analysis of 179 B.C. species of conservation concern in 2007 identified urbanization, agriculture and human disturbance[b] as the greatest contributors to ecosystem conversion and degradation[c] for these plants and animals.[882]

For the 2006 biodiversity threat survey, the 25 experts ranked their level of concern for 12 different human activities that potentially impact elements of biodiversity.[883] The survey identified climate change, agriculture, forestry, urban and rural development, transportation and utility corridors, water development, and oil and gas development as the activities of highest concern (Figure 36).

[a] Based on the IUCN categories of threats to biodiversity: residential development, agriculture, energy and mines, transportation, biological resource use, human intrusion, natural systems modification, invasives/problem species, pollution, geologic and climate change.
[b] Including recreation, tourism, military activities, research, transport, vehicle and vessel traffic.
[c] The term used in the study was habitat loss, which included both ecosystem conversion and ecosystem degradation.

FIGURE 36: Impact of human activities on elements of biodiversity.
SOURCE: Long, G. 2007. Biodiversity Safety Net Gap Analysis. Biodiversity BC, Victoria, BC. 66pp. Available at: www.biodiversitybc.org.



Taken together, these studies suggest that the human activities that most contribute to the three major stresses on biodiversity in B.C. are climate change, agriculture, recreation, urban and rural development, forestry, transportation and utility corridors, oil and gas development and water development. Climate change is expected to be the greatest overriding threat to biodiversity in the future, although the full extent of its impact has not yet occurred.[884,885,886]

3.3.1 CLIMATE CHANGE

Climate is the primary factor enabling and shaping the distribution of organisms and the nature and character of ecosystems,[887] and is therefore a key driver of biodiversity. Climate is defined as the 'average weather' over a period of time, the standard interval being 30 years.[888] Temperature and precipitation, measured monthly, seasonally and annually, are used to represent climate. Global and regional climates vary over millennia, usually changing gradually, but at times, especially during glacial conditions, shifting rapidly (see Section 1.4, p. 15).

British Columbia has experienced at least 4,000 years of relatively stable climate, leading to the current pattern of ecosystems.[889, 890]

Rapid climate change is underway in response to human greenhouse gas (primarily CO_2) emissions.[891] The United Nations Intergovernmental Panel on Climate Change (IPCC) reports that the average global surface temperature has increased by nearly 1°C over the past century and is likely to rise by another 1.4–5.8°C by 2100.[892] A warming atmosphere affects all aspects of the climate system: air pressure and composition of the atmosphere; the temperature of surface air, land, water and ice; the water content of air, clouds, snow and ice; wind direction and speed; ocean currents; ocean temperature, seawater density and salinity; physical processes such as precipitation and evaporation; and the frequency and duration of extreme events. The resulting future climates will be unprecedented in the past 750,000 years.[893] The precise amount of warming and associated changes are uncertain. Nevertheless, significant warming has already taken place in northwestern North America where changes are expected to occur faster and be more pronounced than the global average.[894]

Organisms are sensitive to change in climate and in particular the weather it implies, although individuals, species and ecosystems can tolerate some climatic variation. Future climates are expected to exceed biological tolerances for many species and ecosystems in B.C., leading to widespread effects on biodiversity.[895,896,897] If greenhouse gas emissions continue at present-day rates, key global considerations for biodiversity based on observed trends and climate change impact models are: [898]

- Ecosystems will probably exhibit a wide range of vulnerabilities to climate change because of ecosystem-specific critical thresholds.
- The resilience of many ecosystems is likely to be compromised, especially when associated with environmental contamination, unsustainable resource exploitation and land-use change.
- 20–30% of animal species currently assessed are likely to experience high risk of extinction with 2–3°C of warming.
- Substantial changes will occur in the functioning and structure of terrestrial, freshwater and marine ecosystems with 2–3°C warming.

Most B.C. ecosystems are at high risk from impacts due to climate change.[899,900,901] Notably vulnerable ecosystems that are well represented in the province include boreal forests and mountain ecosystems. Some ecosystems may tolerate a level of future climate change and persist or have an ability to adapt. Others may cross critical thresholds to ecologically novel states. The response of species (e.g., via shifting distributions) may occur at intermediate time scales (from months to centuries), while the response time of the biosphere may be on the scale of centuries or possibly millennia.

Biological responses to changing climates have been widely detected.[902] In North America, several trends indicate that species, ecosystems and biodiversity-related phenomena are already showing effects of climate change, such as:[903]

- Vegetation responses: earlier green-up, bud burst and flowering.
- Wildlife responses: earlier breeding; changes in migration patterns; range changes; mortality.
- Insect responses: B.C.'s mountain pine beetle outbreak.
- Fire responses: increased length of fire season; larger area burned.
- Precipitation responses: earlier snow melt; more rain instead of snow.

Insect distribution and phenology are particularly good indicators of climate change and are already showing responses to changing temperatures and precipitation patterns in the northern hemisphere.[904] Butterflies have proven especially sensitive; for example, shifts in the distribution of Edith's checkerspot (both northward and to higher elevations) are well demonstrated in western North America.[905] In B.C., the rapid expansion and intensification of the mountain pine beetle infestation demonstrates clearly that warming of winter minimum temperatures and lengthening of the growing season not only affect the distribution and abundance of an insect, but can have resulting widespread effects on ecosystems.[906]

Warming temperatures have also affected vertebrates in British Columbia. For birds, changes include earlier arrival and later departure of migrants, increases in overwintering numbers in some species, northward range expansions and changes in the relative density of some species.[907,908] In the freshwater realm, sockeye salmon migration has been gradually delayed in the Okanagan River since 1970 by warming water temperatures.[909] Even a small increase in river temperatures could have profound effects on salmon runs (especially the species that migrate to the upper reaches of rivers like the Fraser), as salmon generally only have sufficient energy reserves to reach their spawning sites[910,911] and increases in temperature can exhaust their energy reserves.[912] Warmer stream temperatures may also facilitate the increase of alien species such as the American shad (*Alosa sapidissima*). The Columbia River population of this introduced anadromous species is estimated to be about 30 million, and a few individuals have been found in the Fraser River. Over the past 50 years, this species has adapted to colder water;[913] if it develops a permanent population in the warming Fraser River, it will reduce the availability of plankton for many species.[914]

Increasing temperature is the primary result of climate change. Previous analyses for British Columbia have shown that temperatures have been rising across the province, with the largest changes in the cold seasons (winter and spring), in nighttime lows, and in those areas of B.C. that have more inter-annual variability.[915,916] Changes in average temperatures can affect the timing of reproduction in plants and animals, timing of species migration, length of the growing season, species distributions and population sizes, and the frequency of insect and disease outbreaks.

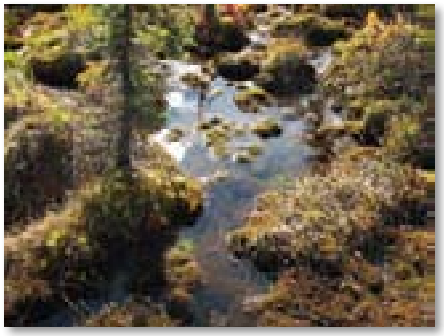
Trends in temperature and precipitation reveal major changes that vary by season and by region over the past 100 years or so. These changes are consistent with the direction of changes in the past 30 years (see Maps 14–18, pp. 179–183), specifically:

- Annual daily minimum and maximum temperatures have warmed in all seasons in all of B.C.
- The strongest warming on a provincial scale occurred in the winter daily minimum temperature, which rose by up to 5.8°C over a 30-year period. Fall temperatures increased the least (0.75–1.45°C).
- The changes in maximum daily temperatures vary widely compared to minimum temperatures. Winters in much of the province have warmed strongly, by 1.5–2.9°C, and springs have also warmed. Summer daily maximum temperatures have warmed in the south and north, but have cooled in central B.C., especially on the adjacent coast. Daily maximum fall temperatures have warmed in the south, but in the north have cooled by 0.5–1.5°C.

Previous studies of the magnitude and direction of climate change suggest that precipitation has increased in southern B.C. by 2–4% per decade and that total annual precipitation has increased in many parts of the province, most noticeably in the Okanagan and north coast regions.[917,918] The long-term annual precipitation trend shows a widespread increase of 10–30% per century in most of the province, except the southwest, where little change has occurred. Precipitation has increased in all seasons throughout most of the province, except in the south, where winter precipitation has changed little or even decreased (Map 14). Precipitation analyses demonstrate that broad annual changes mask significant month-to-month variability trends that have the potential to impact biodiversity.

For this report,1971 to 2000 was used as the assessment period.[a,919] In this recent interval, warming occurred widely throughout the province during the winter and, as was the case for the 100-year trend, annual minimum daily temperatures increased most in the north and least on the south and central coast. In contrast, maximum

[a] For the purposes of this analysis, it was assumed that most elements of biodiversity will be responding to the most recent changes in climate, hence the use of the 1971–2000 time frame.



In B.C., northern regions are experiencing the greatest rates of temperature change.
PHOTO: LIZ WILLIAMS.

daily temperatures rose most on the coast and in the north, and least in the southern interior and southeast. It is important to note that in some areas, such as northern B.C., the absolute rate of change in temperature (e.g., minimum temperature; Map 15) has been large, but relative to the range of natural climatic variation it is less than for the southern part of the province (Map 18). From the perspective of biodiversity and sensitivity of individual species, small average temperature changes in regions of narrow climatic variation (such as in the Coastal Douglas-fir biogeoclimatic zone) may have much more consequence than larger average temperature changes where the climatic variation is greater. Species exposed to large natural variation (as in the Boreal White and Black Spruce biogeoclimatic zone) may have the capacity to tolerate large changes. In general, the greatest relative temperature changes in B.C. are associated with ecosystems of conservation concern (the Coastal Douglas-fir, Bunchgrass and Ponderosa Pine).

For the current modelling approaches, temperature is the most reliable and predictable measure of climate change. Temperature trends may thus be good indicators of those regions or ecosystems with the most potential to change in the future.

MAP 14

Seasonal trends in precipitation from 1971 to 2000

Legend

- River/Stream
- Lake

Precipitation trend

- -11.9 to -9.0
- -8.9 to -6.0
- -5.9 to -3.0
- -2.9 to 0.0
- +0.1 to +3.0
- +3.1 to +6.0

Units are millimetres per decade. Negative numbers indicate a decrease and postive an increase in precipitation levels.

0 250 500
Kilometres

Data sources:
Pacific Climate Impacts Consortium (University of Victoria)

Map by:
Caslys Consulting Ltd

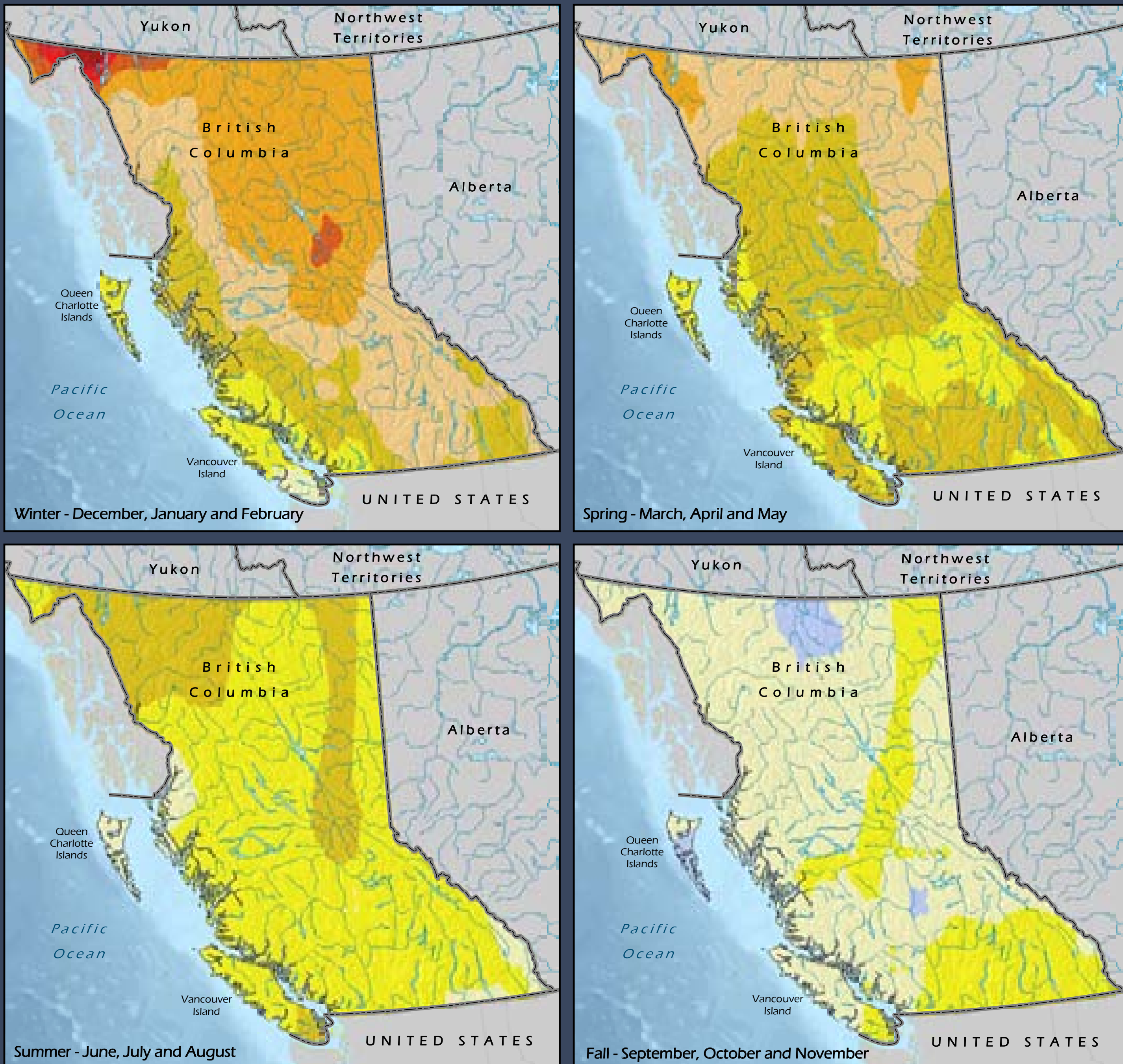
Projection:
BC Albers NAD83

Produced for:

May 28, 2008

MAP 15

Seasonal trends in minimum temperature from 1971 to 2000



Legend

- River/Stream
- Lake

Temperature trend

- -0.25 to 0.00
- 0.00 to +0.25
- +0.26 to +0.50
- +0.51 to +0.75
- +0.76 to +1.00
- +1.01 to +1.25
- +1.26 to +1.50
- +1.51 to +1.75
- +1.76 to +2.00

Units are °C per decade. Negative numbers indicate a decrease and postive an increase in temperature values.

0 250 500

Kilometres

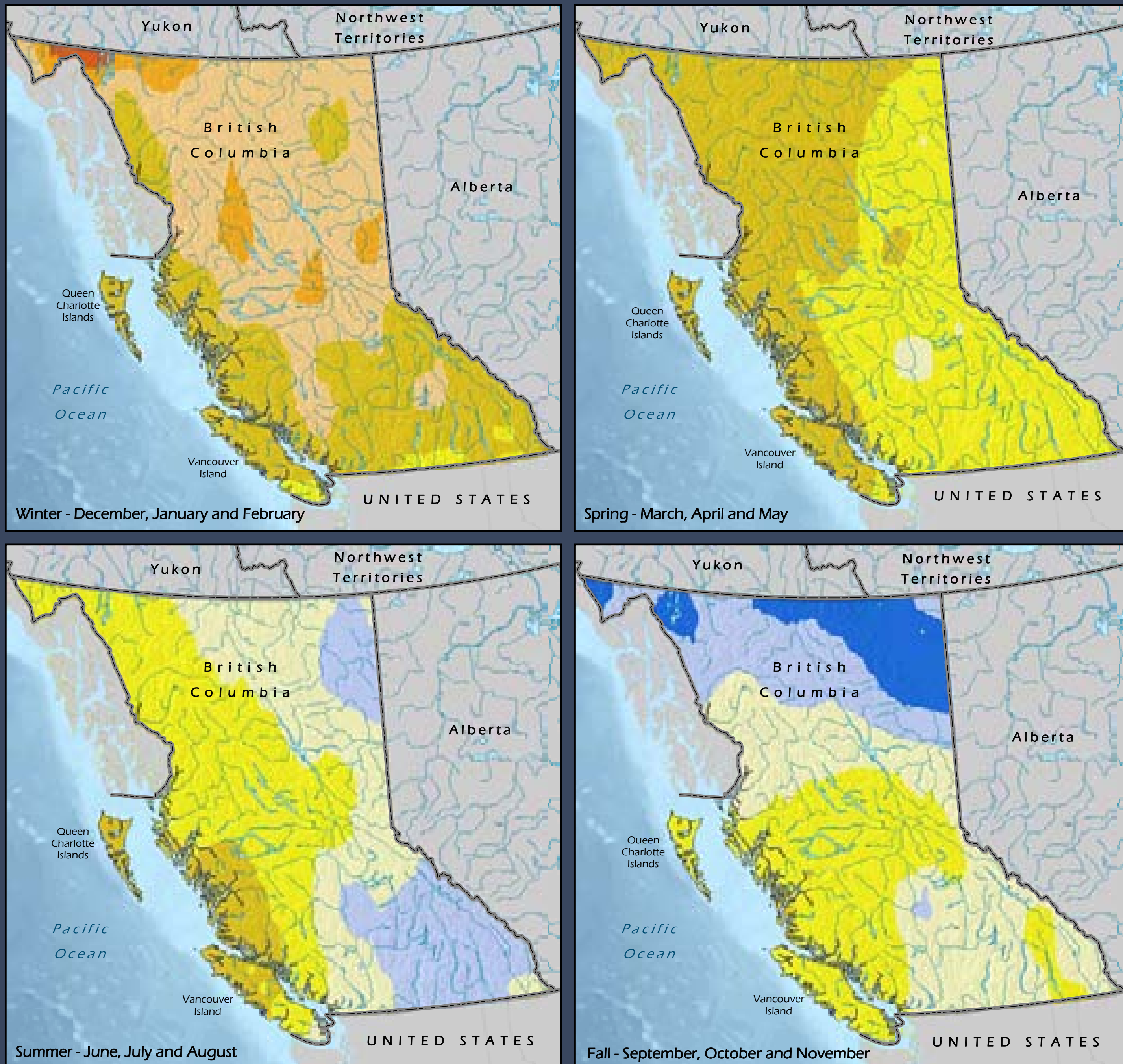
Data sources:
Pacific Climate Impacts Consortium (University of Victoria)

Map by:
Caslys Consulting Ltd

Projection:
BC Albers NAD83

Produced for:

April 14, 2008



MAP 16

Seasonal trends in maximum temperature from 1971 to 2000

Legend

River/Stream
Lake

Temperature trend

- -0.50 to -0.25
- -0.26 to 0.00
- 0.00 to +0.25
- +0.26 to +0.50
- +0.51 to +0.75
- +0.76 to +1.00
- +1.01 to +1.25
- +1.26 to +1.50

Units are °C per decade. Negative numbers indicate a decrease and postive an increase in temperature values.

0 250 500
Kilometres

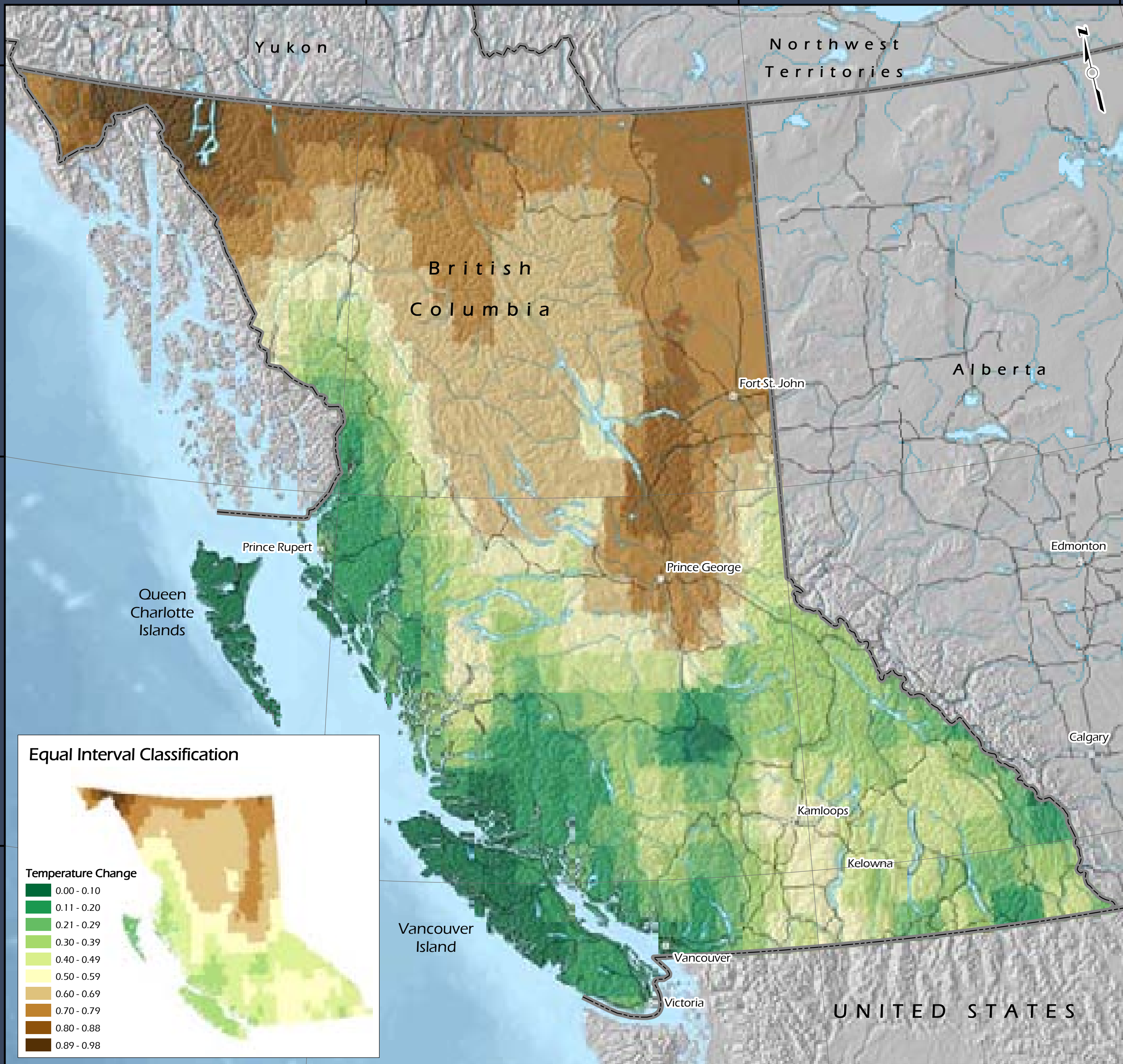
Data sources:
Pacific Climate Impacts Consortium (University of Victoria)

Map by:
Caslys Consulting Ltd

Projection:
BC Albers NAD83

Produced for:

April 14, 2008



MAP 17

Absolute rate of change in minimum temperature (average of all months) from 1971 to 2000

Legend

- City
- Road
- River/Stream
- Lake

Temperature Change

- 0.00 - 0.35
- 0.36 - 0.41
- 0.42 - 0.45
- 0.46 - 0.50
- 0.51 - 0.54
- 0.55 - 0.59
- 0.60 - 0.64
- 0.65 - 0.71
- 0.72 - 0.82
- 0.83 - 0.98

Units are °C per decade.

0 100 200
Kilometres

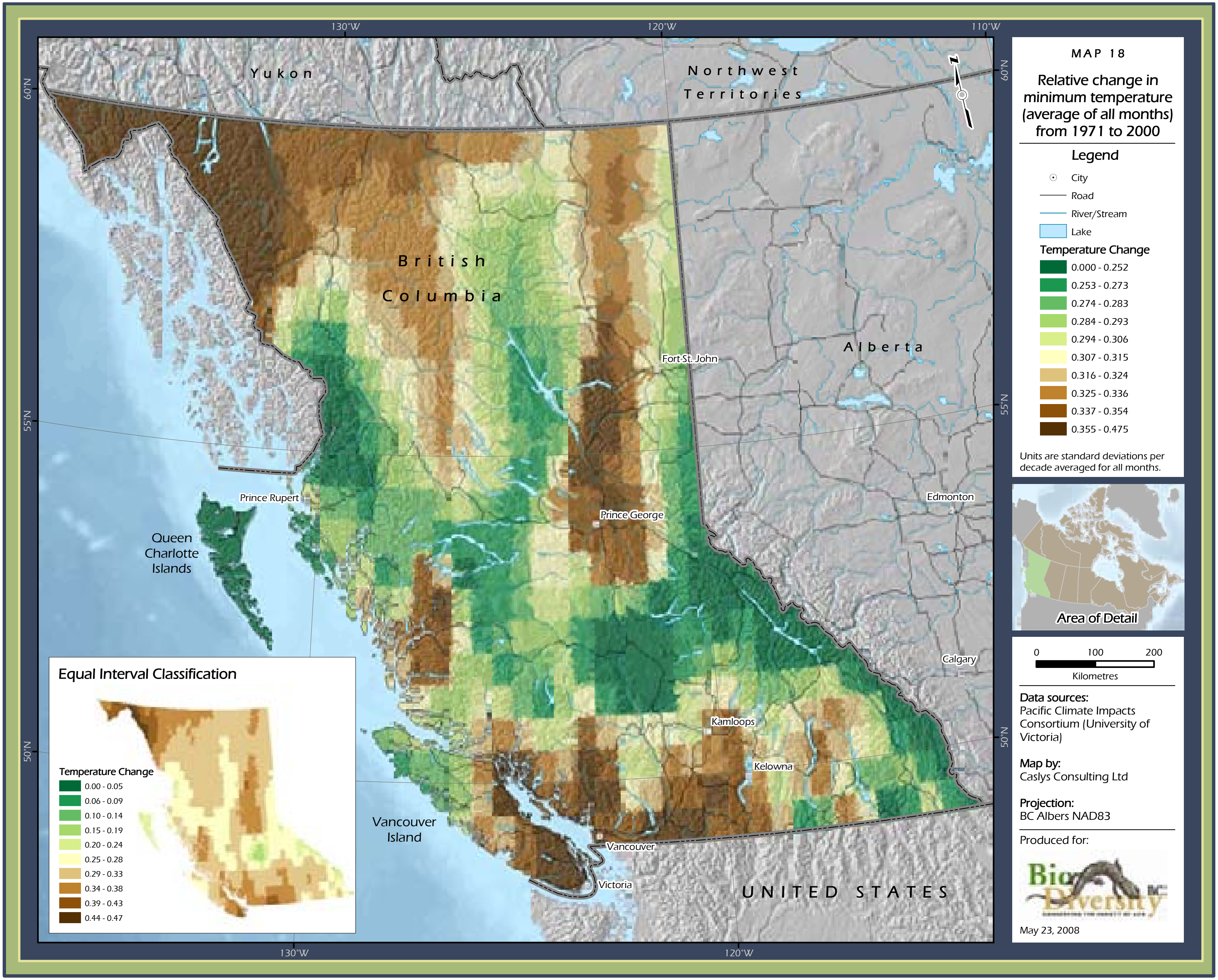
Data sources:
Pacific Climate Impacts Consortium (University of Victoria)

Map by:
Caslys Consulting Ltd

Projection:
BC Albers NAD83

Produced for:

February 5, 2008



MAP 18
Relative change in minimum temperature (average of all months) from 1971 to 2000
Legend
City
Road
River/Stream
Lake
Temperature Change
0.000 - 0.252
0.253 - 0.273
0.274 - 0.283
0.284 - 0.293
0.294 - 0.306
0.307 - 0.315
0.316 - 0.324
0.325 - 0.336
0.337 - 0.354
0.355 - 0.475
Units are standard deviations per decade averaged for all months.
Area of Detail
0 100 200
Kilometres
Data sources:
Pacific Climate Impacts Consortium (University of Victoria)
Map by:
Caslys Consulting Ltd
Projection:
BC Albers NAD83
Produced for:
May 23, 2008
Yukon
Northwest Territories
British Columbia
Alberta
Fort St. John
Prince Rupert
Prince George
Edmonton
Queen Charlotte Islands
Calgary
Kamloops
Kelowna
Vancouver Island
Vancouver
Victoria
UNITED STATES
130°W
120°W
110°W
60°N
55°N
50°N
Equal Interval Classification
Temperature Change
0.00 - 0.05
0.06 - 0.09
0.10 - 0.14
0.15 - 0.19
0.20 - 0.24
0.25 - 0.28
0.29 - 0.33
0.34 - 0.38
0.39 - 0.43
0.44 - 0.47

3.3.1.1 FUTURE CONDITIONS

Measured trends and observed responses clearly indicate that climate change is underway and that this change will affect biodiversity.[920] The degree of change in biodiversity will depend in part on the size and rate of future climate change and its geographic variability. Numerical climate models of atmosphere, ocean and land generate projections that provide insight into future temperature and precipitation trends as greenhouse gas concentrations increase. The outputs from global models vary according to the structure of the model and the atmospheric concentration of greenhouse gasses, mainly CO_2, used in a model. Typically, future conditions are presented as a range of scenarios (low, medium and high) from several models for specific time horizons.

Data from three models and emission scenarios, representing low, medium and high change, show that warming will be well underway by 2020 and that widespread major warming likely will have occurred in B.C. by 2050 (Figure 37).[921] By 2080, the potential mean annual temperature increase for all of B.C. is shown to be in the range of 3°C (low-change scenario) to 4.8°C (high-change scenario).[922] Results from a slightly different approach, in which values from many models for a range of greenhouse gas emissions are used, reveal similar widespread warming beginning by 2020.[923] By 2080, all regions of B.C. will have warmed by at least 2.5°C (low-change scenario) and some parts, such as the north, by as much as 10°C (high-change scenario). Notably, temperature trends for northern B.C. for the 1971–2000 interval already reveal warming at a rate of 5–10°C per century for minimum daily temperatures.[924]

Climate models are less capable of anticipating future precipitation than future temperatures. Nevertheless, broad patterns are evident (Figure 38). The mean annual precipitation increase for B.C. is shown to be in the range of 9% (under a low-change scenario) to 18% (under a high-change scenario) by 2080,[925] with most of the increase occurring in the winter and decreased precipitation projected for the summer.[926]

Increases in mean annual precipitation will be evident by 2020. Northern B.C. appears to exhibit the greatest potential for increased precipitation.

The differences across the range from low- to high-change scenarios reinforce the need to explicitly recognize and account for the uncertainties that exist in projections of future climate. That said, the results from data for B.C. are consistent with those reported by the IPCC for the northern hemisphere.[927] Maps 14–16 show important seasonal trends and differences that will undoubtedly have key consequences to many elements of biodiversity. For example, for anadromous fish, trends toward decreased autumn and increased winter precipitation on the coast can lead to increased stress, followed by winter flooding and stream erosion with negative consequences for survival. An increase in annual precipitation without an increase in summer precipitation offers little benefit to species that need moisture during the hot, dry season, and summer precipitation is indeed projected to decrease.[928]

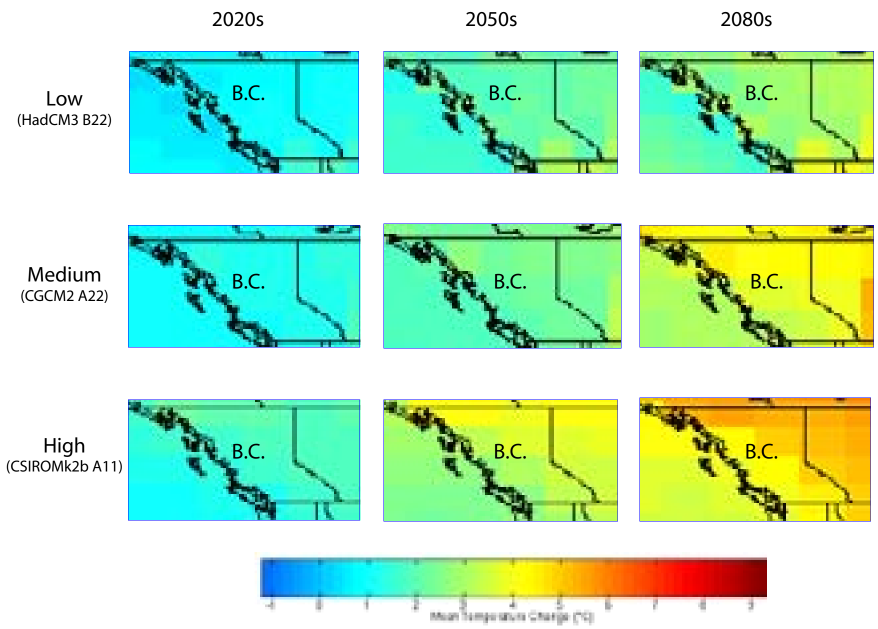


FIGURE 37: Projected mean annual temperature change for the 2020s, 2050s and 2080s for three climate change scenarios: low, medium and high.

SOURCE: Murdock, T.Q., A.T. Werner and D. Bronaugh. 2007. Preliminary Analysis of BC Climate Trends for Biodiversity. Biodiversity BC, Victoria, BC. 24pp. Available at: www.biodiversitybc.org.

NOTES: HadCM3 B22 = Hadley Centre Coupled Model with a low greenhouse gas emission future. CGCMs A22 = Canadian Global Climate Model 2 with an intermediate greenhouse gas emission future. CSIROM2b A11 = Commonwealth Scientific and Industrial Research Organization Model with a high greenhouse gas emission future.

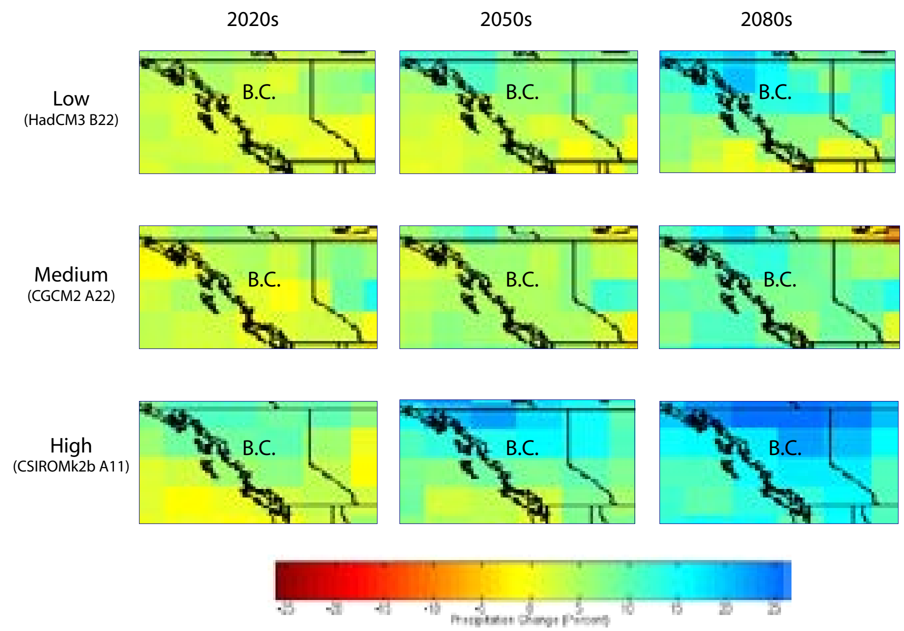


FIGURE 38: Projected mean annual precipitation change for the 2020s, 2050s and 2080s for three climate change scenarios: low, medium and high.

SOURCE: Murdock, T.Q., A.T. Werner and D. Bronaugh. 2007. Preliminary Analysis of BC Climate Trends for Biodiversity. Biodiversity BC, Victoria, BC. 24pp. Available at: www.biodiversitybc.org.

NOTES: HadCM3 B22 = Hadley Centre Coupled Model with a low greenhouse gas emission future. CGCMs A22 = Canadian Global Climate Model 2 with an intermediate greenhouse gas emission future. CSIROM2b A11 = Commonwealth Scientific and Industrial Research Organization Model with a high greenhouse gas emission future.

3.3.1.2 IMPLICATIONS OF CLIMATE CHANGE FOR BIODIVERSITY IN BRITISH COLUMBIA

Measured trends and data from models point to unprecedented transformation of global climate that will have major impacts on biodiversity. These impacts will exacerbate non-climate factors related to human activity, such as land-use changes, pollution and resource use.[929] Climate trends reported here specifically for B.C., as well as consideration of global climate change patterns, indicate that our region can expect greater-than-average climate change. A comprehensive analysis of the effects of climate change on biodiversity is beyond the scope of this report, but several published studies, as well as unpublished data, provide the basis for a summary.[930,931,932,933,934]

Potential climate change impacts can be considered on the basis of information from measured trends, paleoecological studies (see Section 1.4, p. 15), impacts models and a general consideration of the requirements of species and ecosystems.[935,936] Practically, the identification of biodiversity attributes (i.e., populations, species, ecosystems, processes) especially sensitive to climate change provides a basis for selecting key indicators of biodiversity health.

Several key principles need emphasis when considering the potential consequences of climate change for biodiversity:

- Considering the uncertainty in the magnitude of climate change, it is even more difficult to anticipate the responses of species and ecosystems, most of which are poorly understood.
- Responses are likely to be complex, involving interspecies relationships and critical thresholds.
- Ecosystems do not migrate; species do, and they may or may not re-assemble into the same ecosystems as in the past.
- The rate of climate change will exceed the ability of most species to migrate and adjust their range to new conditions.
- Many species, especially those of old-growth ecosystems, will likely undergo population and range reduction and experience serious declines to levels that may be too low for recovery before they are able to expand into new regions.
- Extreme climatic events will punctuate more gradual changes, leading to unanticipated ecological changes, including extinction.
- Expansion of alien species' ranges may be to the detriment of native species.
- Regions of high natural climatic variability may have greater natural resilience than those with low natural variability.

Potential impacts at the provincial level can be readily appreciated by comparing projected gains and losses in the climate envelope[a] for each biogeoclimatic zone (Figure 39). By 2085, only 22% of the province will still have the same zonal climate envelope that it had in 1995.[937] By 2085, the climate envelopes for the Ponderosa Pine, Interior Cedar–Hemlock, Interior Douglas-fir, Bunchgrass and Coastal Douglas-fir zones will increase. However, while these zones will increase in extent, their condition may not necessarily remain or improve. These zones may experience a loss of resilience, increase of alien species or expansion of other ecosystems (e.g., deserts from southern regions in the United States).[938]

Figure 40 shows the shift in climate envelopes from the present to 2085, represented by biogeoclimatic zonal climates.[b] Climate envelopes can predict potential vegetation changes, but they cannot anticipate the speed at which species can migrate or the disturbance events that will potentially cause a shift to a new ecological community. As well, in the absence of suitable soils, vegetation will not become established regardless of the climate.

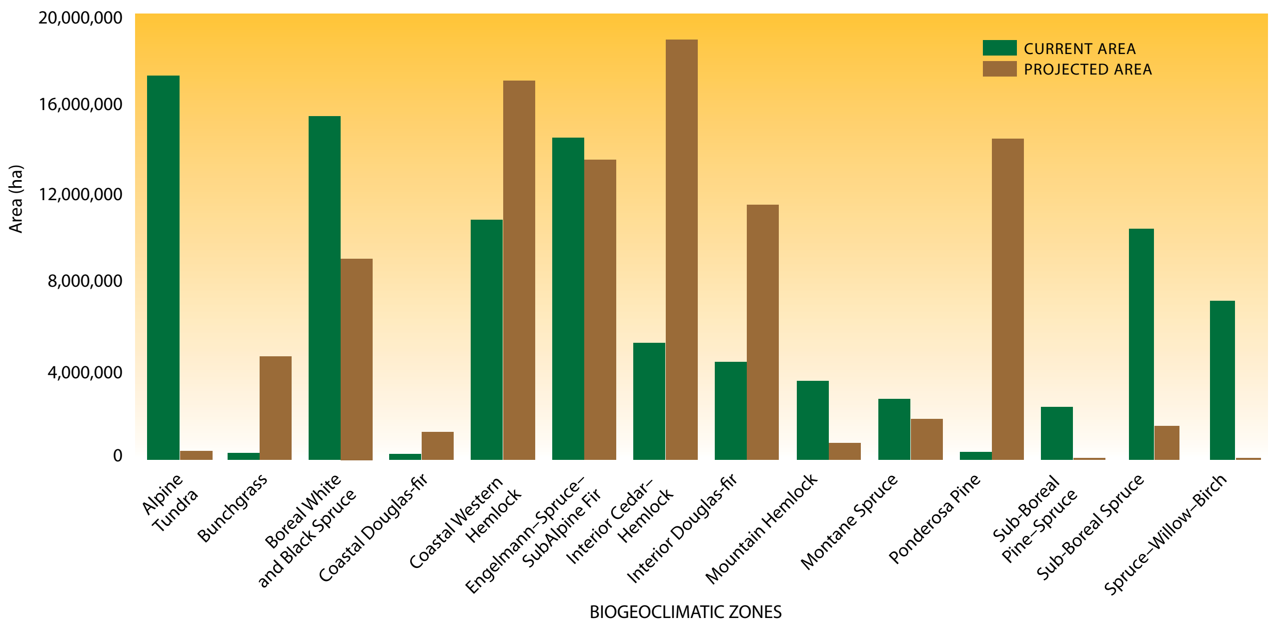


FIGURE 39: Climate envelopes for biogeoclimatic zones in B.C.: current distribution and projected distribution (2085).
SOURCE: Compiled from data in Hamann, A. and T. Wang. 2006. Potential effects of climate change on ecosystem and tree species distribution in British Columbia. Ecology 87: 2773-2786.
NOTE: The Alpine Tundra zone has been split into three zones since this analysis was done.

[a] A climate envelope describes the area of suitable climate for a species or ecosystem in terms of temperature and precipitation. Climate envelope models determine the current distribution of the species or ecosystem, then map the location of this same envelope under a climate change scenario.
[b] This shift is based primarily on a model prepared by the Canadian Centre for Climate Modeling and Analysis (the CGCM1gax general circulation model using the IS92a emission scenario). Although the modelling was done at the BEC variant level, the resulting information has been summarized at the zone level for these maps. Each of the maps represents a 30-year average. The 'current' map is an average for 1981–2010, and the 2085 map is an average for 2071–2100.

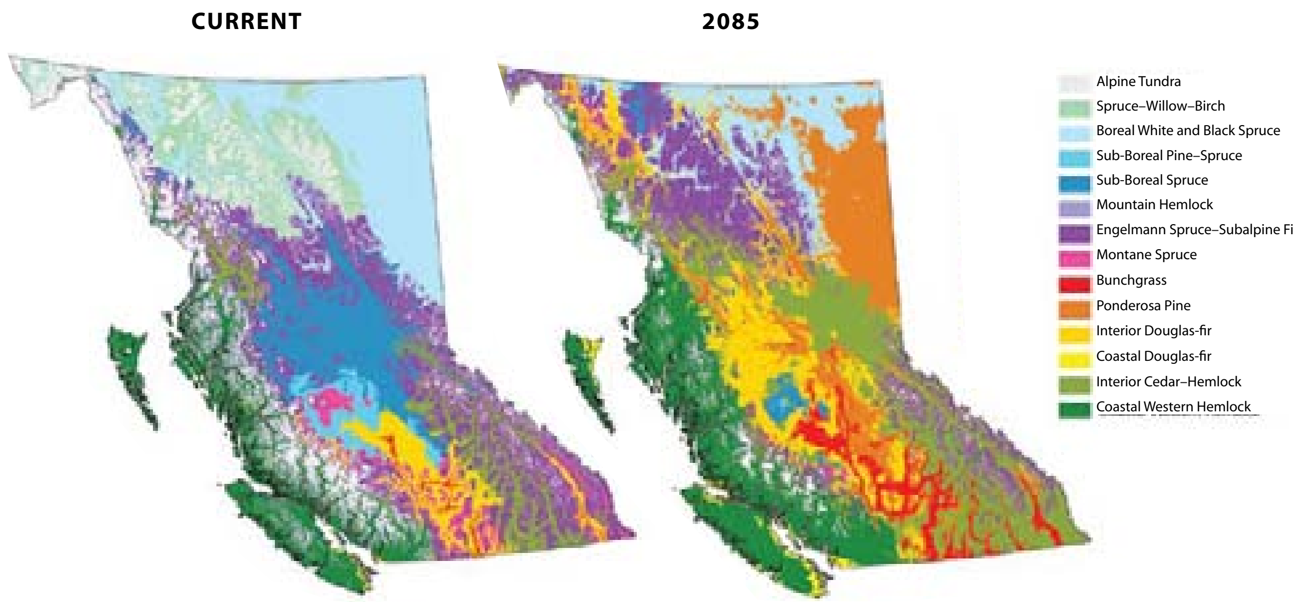


FIGURE 40: **Potential shift in biogeoclimatic zones by 2085 due to climate change.**
SOURCE: Adapted from Hamann, A. and T. Wang. 2006. Potential effects of climate change on ecosystem and tree species distribution on British Columbia. Ecology 87: 2773-2786.
NOTE: The Arctic Tundra zone has been split into three zones since this analysis was done. 2085 represents the average of the period from 2071 to 2100.

The key potential consequences of climate change to B.C.'s biodiversity are further summarized on the following pages, with descriptions of specific effects on different ecosystem types based on empirical information as well as modelling.

SPECIES OF CONSERVATION CONCERN

Although there could be some benefits for species of conservation concern associated with warm climates,[939] extinction may be expected for species and populations that are already threatened by small population size, loss of unique habitats and low reproduction/dispersal rates (among other factors).[940] Climate change will likely exacerbate these existing stresses and conditions. Fragmentation of habitat and of populations in particular, makes biodiversity elements more vulnerable to increased variation in climate, especially extreme climate events. Increased fire activity may be of particular concern. Species associated with ecosystems that are exceptionally prone to climate change, such as the alpine tundra, likely will be at high risk of loss.

FRESHWATER ENVIRONMENTS

To date there has been no comprehensive evaluation of the potential effects of climate change on B.C.'s freshwater ecosystems, though impacts on salmon and other freshwater fish have received attention.[941,942] Major impacts must be expected because changes in temperature and precipitation (warmer and drier summers, for example) may work in tandem to create increased impacts and because aquatic environments are prone to extreme climatic events such as floods. Furthermore, human activity has degraded many aquatic systems. As freshwater systems are constrained by topography (i.e., unable to shift), connectivity of freshwater systems will be important to enable these systems to adjust.

Warmer ocean, lake and river water may be already impacting salmon and other fish populations by influencing migration timing and food availability and limiting use of river systems.[943] Models indicate that temperatures will increase further and strong effects on salmon must be expected. This expectation is supported by the observed association between reduction in Fraser River sockeye populations and increasing river temperatures and changes to river flow volume and timing.[944] Changes in runoff and other flow characteristics of streams are expected[945] and may impact salmon spawning beds, either through erosion and sediment deposition at winter high flows and flood events or by exposing them during low water. In rainfall-driven streams, extended summer low-flow periods are expected, further increasing water temperature, favouring warm water species and altering community structure and functioning. In snowmelt- and glacier-fed streams, the intensity and timing of freshet floods are expected to change. As a result of reduced snow cover and decline of glaciers, some river systems may become rainfall-driven, altering their ecology profoundly (see Section 2.5.2.3-D, p. 149).

Other measured effects include increased ocean acidity (see Text box 17, p. 129)[946] and increased coastal water turbidity, which may reduce the availability of fish prey species for seabirds. With the increase in temperature and longer ice-free periods, lakes and streams that do not have current nutrient limitations may increase in productivity.[947] Reduction in salmonid populations in river systems may decrease food for forest-dwellers such as bears and impact nutrient cycling and terrestrial food webs (see Section 2.5.1.3-F, p. 121).[948]

Paleoecological studies suggest not only changes in the composition of lake ecosystems because of warmer water,[949] but also potential changes in the size and depth of small lakes.[950] Reduced water volume clearly would result in alterations in shoreline and planktonic communities.

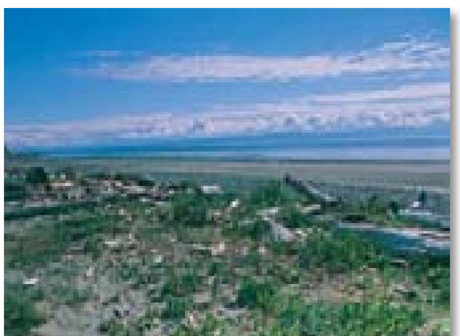
Wetland ecosystems, such as Little Big Bar in the southern Cariboo region, are vulnerable to climate change.
PHOTO: BRUCE HARRISON.

WETLANDS

Wetlands are particularly vulnerable to climate change because the physical landscape that supports this land cover type is restricted.[951] Generally, wetlands of cool, moist climates, such as bogs with stable hydrology, will be negatively impacted, whereas marshes with fluctuating water tables and higher nutrient levels will be favoured. Paleoecological evidence suggests that shallow-water interior wetlands are likely to dry up.[952] Changes in wetlands will impact not only obligate species, but will have major consequences for the breeding and migration of birds. Increasing human demand for water will likely intensify the impacts of climate change.

COASTAL ECOSYSTEMS

Global sea levels are rising at surprisingly high rates compared to model projections.[953] Coastline ecosystems, such as intertidal communities, estuaries and salt marshes, and the species that use them, will be impacted by flooding, increased wave and storm activity and changes in sedimentation and erosion.[954,955] Rising water levels will squeeze lowland coastal habitats against natural and artificial barriers such as mountains and dikes. Sediments may bury coastal wetland surfaces. Saltwater intrusion will alter soil and water chemistry and lead to extirpation of freshwater plants, resulting in habitat loss for migrating birds. The erosive force of storm surges may breach natural protective barriers such as sand spits. High-energy intertidal ecosystems such as those of rocky headlands may have considerable resilience, whereas estuaries, especially those constrained by dikes on subsiding deltas (e.g., the Fraser River Delta) are at high risk of impact. Changes in stream hydrology will impact estuarine habitats through changes to water flow and sediment load resulting in alteration to nearshore productivity, such as in sites of nutrient upwelling. An increase in CO_2 and the resulting increase in ocean acidity (see Text box 17, p. 129) will affect the ability of crustaceans to develop shells, which could modify food webs.[956]



Rising sea levels will result in the loss of some coastal ecosystems.
PHOTO: TRUDY CHATWIN.

ALPINE AND SUBALPINE PARKLAND ECOSYSTEMS

Cold, high-elevation ecosystems are particularly vulnerable to climate change because of their restricted landscape position and elevational limits.[957] Treelines were about 100 m higher during warmer intervals only 8,000 years ago.[958] Increases in the length of the growing season, with warmer temperatures and reduced snow duration and snow pack (especially on the coast), will favour woody species, including trees. The climate envelope for alpine ecosystems may decrease by 60% by 2025 and 97% by 2085, with treelines (approximately equal to the lower boundary of the alpine zone) moving upslope by 168 m and 542 m, respectively.[959] Alpine and subalpine patches in southern B.C. are small and especially vulnerable to climate change, as the land is mostly rock at the elevations where these ecosystems occur.

The subalpine Spruce–Willow–Birch biogeoclimatic zone climate envelope could largely disappear by 2055.[960] However, the mountain temperature gradient is steep and alpine climates will likely persist, especially in northern B.C.

The extent of B.C.'s northern forests, like this black spruce *(Picea mariana)* forest, is expected to decline.
PHOTO: LIZ WILLIAMS.

NORTHERN AND HIGH-ALTITUDE SPRUCE FORESTS

Climate impact modelling suggests a high risk for the transformation of northern and high-altitude spruce forests to ecosystems typical of southern B.C.[961] A model of the future distribution of western redcedar suggests that large parts of northern B.C. will be suitable for this species.[962] The climate envelope for the Sub-Boreal Spruce and Sub-Boreal Pine–Spruce biogeoclimatic zones is expected to be reduced by more than half by 2055 and more than 80% by 2085. The climate envelope for the B.C. version of the boreal forest (the Boreal White and Black Spruce biogeoclimatic zone) will remain stable through 2055, but decline by about half by 2085.

The current mountain pine beetle epidemic has already led to widespread changes in these forests (see Text box 16, p. 105), and other insects, such as the western spruce budworm (*Choristoneura occidentalis*) could also reach epidemic levels. The incidence of fire in northern coniferous forests is increasing and is projected to increase even more.[963] Warming soil temperatures may be unfavourable to the growth of forest floor mosses, a key element of northern spruce forests. Changes in structure and composition are likely to have major impacts on ungulate populations.

Engelmann Spruce–Subalpine fir forests, at least in southern B.C., are a relatively recent development in response to the spread of cool and moist climates at mid to high elevations.[964] They could be expected to decline in area with climate change. The Engelmann Spruce–Subalpine fir climate envelope is predicted to be stable until 2085, largely because increases in the north offset widespread losses in the south.[965]

SOUTHERN DRY FORESTS

Dry interior forest dominated by pine species or Douglas-fir likely covered a much larger area than today under the warm and dry climate of 8,000 to 6,000 years ago,[966] a time when fires were also more frequent. These dry forests occurred notably where moist Interior Cedar–Hemlock forest occurs today. Climate impact models suggest that the climate envelopes for the Interior Douglas-fir and Ponderosa Pine zones will expand widely into areas currently occupied by northern spruce forest climates (i.e., northeast B.C.) by 2085. Insect epidemics will likely remain a threat. Data from the fossil record and impact models suggest grasslands may replace dry conifer forest at low to mid elevations in southern interior B.C.[967,968,969] Upon disturbance, these forests may be at increased risk of invasion by alien species.

COASTAL AND INLAND TEMPERATE RAINFORESTS

The fossil record indicates that major shifts in geographic range, and possibly in composition, can be expected for coastal and inland temperate rainforests under a warmer future climate,[970] with Douglas-fir-dominated stands displacing western redcedar–hemlock stands in relatively dry sectors. Novel species combinations may be expected.[971] In the driest portion of the coastal forest, expansion of the Garry oak's range is expected, as are increases in the abundance of some rare species such as Oregon ash.[972] However, the Garry oak ecosystem may not increase, due to fragmentation and alien species. Rapid expansion in the Coastal Douglas-fir zone climate envelope may result in a 336% increase by 2085.[973] The climate envelope of the Coastal Western Hemlock zone is projected to increase steadily in elevation at the cost of the subalpine Mountain Hemlock zone, which may be strongly impacted (79% decline by 2085).[974] Drier summer conditions could reduce the suitability of coastal forests as habitat for mosses and other bryophytes.

The Interior Cedar–Hemlock zone climate envelope is also anticipated to increase, especially in central B.C.[975] However, a projection for western redcedar shows widespread decline in southern B.C., accompanied by widespread expansion in the north.[976] Paleoecological studies reveal that these forests arose in response to a cooling and moistening climate in the last two millennia.[977,978] Hence, a decline in area might be expected with warming.

GRASSLANDS

The fossil record and impact models suggest that the grasslands climate envelope may expand enormously, more than for any other ecosystem type.[979,980,981] Alien species may dominate new grasslands. Rare northern grasslands in the Boreal White and Black Spruce zone could decrease as a result of warmer, wetter conditions and encroachment by woody plants resulting from climate change.[982]

ALIEN SPECIES

Alien species may expand as climate change modifies the frequency and intensity of extreme climatic events, resulting in a reduced resistance to alien species invasions,[983] and therefore creating better opportunities for alien species to establish and expand.[984] Climate change may expedite the colonization of wide areas by alien species in both the terrestrial and freshwater realms. For instance, alien warm-water fish species, such as smallmouth and largemouth bass (*Micropterus dolomieu* and *M. salmoides*) and yellow perch, may thrive as water temperatures increase.[985] These species may out-compete and/or prey on cold-water native species. Similarly, increased frequency and magnitude of forest fires (and our responses to them) will create openings vulnerable to colonization by alien plants.

3.3.2 AGRICULTURE

Agriculture consists of two forms of production: intensive and extensive. Intensive production systems have large labour and other capital costs (e.g., cultivation of field crops, orchard crops, horticultural crops, vineyards, feedlots), while extensive systems have much lower inputs (e.g., grazing). Intensive agriculture is generally located in areas of high ecosystem productivity where soils are the most fertile, such as valley bottoms and coastal floodplains. Typical activities associated with intensive agriculture include fertilization, tillage, annual planting and harvesting, pesticide application and irrigation. Extensive agriculture occurs mainly in grassland ecosystems and covers greater areas of land, but the activities are less intensive (e.g., rotational grazing).

Impacts of some agricultural activities occur through ecosystem conversion, ecosystem degradation, introduction of alien species and environmental contamination. Agricultural activities can also modify ecosystem processes. Ecosystem conversion occurs the most in areas with rich soil, such as floodplains and valley bottoms that are converted to intensive agricultural crops (e.g., berries, nurseries) or buildings (e.g., greenhouses). However, above the valley bottoms in the south Okanagan there was a 500% increase in the amount of land converted to vineyards between 1990 and 2005,[986] contributing to the loss of the antelope-brush / needle-and-thread grass ecosystem (see Figure 9, p. 39). Once land has been converted from natural ecosystems to agriculture, some crops (e.g., vegetables, grains and grass) still provide food and habitat for wildlife. However, through agricultural intensification, many of the lands are converted to other uses, such as berry farms, nurseries and greenhouses, which reduce the value of the land to biodiversity. Table 27 shows a significant increase in these types of intensive agriculture uses in the Greater Vancouver Regional District (now known as Metro Vancouver).

Drainage of wetlands and upland areas can change hydrology, resulting in ecosystem degradation. The diversion of streams for water storage and irrigation may result in low flows for fish. Agriculture can also alter ecological processes in both terrestrial and freshwater realms through changes to soil, water and species composition by contamination from animal waste, fertilizer and pesticides, and the subsequent eutrophication of surface water from agricultural runoff[987] and through planting of non-native plants such as hay crops. In addition, fragmentation of ecosystems occurs as more fences, buildings and roads are installed or built. Overgrazing can compact soil and reduce riparian areas, resulting in increased stream temperature and channel instability and invasion by alien species.[988] Water withdrawal from streams for irrigation purposes can reduce stream flow, impacting fish, as well as reducing the volume of water in wetlands, which impacts species such as amphibians. The transport of alien species may also allow the introduction of disease.[989]

Much of the Okanagan's native ecosystems have been converted to agricultural uses such as vineyards.
PHOTO: TORY STEVENS.

The Greater Vancouver Regional District experienced a 527% increase in greenhouses between 1981 and 2001.
PHOTO: ISTOCK.

TABLE 27. AGRICULTURAL LAND USE WITHIN THE GREATER VANCOUVER REGIONAL DISTRICT BETWEEN 1981 AND 2001.

TYPE OF USE	AREA (HA)		CHANGE	
	1981	2001	AREA (HA)	%
Nurseries	159	1,460	1,301	818%
Greenhouses	45	282	237	527%
Buildings and woodlots	2,261	7,179	4,918	218%
Berries and fruit	1,445	3,940	2,495	173%
Grasses (grazing, hay, turf)	12,240	19,204	6,964	57%
Vegetables	5,685	6,737	1,052	19%
Grains	1,370	1,255	-115	-8%
Total	**23,205**	**40,057**	**16,852**	**73%**
Unmanaged land (idle)	414	293	-121	-29%

SOURCE: Prepared for this report with data from the Census of Agriculture (1981 and 2001).

3.3.3 FORESTRY

Seventy percent of B.C.'s land is covered by forest (see Figure 7, p. 25), and timber has been harvested, or is expected to be harvested, from approximately 46% of B.C.'s forests;[990] this excludes protected forests, other reserves and forests that are considered uneconomical for timber production. Specific forestry activities include building access roads, silviculture (harvest and re-establishment) and fire suppression. These activities can result in ecosystem degradation and disturbance. Forestry-related activities affect species and ecosystems in different ways, including fragmentation of habitat and disruption of movement corridors; simplification of forest communities; alteration of age-class distribution, tree species distribution and stand structure; and loss of key habitat elements such as wildlife trees (see Section 2.5.1.2-F, p. 108) and coarse woody debris (see Section 2.5.1.2-I, p. 113).[991] Changing a forest from a complex of multiple tree species of different ages to a monoculture simplifies ecological communities. Herbicides applied during silviculture operations are toxic to some animal species and affect others by eliminating food plant species.[992]

An assessment of 3,199 B.C. vertebrate and vascular plant species and subspecies classified 41% as forest-associated, and 8% of these are of conservation concern.[993] All of B.C.'s freshwater fish and amphibians are considered forest-associated,[a] as well as 75% of mammals and 60% of birds.[b] Most logging in B.C. takes place in the productive, easily accessible, low-elevation valleys or slopes where the majority of species also live. Many

[a] A forest-associated species is one with a measurable dependence on a forest ecosystem for any aspect of its life history.
[b] Includes subspecies and populations.

species (e.g., marbled murrelets and certain lichens and invertebrates) are known to rely on old, large trees and the oldest age classes of forests. [994,995,996,997]

Figure 41 shows the annual timber harvest in B.C. between 1912 and 2006. About 40% of the province's land area is occupied by forests that are less than 140 years old, mostly due to a combination of logging, clearing and burning.[998] Younger forests cover a greater proportion of the B.C. interior than of the coast, likely due to the greater frequency of fires in the interior, combined with the higher volume of forest harvesting in the interior since the mid 1970s.[999] The prevalence of younger forests will increase in the interior as a result of the current mountain pine beetle infestation (see Text box 16, p. 105). These trends in harvest volume and age classes are reflected in a growing proportion of managed stands, which often have less biodiversity than the original forests.

Approximately 9% of the total land area of British Columbia has been logged since the 1970s (Table 28, Map 19). Although logging prior to this time is not reflected in the map or the table, it was significant in some areas of the province. The Coastal Douglas-fir zone was almost entirely logged in the early 1900s, and forests more than 100 years old in this zone now occupy only 4% of the area occupied 150 years ago.[1000] Similarly, only 0.5% of the old forest that once dominated parts of the central Okanagan remains, now reduced to fragmented patches of less than 3 ha each.[1001]

Forestry can cause ecosystem degradation.
PHOTO: ISTOCK.

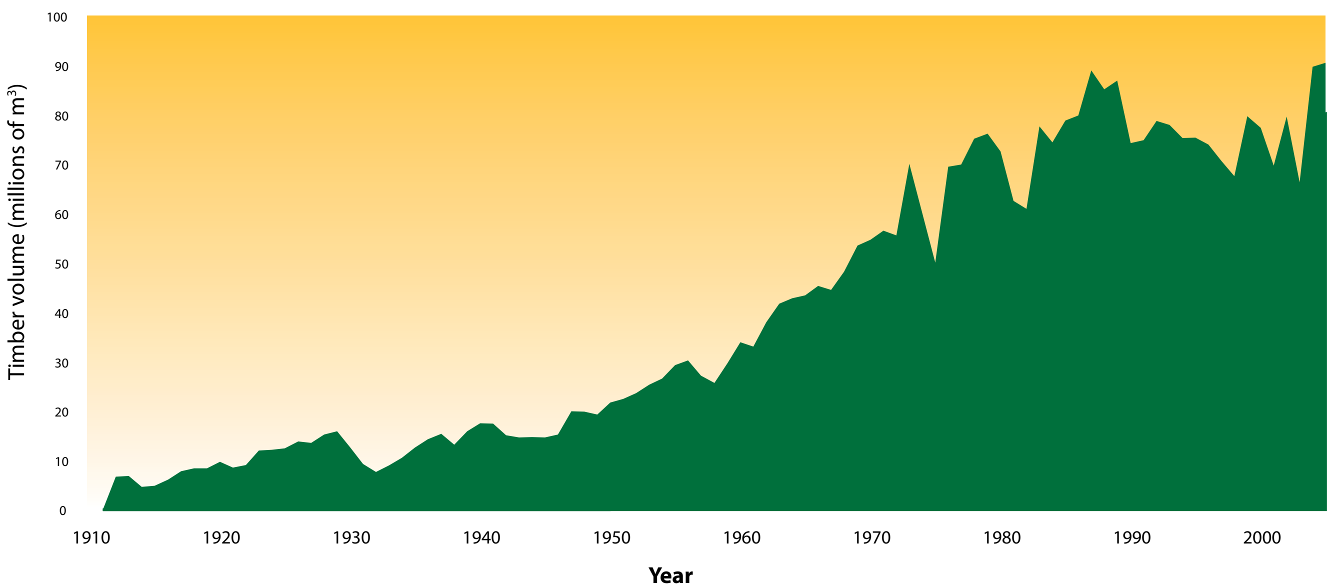


FIGURE 41: **Total timber harvest, 1912–2005/06 (private and Crown land).**
SOURCE: B.C. Ministry of Forests and Range. 2006. The State of British Columbia's Forests, 2006. Forest Practices Branch, Victoria, BC. Available at: www.for.gov.bc.ca/hfp/sof/2006/.

TABLE 28. PERCENT OF LAND LOGGED IN B.C. SINCE THE 1970S BY BIOGEOCLIMATIC ZONE.

BIOGEOCLIMATIC ZONE	PERCENT OF TOTAL LAND AREA LOGGED SINCE 1970s
Sub-boreal Spruce	23%
Interior Douglas-fir	22%
Montane Spruce	22%
Interior Cedar–Hemlock	22%
Sub-boreal Pine–Spruce	17%
Coastal Western Hemlock	14%
Ponderosa Pine	8%
Engelmann Spruce–Subalpine Fir	6%
Coastal Douglas-fir	6%
Boreal White and Black Spruce	5%
Mountain Hemlock	2%
Spruce–Willow–Birch	<0.5%
Bunchgrass	<0.5%
Interior Mountain-heather Alpine	<0.5%
Coastal Mountain-heather Alpine	<0.5%
Boreal Altai Fescue Alpine	<0.5%
Province	**9%**

SOURCE: Prepared for this report.
NOTE: Based on imagery taken between 1991 and 2001 that classified areas recently logged up to 20 years old (as well as other sources for logging since the images were taken). Logging that occurred more than 20 years before the images were taken is not included.

The biogeoclimatic zones with the greatest proportion logged since the 1970s are the Sub-boreal Spruce (23%), Interior Douglas-fir (22%) and Montane Spruce (21%). There has been little or no logging in relatively inaccessible parts of the coast, the Rocky Mountains and the northwest and north-central regions.

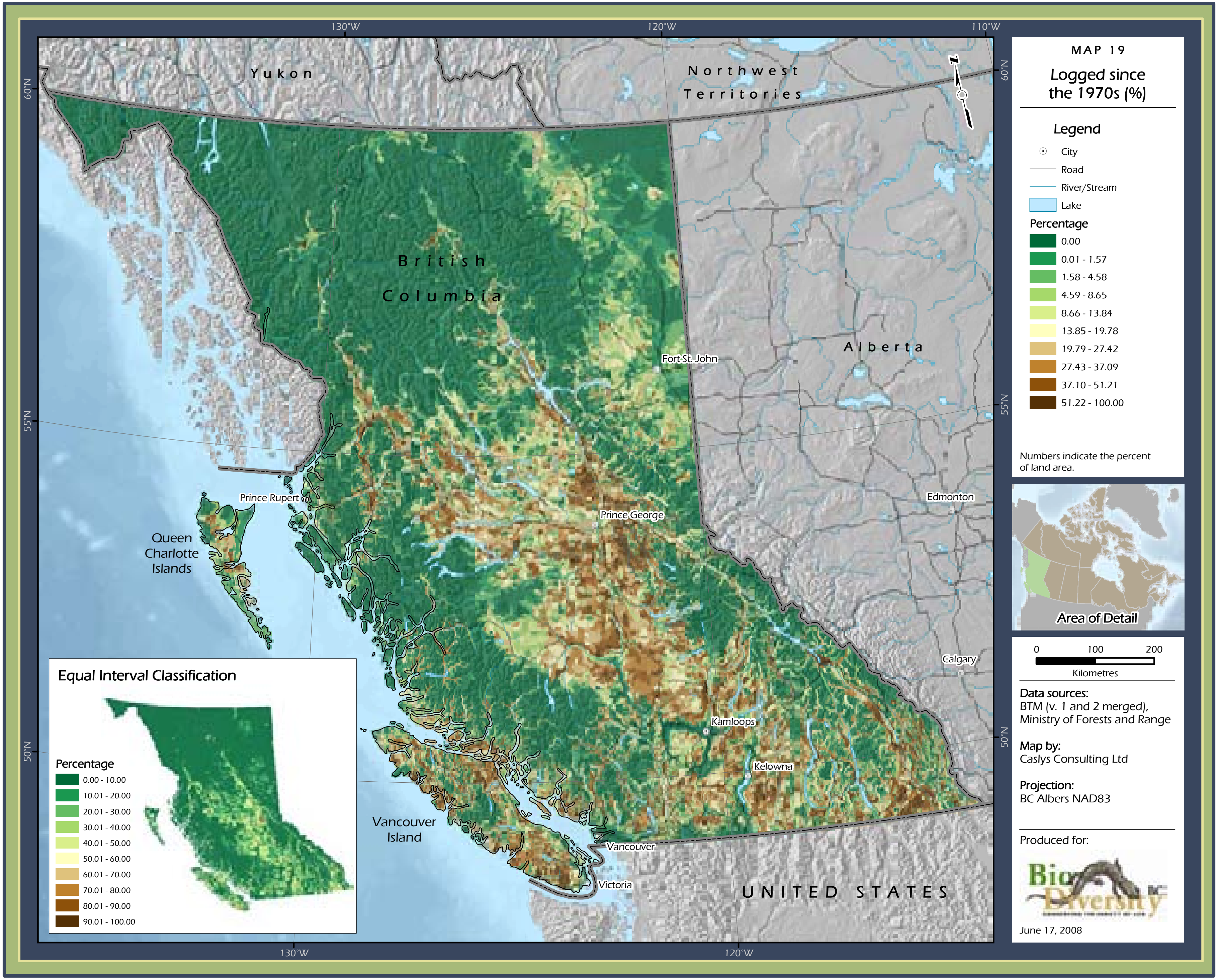
3.3.4 URBAN AND RURAL DEVELOPMENT

Human activities within this category are associated with residential, commercial and industrial development, sewage and solid waste disposal, and infrastructure for water and power supply. These activities result in ecosystem conversion, ecosystem degradation, environmental contamination, species mortality and increases in alien species. The most immediate impact of urban and rural development is the conversion of natural landscapes to buildings, parking lots and playing fields, resulting in the loss of species and ecosystems along with the impairment of ecosystem functions. While some activities do not result in complete ecosystem conversion, there can be significant degradation, such as habitat fragmentation, predation by domestic animals and disruption of surface water flow over impervious surfaces.[1002] Runoff from impervious surfaces affects the hydrology of streams and impacts sediments and temperature in aquatic environments.[1003,1004]

The infrastructure and activities associated with development can also create point and non-point source pollution, such as waste discharges into water bodies (e.g., Victoria's sewage discharge into the Strait of Juan de Fuca), airborne pollutants from factories, contamination of nearshore areas, pollution associated with automobile oil on roads and application of fertilizers and pesticides on residential properties.

Increases in the planting of alien species for landscaping, greater movement of people and goods both nationally and internationally, and increased disturbance of sites along roadways can facilitate the introduction of alien species.

Clearly, an increasing population negatively impacts biodiversity in many ways and, as the population increases, the impacts on biodiversity will continue. Since 1971, the province's population has almost doubled to 4.3 million and is expected to reach close to 6 million by 2031 (Figure 42). In the 2006 Canadian census, British Columbia was the third-fastest growing province in Canada, its population increasing by 5.3% between 2001 and 2006, compared to 4.9% between


MAP 19
Logged since the 1970s (%)
Legend
City
Road
River/Stream
Lake
Percentage
0.00
0.01 - 1.57
1.58 - 4.58
4.59 - 8.65
8.66 - 13.84
13.85 - 19.78
19.79 - 27.42
27.43 - 37.09
37.10 - 51.21
51.22 - 100.00
Numbers indicate the percent of land area.
Area of Detail
0
100
200
Kilometres
Data sources:
BTM (v. 1 and 2 merged), Ministry of Forests and Range
Map by:
Caslys Consulting Ltd
Projection:
BC Albers NAD83
Produced for:
June 17, 2008
Equal Interval Classification
Percentage
0.00 - 10.00
10.01 - 20.00
20.01 - 30.00
30.01 - 40.00
40.01 - 50.00
50.01 - 60.00
60.01 - 70.00
70.01 - 80.00
80.01 - 90.00
90.01 - 100.00
130°W
120°W
110°W
60°N
55°N
50°N
Yukon
Northwest Territories
British Columbia
Alberta
Fort St. John
Prince Rupert
Prince George
Edmonton
Queen Charlotte Islands
Calgary
Kamloops
Kelowna
Vancouver Island
Vancouver
Victoria
UNITED STATES

B.C.'s population has nearly doubled since 1971.
PHOTO: LEITH LESLIE.

1996 and 2001. This growth was concentrated in the lower mainland, eastern Vancouver Island and Okanagan areas, as well as in the northeast corner of the province (Figure 43).[1005]

Many impacts on biodiversity are associated with population size, but the location of growth is also a major factor. Within B.C., human population is concentrated where species richness is highest: the lower mainland, the east and south coasts of Vancouver Island, and the low-elevation lake and river valleys of the southern interior. The impacts to biodiversity are relatively permanent; even reductions in human population (experienced in some areas of the province) do not necessarily improve the status of biodiversity, since infrastructure such as roads and buildings remains. Given continued population growth in low-elevation areas, the impact of urban development on biodiversity is expected to intensify.

In addition to population growth and geographic location, the density of the growth is an important factor that impacts biodiversity. Since World War II, low-density housing has been the dominant form of residential development in North America creating urban and suburban sprawl and resulting in fragmentation of forests and farmland and impacts to both streams and wildlife.[1006] The number of people living in each dwelling in B.C. is decreasing (from 2.62 persons in 1991, to 2.60 in 1996, and 2.50 in 2001).[1007,1008] This trend is occurring in all regions of B.C., leading to an escalation in the number of dwellings required to house the same population and therefore impacting biodiversity.

Urbanization creates large amounts of impervious surfaces: parking lots, building and roads. Instead of soaking into the ground, precipitation runs off the impervious surfaces and into storm drains. Recent research

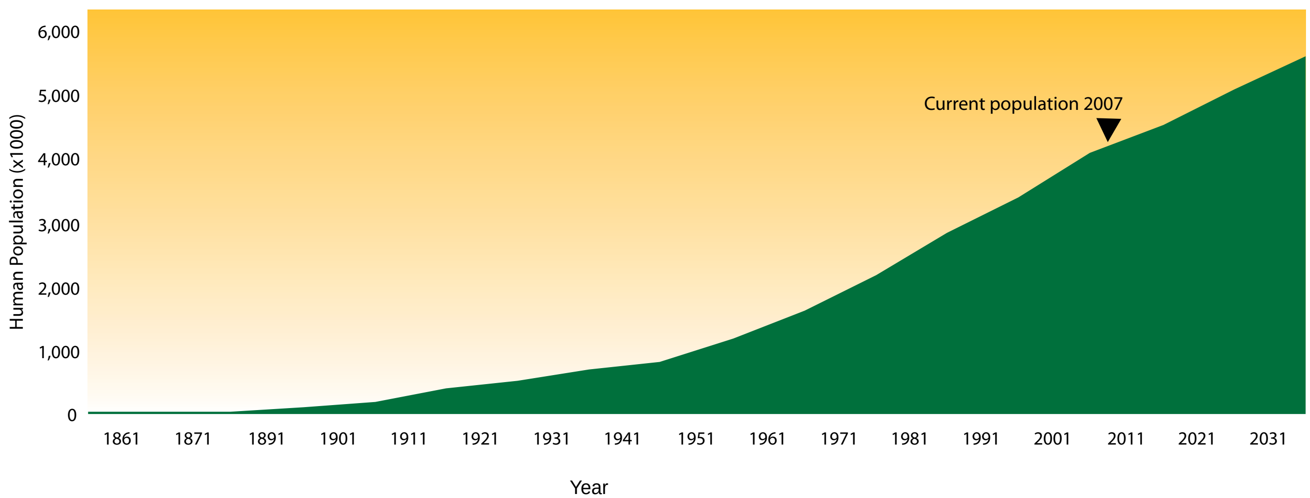


FIGURE 42: **Population growth for B.C. (1861–2006) with a projection to 2031.**
SOURCE: B.C. Stats. 2007. British Columbia Population 1867 to 2007. Available at: www.bcstats.gov.bc.ca/data/pop/pop/bc1867on.csv.

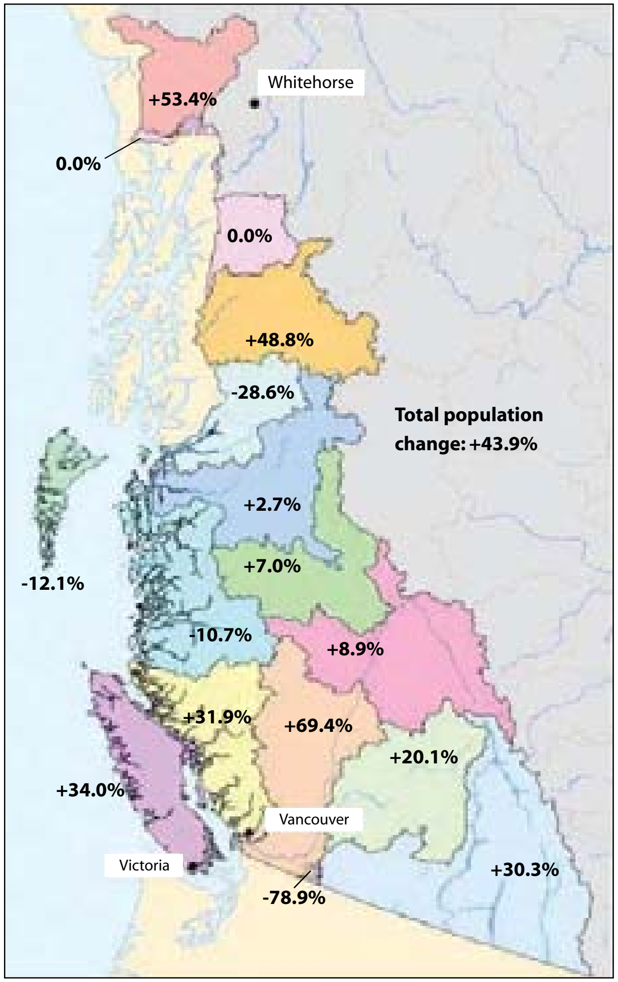


FIGURE 43: **B.C. population change (selected areas), 1981–2001.**
SOURCE: Statistics Canada. 2006. Canadian Environmental Sustainability Indicators: Socio-Economic Information 2006, Revised. Statistics Canada Environment Accounts and Statistics Division, Ottawa, ON. Catalogue No. 16-253-XIE.

shows that stormwater-related impacts typically start to occur once the impervious percentage of a watershed reaches about 10%.[1009] In B.C. examples of impervious area measurements include 4.6% in the French Creek watershed on Vancouver Island[1010] and 48% in the Tilbury Industrial Area in the Municipality of Delta.[1011] More than 2,725 watersheds were evaluated in the Georgia Basin–Puget Sound region between 1992 and 2000, and 58 of them showed an increase in impervious area of 2–19% of their total area (Figure 44).[1012] Between 1990 and 2000, Vancouver created 67 km^2 of impervious surfaces along the edges of existing urban areas or as infill within those areas.[1013]

3.3.5 TRANSPORTATION AND UTILITY CORRIDORS

This category of human activity includes the infrastructure and activities associated with the movement of people, commodities and information. Specific infrastructure includes sea ports and airports, and linear features such as roads, hydro and communications transmission corridors, seismic lines, pipelines and railways. These activities impact biodiversity through ecosystem conversion, ecosystem degradation and the introduction of alien species and species disturbance. The construction of ports and similar structures converts natural ecosystems to land cover that excludes species and ecosystems. Even relatively narrow roads through forest can produce marked edge effects that may have negative consequences for the function and

Parking lots are large impervious surfaces where rainwater is not able to soak into the ground and is instead channelled into storm drains.
PHOTO: ISTOCK.

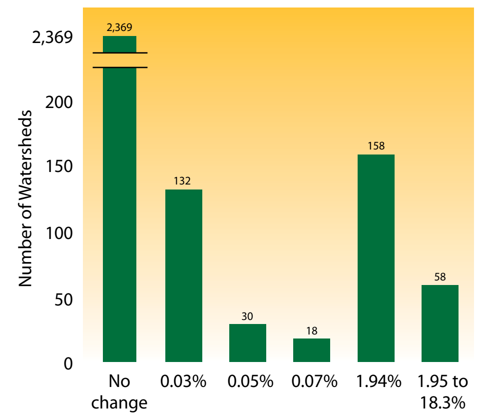
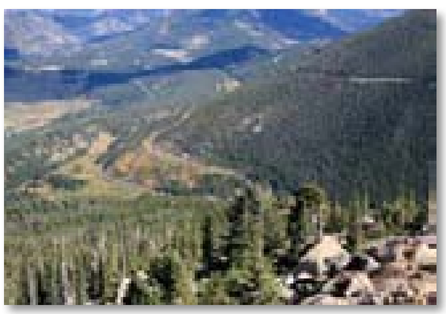


FIGURE 44: **Change in impervious area in the Georgia Basin–Puget Sound region, 1992–2000.**
SOURCE: U.S. Environmental Protection Agency. Puget Sound Georgia Basin Ecosystem Indicators: Urbanization and Forest Change. Available at: www.epa.gov/region10/psgb/indicators/urbaniz_forest_change/what/.

Utility corridors and roads fragment ecosystems.
PHOTO: IVARS LINARDS ZOLNEROVCHS.



Resource access roads in many areas of the province have the potential to be decommissioned.
PHOTO: RAY ROPER.

diversity of these ecosystems.[1014] There is also significant ecosystem degradation in the area beyond the actual feature. The construction of linear features alters hydrology in water courses and increases sedimentation, and can disconnect streams from floodplains and block aquatic species movement.

Roads and other linear features impede the movement of native species, facilitate invasion by alien species and alter predator-prey relationships. Specifically, roads can fragment ranges, populations, habitats and ecosystems,[1015,1016,1017] and reduce gene flow, resulting in loss of genetic diversity.[1018] Roads can increase access to previously inaccessible areas, resulting in increased road kill of wildlife and increased access for legal and illegal fishing and hunting. Both on-road traffic and off-road vehicles create disturbance, which can alter species behaviour. Roads also facilitate ecosystem conversion, ecosystem degradation, alien species invasion and environmental contamination.[1019,1020]

The ecological impacts of roads can affect approximately 20 times the land area that the roads actually cover.[1021] Hence roads and other linear features are a useful index for the cumulative impact on biodiversity. Between 1988 and 2000, road length in B.C. increased by 48%, from an estimated 387,000 km to more than 570,000 km (Figure 45).[1022] By 2005, total road length was 702,574 km, a 23% increase in just five years, and an 82% increase since 1988. This is a conservative estimate of the expansion of linear features in B.C., as it does not include seismic lines.

Table 29 shows density of roads and other linear features across B.C.'s biogeoclimatic zones, including main and secondary roads, forest access roads, transmission lines, railways, seismic lines and pipelines. The highest densities of roads are found in the Coastal Douglas-fir, Ponderosa Pine, Bunchgrass and Interior Douglas-fir zones, all zones of conservation concern (see Section 2.2.1.1, p. 30).[1023]

The density of roads and other linear features varies across the province, with the greatest densities in the northeast, central interior and southwest (including Vancouver Island) and in major valleys in the southern interior (Map 20). Seventy-six percent of B.C.'s roads are forest access roads. The area of high density in the northeast corner of the province is largely due to seismic lines used for oil and gas exploration. Although seismic lines are allowed to revert back to forest after use, thousands of kilometres of new lines are cut each year.[1024] Large tracts of mountainous land in the northwest of the province and along the central coast are relatively free of disturbance from roads.[1025]

TABLE 29. PRESENCE OF ROADS OR OTHER LINEAR FEATURES IN B.C. BY BIOGEOCLIMATIC ZONE.

BIOGEOCLIMATIC ZONE	ROAD DENSITY (KM/KM²)	PERCENT OF 1-HA UNITS WITH ROADS PRESENT
Coastal Douglas-fir	4.7	38%
Ponderosa Pine	3.0	28%
Bunchgrass	2.8	25%
Interior Douglas-fir	2.1	22%
Boreal White and Black Spruce	1.4	15%
Interior Cedar–Hemlock	1.3	14%
Sub-boreal Spruce	1.3	13%
Montane Spruce	1.3	14%
Sub-boreal Pine–Spruce	1.1	12%
Coastal Western Hemlock	0.9	9%
Engelmann Spruce–Subalpine Fir	0.3	3%
Mountain Hemlock	0.1	1%
Spruce–Willow–Birch	0.1	1%
Boreal Altai Fescue Alpine	<0.1	<1%
Interior Mountain-heather Alpine	<0.1	<1%
Coastal Mountain-heather Alpine	0.0	0%
Province		**8.0%**

SOURCE: Prepared for this report.
NOTE: Density and percent figures include other linear features.

3.3.6 WATER DEVELOPMENT

Water development activities include the use of water, as well as the associated infrastructure, such as dams. In B.C., the allocation of water is governed by water licenses and short-term use approvals that are issued for a variety of purposes, such as domestic or municipal water supply, irrigation, industrial and commercial uses, mining, power production, oil and gas drilling and injection, and water storage.[1026] Table 30 (p. 204) shows water allocation for selected purposes in B.C.'s nine Major Drainage Areas.

The diversion of water from lakes can cause excessive drawdown of surface water sources with consequent disruption of aquatic and riparian habitat.[1027] In rivers, water diversions reduce flow and lower water levels, which can create barriers to movement of fish and other aquatic species.[1028,1029] Withdrawal of water from streams can affect the biological carrying capacity of the stream, cause changes in temperatures and alter life history stages of aquatic organisms, depending on when and how much water is removed. Fish and other animals are sometimes trapped or die when drawn into diversion channels or other in-stream structures, such as turbines. Wastewater from industrial uses is often returned to the source water body with contaminants and/or a significant change in temperature.

There are about 30,000 licenses for water diversion[a] in B.C., for a total permitted volume of more than 21 billion kL per year; this does not include water diverted for power production or water storage for dams, or allocations for conservation purposes. According to 1999 data, over 97% of water licensed is used for power production, including storage, while the remaining 3% is used for drinking water, agriculture and consumptive

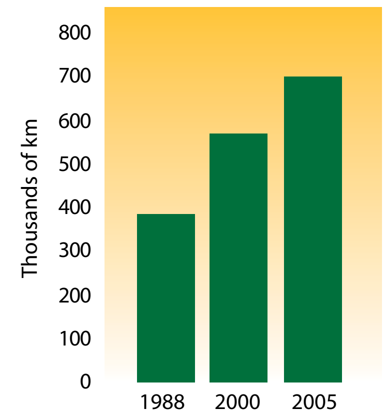
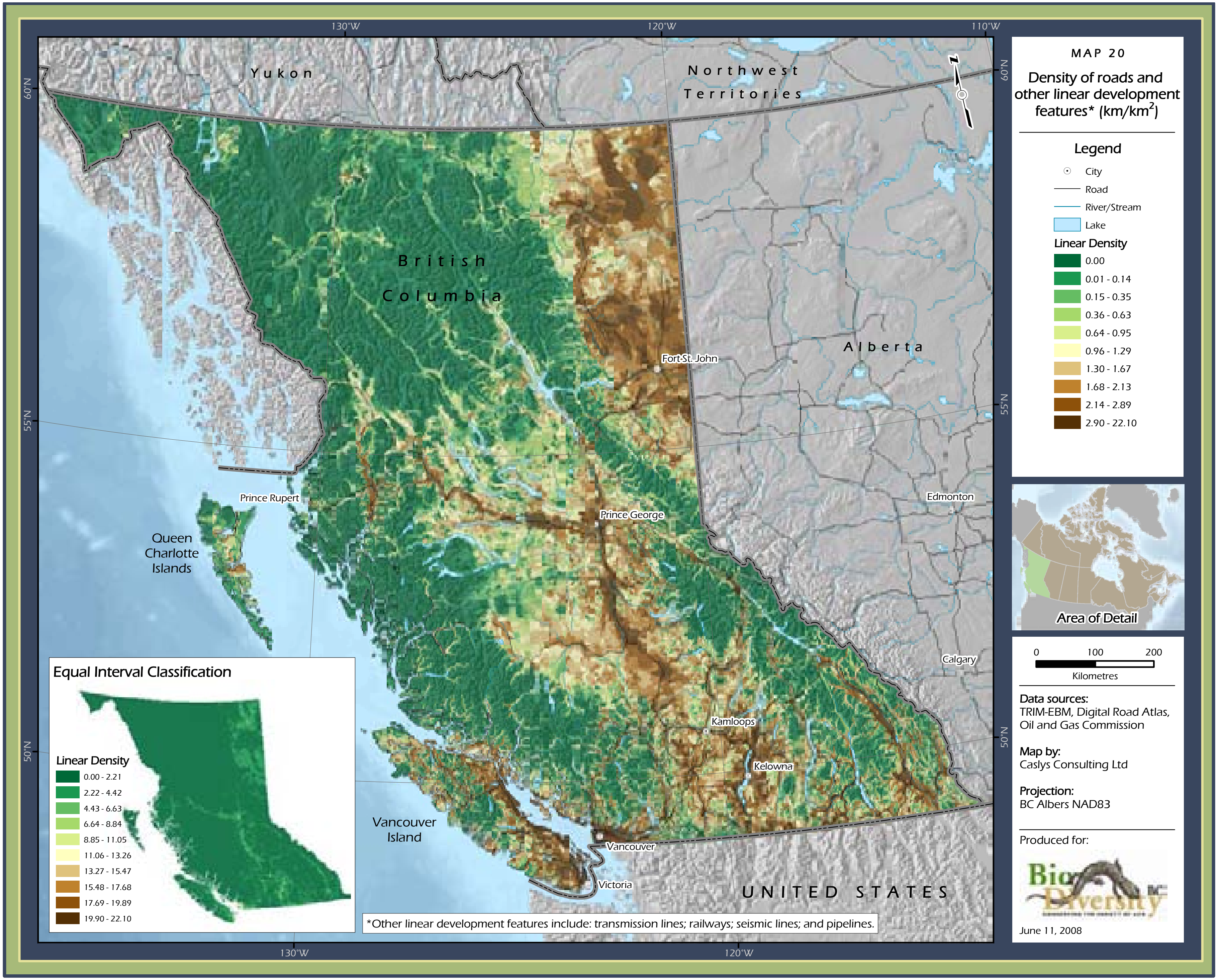


FIGURE 45: **Length of roads in B.C. in 1988, 2000 and 2005.**
SOURCE: B.C. Ministry of Environment. 2007. Environmental Trends 2007. State of Environment Reporting Office, Victoria, BC. Available at: www.env.gov.bc.ca/soe/et07/.
NOTE: Includes all main and secondary roads, including paved, unpaved, and rough roads, forest service roads, and other forest and non-forest roads.

[a] Diversion includes the following uses: domestic, waterworks (e.g., sewage ponds, local water authorities), industry, institution, agriculture, and other.


MAP 20
Density of roads and other linear development features* (km/km^2)
Legend
City
Road
River/Stream
Lake
Linear Density
0.00
0.01 - 0.14
0.15 - 0.35
0.36 - 0.63
0.64 - 0.95
0.96 - 1.29
1.30 - 1.67
1.68 - 2.13
2.14 - 2.89
2.90 - 22.10
Area of Detail
0
100
200
Kilometres
Data sources:
TRIM-EBM, Digital Road Atlas, Oil and Gas Commission
Map by:
Caslys Consulting Ltd
Projection:
BC Albers NAD83
Produced for:
June 11, 2008
130°W
120°W
110°W
60°N
55°N
50°N
Yukon
Northwest Territories
British Columbia
Alberta
Fort St. John
Edmonton
Calgary
Prince Rupert
Prince George
Queen Charlotte Islands
Kamloops
Kelowna
Vancouver Island
Vancouver
Victoria
UNITED STATES
Equal Interval Classification
Linear Density
0.00 - 2.21
2.22 - 4.42
4.43 - 6.63
6.64 - 8.84
8.85 - 11.05
11.06 - 13.26
13.27 - 15.47
15.48 - 17.68
17.69 - 19.89
19.90 - 22.10
*Other linear development features include: transmission lines; railways; seismic lines; and pipelines.

industrial and commercial uses.[1030] The total volume of surface water licenses doubled between 1960 and 1990 (Figure 46).

In recent years, water restrictions have been registered against streams when the demand for licenses exceeds the capacity of the water supply.[1031] Water restrictions increased seven-fold between the 1960s and the 1990s. Between half and two-thirds of available surface water in populated regions of B.C. has been allocated (see Text box 18, p. 164).[1032]

Dams are built primarily for hydroelectric power generation, flood control and irrigation. In B.C., mountainous terrain, high-volume rivers and long, narrow valleys make dam construction relatively easy. Ninety percent of B.C.'s electricity is generated by hydroelectric dams, and more than 70% of this is produced by dams on the Peace and Columbia rivers.[1033] Of the 2,200 registered dams in British Columbia, 44 are for generating hydroelectric power, including 13 on the Columbia River, two on the Peace River, 11 in the lower mainland, seven on Vancouver Island and two on the mainland coast.[1034,1035] The thousands of other dams are generally small and used for domestic water sources, run-of-river power production and local industrial uses. Like the larger dams, these smaller dams can also impede fish passage, trap nutrients and alter flow regimes. Recent interest in run-of-river projects has raised questions about the cumulative impacts of these often small operations. These include water diversion and increased roads and transmission lines.

Impacts from dams result in both ecosystem conversion and degradation related to infrastructure, upstream reservoirs and degradation of downstream ecosystems. The inundation of a reservoir upstream of a dam results in ecosystem conversion through the extirpation of riparian and valley-bottom habitats, which typically support high levels of biodiversity.[1036] Besides decreasing biodiversity in adjacent riparian plant communities,[1037] flooded riparian vegetation can be a source of methane and CO_2, both greenhouse gases that contribute to climate change.[1038] Reservoirs slow the velocity of the water, trapping sediments and nutrients that normally deposit in estuaries and deltas downstream and building up on the bottom of the reservoir.[1039] Many species have difficulty adjusting to the sometimes daily fluctuating water levels in a reservoir, and aquatic biodiversity is lower in a reservoir than in a lake of similar size and location (see Section 2.5.1.3-C, p. 116).

Dams also create significant ecosystem degradation by hampering the movement of migratory and anadromous fish species (which reduces the transfer of marine-derived nutrients into interior ecosystems), changing turbidity and sediment levels to which species and ecosystems are adapted, disrupting normal processes of river channel scouring and silt deposition, preventing normal downstream movement of large woody debris, changing water temperature and oxygen conditions, providing habitat for alien species and creating unstable, early seral

Dams, such as the Revelstoke Dam, have both upstream and downstream impacts.
PHOTO: DANIEL ROSS.

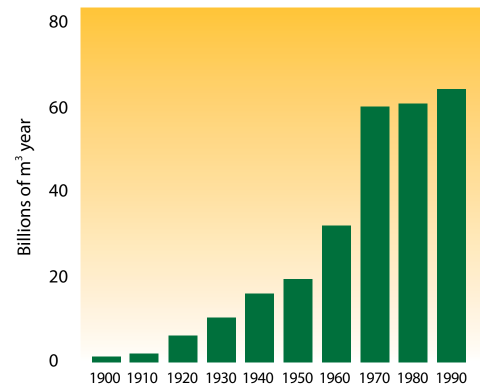


FIGURE 46: **Trends in surface water licensing in B.C.**
SOURCE: B.C. Ministry of Environment, Lands and Parks. 2000. Environmental Trends in British Columbia 2000. State of Environment Reporting Office, Victoria, BC. 54pp. Available at: www.env.gov.bc.ca/soerpt/files_to_link/etrends-2000.pdf.

TABLE 30. SURFACE WATER ALLOCATION IN B.C. BY MAJOR DRAINAGE AREA.

MAJOR DRAINAGE AREA	VOLUME OF LICENSED WATER ALLOCATION (KILOLITRES/YEAR)
Fraser	10,617,165,159
Coastal	6,960,674,550
Columbia	3,191,406,652
Skeena	547,689,512
Mackenzie	393,667,691
Stikine	1,002,531
Nass	816,950
Yukon	816,924
Taku	27,990
Provincial total	**21,713,267,959**

SOURCE: Prepared for this report based on data from the B.C. Ministry of Environment.
NOTE: This excludes water storage, diversion for dams and allocations for conservation purposes.

communities along shorelines. A dam typically decreases the annual flood below the dam and may increase flow during the summer so that the river no longer deposits sediments downstream. Decreased delivery of water and nutrients to downstream ecosystems, such as marshes and riparian areas, can cause a shift to species that are adapted to drier conditions. Water that flows through turbines into a river is colder and less oxygenated, because it originates from deep in the reservoir and does not mix with surface air. Vegetation, wildlife and fish populations can be altered for hundreds of kilometres downstream.[1040]

The Major Drainage Areas in B.C. that are most significantly affected by dams are those of the Columbia, Coastal, McKenzie and Fraser rivers and, less significantly, the Skeena River. A dam can influence extensive areas of the upstream watershed (see Map 21). Some river systems in B.C. are affected by dams built outside the province.

In B.C., oil and gas development is concentrated in the northeastern part of the province.
PHOTO: DON WILKIE.

3.3.7 OIL AND GAS

Terrestrial oil and gas development includes exploration, extraction and transportation activities, each with their own set of impacts on biodiversity. Primary and secondary impacts of oil and gas extraction include ecosystem conversion, ecosystem degradation (including fragmentation), species disturbance, environmental contamination of soil, water and air, soil compaction and erosion and sedimentation of waterways.[1041,1042] Secondary impacts, such as the construction of roads and seismic lines and the development of settlements and infrastructure to support workers, can have significant effects. Oil and gas in B.C. are high in sulphur, and long-term wind deposition of sulphur on vegetation or soil can impair ecosystem functioning through reduced diversity of species and dramatically reduced foliage cover.[1043]

At present, most activities associated with petroleum or natural gas extraction in B.C. take place in the relatively flat, rolling plain in the northeast corner of the province (see Map 22, p. 208), an extension of the interior

TABLE 31. DENSITY OF OIL AND GAS SITES IN B.C. BY BIOGEOCLIMATIC ZONE.

BIOGEOCLIMATIC ZONE	DENSITY (NUMBER OF SITES/1,000 KM²)
Boreal White and Black Spruce	196
Engelmann Spruce–Subalpine Fir	3
Coastal Douglas-fir	2
Montane Spruce	2
Spruce–Willow–Birch	2
Sub-boreal Spruce	1
Interior Douglas-fir	<1
Interior Cedar–Hemlock	<1
Sub-boreal Pine–Spruce	<1
Coastal Western Hemlock	<1
Ponderosa Pine	<1
Mountain Hemlock	<1
Bunchgrass	<1
Interior Mountain-heather Alpine	<1
Coastal Mountain-heather Alpine	<1
Boreal Altai Fescue Alpine	<1

SOURCE: Prepared for this report.

plains of Alberta. There are currently more than 32,000 oil and gas facilities, including wells, in the province, with most of the sites concentrated in the Boreal White and Black Spruce biogeoclimatic zone (Table 31).

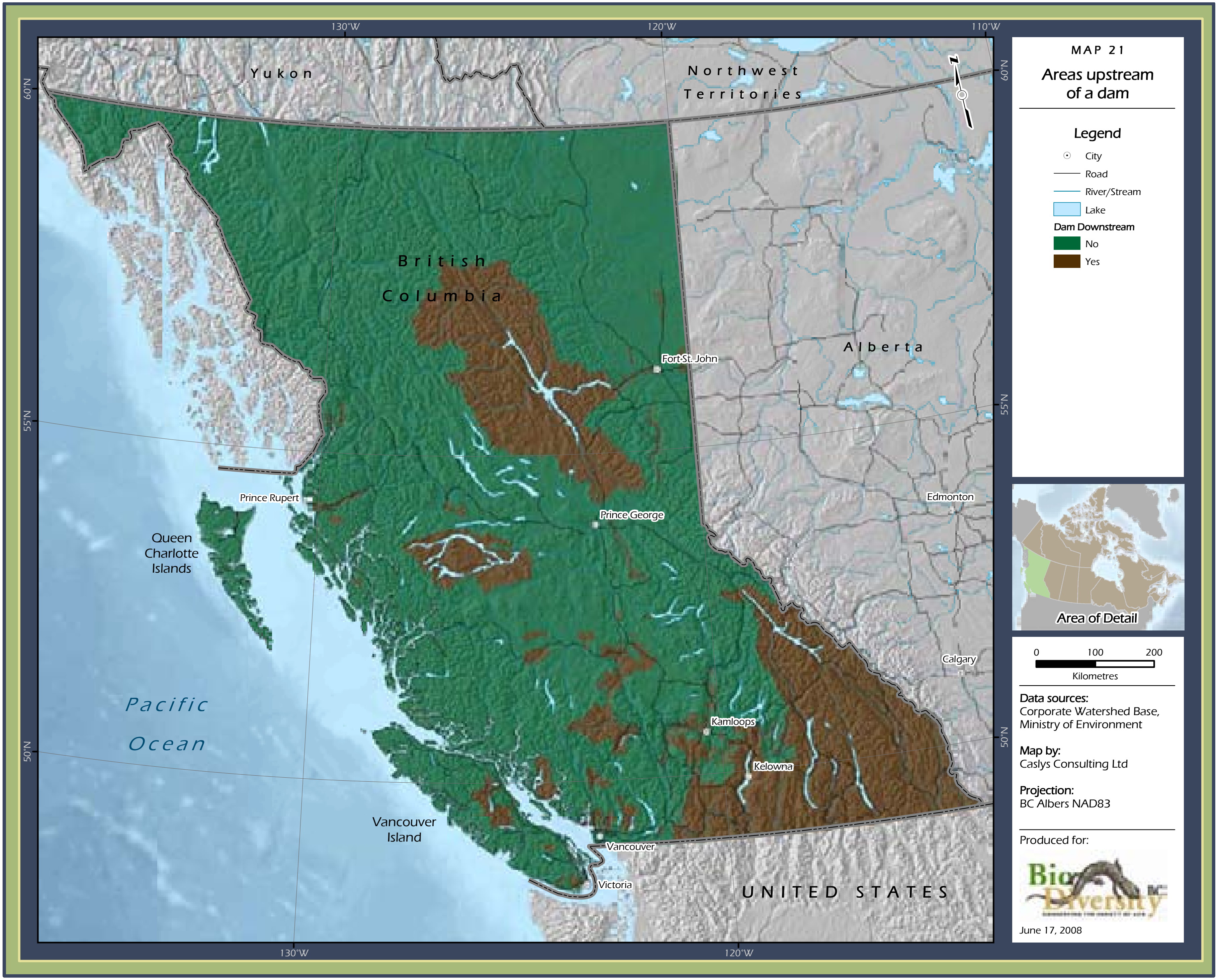
3.3.8 RECREATION

British Columbia is known for its outdoor recreation opportunities, and recreational activities are considered among the human activities most likely to have an increased impact on biodiversity in the future.[1044] Impacts from recreation occur year-round, but are not equal throughout the province or within the terrestrial and freshwater realms. Participation in motorized backcountry recreation, especially snowmobiling, is increasing.[1045,1046] Since 1995, the retail sale of recreational off-highway vehicles has risen by 350% and is continuing to grow.[1047]

Motorized recreation is often in conflict with wildlife values, since high-quality wildlife habitat, such as ungulate winter range or alpine meadows, has attributes of value to motorized recreationists.[1048] Impacts from snowmobiling, heli-skiing, snow-cat skiing and backcountry skiing have been observed on mountain caribou.[1049] Of particular concern is habitat displacement from late winter foraging areas in response to snowmobiling.[1050] Hard-packed trails also allow predators to reach subalpine foraging areas, increasing predation on mountain caribou.[1051] Responses of ungulates to helicopters vary according to species, level of activity, season and quality of nearby cover, as well as the aircraft's altitude and distance from the animal.[1052]

Recreational impacts include trampling of vegetation, introduction and spread of alien species, disturbance of wildlife, sedimentation of streams or wetlands, and legal and illegal hunting, fishing and collecting (e.g., mushroom and berry picking). Irresponsible motorized vehicle recreation in natural ecosystems can result in soil erosion, noise pollution, air and water pollution, damage to vegetation, litter, and fire hazards.[1053] Noise from the motors of vehicles such as helicopters, airplanes and snowmobiles can disrupt denning, nesting, dispersal

Motorized outdoor recreation is rapidly increasing in B.C., facilitating access to remote areas and causing disturbance to sensitive species.
PHOTO: RONNIE COMEAU.



MAP 21
Areas upstream of a dam
Legend
City
Road
River/Stream
Lake
Dam Downstream
No
Yes
Yukon
Northwest Territories
British Columbia
Alberta
Fort St. John
Prince Rupert
Prince George
Edmonton
Calgary
Kamloops
Kelowna
Vancouver
Victoria
Queen Charlotte Islands
Vancouver Island
Pacific Ocean
UNITED STATES
130°W
120°W
110°W
60°N
55°N
50°N
Area of Detail
0
100
200
Kilometres
Data sources:
Corporate Watershed Base, Ministry of Environment
Map by:
Caslys Consulting Ltd
Projection:
BC Albers NAD83
Produced for:
June 17, 2008

and mating behaviour[1054] and drive animals away from their preferred habitats, causing stress and expenditure of energy. As well, exhaust from motorized vehicles results in localized environmental contamination.[1055]

Activities associated with recreation also have significant impacts in the freshwater realm, particularly when lakes are altered to improve fishing opportunities. Some previously fishless lakes and ponds have been poisoned and then aerated to improve the survival of introduced game fish, which are generally predatory (see Section 2.5.2.3-G, p. 153). Predatory fish, such as trout, forage on amphibian eggs and larvae and have resulted in the loss of some tiger salamander breeding populations.[1056,1057] Introduced predatory fish may be responsible for numerous amphibian population declines and local extirpations, as well as changes in the structure of amphibian communities.[1058] Trout introductions may fragment and isolate populations of amphibian species and reduce the ability of amphibians to move from lake to lake.[1059] The introduction of fish can also result in behavioural changes in lake invertebrates, causing them to become less active and seek refuge more often,[1060] affecting their availability as prey, as well as the primary and secondary trophic communities.[1061]

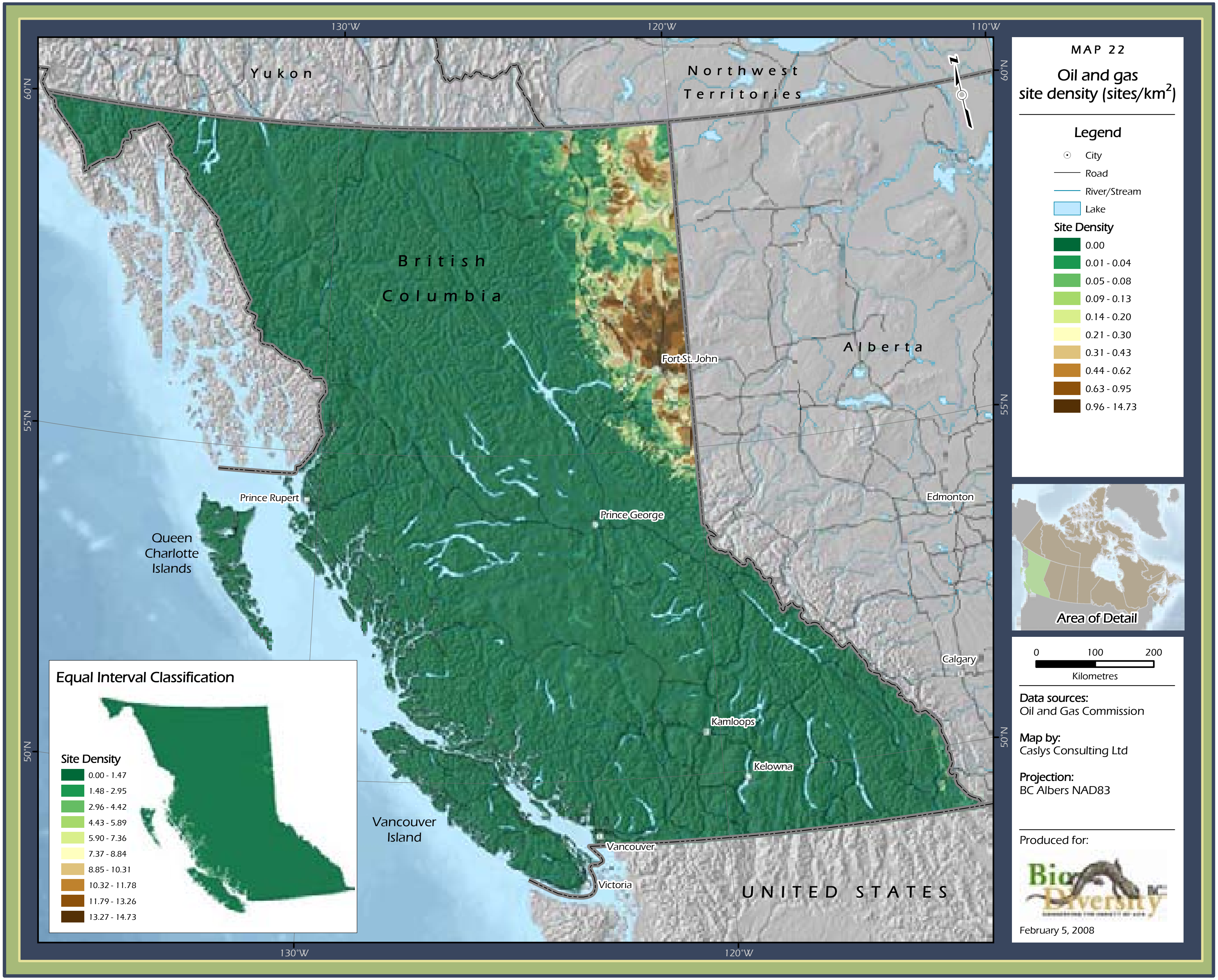
Introduction of new fish species into lakes that already contain fish can also impact biodiversity. For example, the introduction of the brown bullhead (*Ameiurus nebulosus*) caused the extinction of the Hadley Lake benthic and limnetic sticklebacks.[1062]

3.3.9 GRAZING

Roughly 90% of British Columbia's remaining grasslands are grazed by domestic livestock, either through deeded private rangelands, grazing tenures on provincial Crown land or grazing regimes on First Nations land.[1063] Grazing also affects riparian areas associated with grasslands, as well as some alpine and forested ecosystems. Grasslands and associated wetlands represent a tiny portion of the province's land base, but have very high levels of biodiversity. Grasslands cover less than 1% of the province's land base, but provide critical habitat for more than 30% of B.C.'s terrestrial species of conservation concern.[1064]

The most significant impacts of livestock grazing are ecosystem degradation, ecosystem conversion, and the introduction and spread of alien species. In B.C., grazing primarily results in ecosystem degradation. Conversion of grasslands or other native ecosystems to cultivated pastures affects only a small proportion of the land base affected by grazing.[1065] Poor management practices, such as overgrazing and continuous grazing, degrade native plant communities and reduce wildlife habitat; in some cases, riparian vegetation is completely eliminated.[1066]

Grazing by wild ungulates can also impact biodiversity. For example, in the East Kootenay Trench, combined grazing by domestic livestock and wild ungulates (bighorn sheep, elk, white-tailed deer and mule deer)


MAP 22
Oil and gas site density (sites/km²)
Legend
City
Road
River/Stream
Lake
Site Density
0.00
0.01 - 0.04
0.05 - 0.08
0.09 - 0.13
0.14 - 0.20
0.21 - 0.30
0.31 - 0.43
0.44 - 0.62
0.63 - 0.95
0.96 - 14.73
Area of Detail
0
100
200
Kilometres
Data sources:
Oil and Gas Commission
Map by:
Caslys Consulting Ltd
Projection:
BC Albers NAD83
Produced for:
Bio Diversity
February 5, 2008
130°W
120°W
110°W
60°N
55°N
50°N
Yukon
Northwest Territories
British Columbia
Alberta
Fort St. John
Prince Rupert
Queen Charlotte Islands
Prince George
Edmonton
Calgary
Kamloops
Kelowna
Vancouver Island
Vancouver
Victoria
UNITED STATES
Equal Interval Classification
Site Density
0.00 - 1.47
1.48 - 2.95
2.96 - 4.42
4.43 - 5.89
5.90 - 7.36
7.37 - 8.84
8.85 - 10.31
10.32 - 11.78
11.79 - 13.26
13.27 - 14.73

has resulted in significant pressure on the area's open grasslands. In the Peace region, bison probably played a role historically in shaping aspen parkland and grassland ecosystems, but the extent of their influence is not well understood.[1067]

3.3.10 INDUSTRIAL OPERATIONS

Industrial operations refers to infrastructure and activities associated with large production facilities, such as factories, pulp and paper mills, refineries and smelters. The most significant impact of industrial operations is environmental contamination. Other impacts include ecosystem degradation, species disturbance and species mortality.[1068] Water development impacts associated with industry are discussed in Section 3.3.6 (p. 201).

Numerous substances that have deleterious biophysical effects are currently released into the environment by industrial operations or were released in the past and are now no longer used, yet continue to be present (see Section 3.2.4, p. 169). These contaminants include toxic biochemicals, heavy metals, persistent organic pollutants, airborne fine particulates, excess nutrients released into aquatic environments (e.g., nitrogen or phosphorus) and pharmaceuticals.[1069]

The National Pollutant Release Inventory tracks the release, disposal and recycling of more than 300 pollutants by industrial, commercial and institutional facilities in Canada. In 2005, the 12 toxic pollutants discharged on-site in the largest quantities in B.C. were: hydrogen sulphide, sulphur dioxide, ammonia, methanol, hydrochloric acid, manganese, nitrate, styrene, hydrogen fluoride, zinc, chlorine dioxide and sulphuric acid. Discharges include unintentional spills and leaks, intentional releases (e.g., emissions to air from stacks, discharges to surface waters) and on-site disposal within the boundaries of the facility site (e.g., to landfills, underground injection).[1070]

3.3.11 MINING

Mining includes all infrastructure and activities associated with the extraction of geological materials, such as coal, metals, gems, construction aggregates, clay, shale and dimension stone. Impacts include surface and subsurface soil disturbance; aquatic, terrestrial and atmospheric pollution; erosion; and sedimentation from overburden and waste rock disposal.

Mining operations often result in ecosystem degradation or conversion, but only affect a relatively small portion of the provincial land base. Exploration activities have a larger footprint. Freshwater ecosystems are generally more affected by ecosystem conversion and degradation than are terrestrial ecosystems.[1071] Mines are also major freshwater users and their wastewater often contains contaminants when returned to the source water

Some freshwater fish are raised in land-based lakes, ponds or tank operations.
PHOTO: ISTOCK.

body. Approximately 60 decommissioned B.C. mines present pollution issues of toxic metal leaching (copper, zinc and cadmium are typical examples) and acid rock drainage into the environment.[1072]

Gravel pits facilitate the dispersal of alien plant species because many of these species thrive in disturbed sites and because materials are continuously being moved in and out of these sites and along road corridors.[1073]

3.3.12 AQUACULTURE

Three main species groups are currently cultured in B.C. waters: salmon and other finfish; shellfish; and marine plants. Operations that take place in marine waters (e.g., salmon farming, deep-water shellfish farming, offshore marine plant cultivation) are outside the scope of this report.

Shellfish species that are cultivated in intertidal and estuarine ecosystems include clams and oysters (the latter are also cultivated in deep-water systems). In B.C., freshwater finfish aquaculture occurs primarily on private land and encompasses commercial enterprises such as salmon and trout hatcheries, trout farms and fee-fishing operations. About 34 small-scale farms raise rainbow trout (*Oncorhynchus mykiss*) in B.C. and a few facilities raise other freshwater species, such as tilapia (*Oreochromis niloticus*), carp (*Cyprinus carpio*) and signal crayfish (*Pacifastacus leniusculus*), in land-based lakes, ponds or tank operations.[1074]

The primary impact of shellfish and finfish aquaculture is introduction of alien species, since many cultivated species are non-native. Two of the province's leading shellfish aquaculture species, the Pacific oyster and Manila clam, were both introduced to B.C. waters in the early 1900s and have since greatly expanded their range (see Text box 19, p. 168). Freshwater hatcheries and fish farms and some shellfish aquaculture operations impact biodiversity through ecosystem degradation (e.g., habitat modification, installation of netting). Environmental contamination and direct mortality of species that prey on aquaculture stocks are also potential impacts.[1075]

3.4 Data Gaps

3.4.1 GENERAL

A threats framework that better integrates both terrestrial and freshwater activities and stresses is required. The current threats framework, based on the IUCN definitions, works well for the terrestrial realm, but has limited application in the freshwater realm, since many impacts are categorized as degradation. An additional descriptor labelled 'Mechanism' could be added. For example a 'stress' of hydrological alteration would include several 'mechanisms' such as land cover conversion, water withdrawal or channelization, all of which derive from several 'sources' (e.g. agriculture, urban development).

Data gaps include the time lag to document trends for impacts that can occur quickly (e.g., seismic lines) and the status and trends of all human activities and stresses. Land cover mapping (i.e., Baseline Thematic Mapping) and road data are out of date. Forest harvesting data are fragmented and not available for dates prior to the 1970s. The specific effects of many stresses on B.C.'s biodiversity are not well understood. The interaction between many stressors (i.e., cumulative effects) and the responses by elements of biodiversity are not well documented.

3.4.2 CLIMATE CHANGE

The examination of impacts of climate change is in its early stages. Some of the key gaps include: observation programs for climate-sensitive biodiversity attributes; climate data from sparsely populated, but biologically important regions, such as northern B.C. and the montane and alpine zones; and hydrometric data. There is also a lack of regional climate models. The relationship between climate variables and the geographical distribution of key ecological processes, ecosystems and species, especially climate-sensitive indicator species,[a] is not well understood.

[a] An indicator species is a species whose status provides information on the overall condition of the ecosystem and of other species in that ecosystem.

4 Major Findings

4.1 Introduction

Biodiversity exists at the level of genes, species and ecosystems, and all of these levels are integrated through ecological processes such as fire, predation and decomposition. These processes play a vital role in shaping biodiversity by acting at a range of scales, with varying intensity, frequency and duration. The resulting synergy means that biodiversity is much greater than the sum of its parts.

British Columbia has high ecosystem diversity as a result of its mountainous topography, coastal location and the resulting variety of local climates. Topography has limited human activities in much of the province, and, combined with B.C.'s brief history of non-indigenous settlement and intensive industrial development, has resulted in relatively high levels of ecological integrity in the province's more remote and inaccessible areas. Conversely, these factors have concentrated impacts in low-elevation areas where ecological integrity has been significantly compromised.

British Columbia's extraordinary biodiversity cannot be taken for granted. Throughout the province there is compelling scientific evidence that it is being significantly altered by individual and cumulative stresses resulting from human activities that are impairing ecological integrity. Climate change is an overriding impact that is already taking a toll on B.C.'s biodiversity and is expected to become an increasingly significant threat in the medium and long term. Loss of biodiversity threatens the ecological services on which we all depend.

THE STATUS OF BIODIVERSITY IN B.C. CAN BE SUMMARIZED AS FOLLOWS:

British Columbia's biodiversity is globally significant because of its variety and integrity, but without immediate action, it is vulnerable to rapid deterioration, especially in light of climate change.

PHOTO: JON FAULKNOR.

The concept of ecological resilience – that is, the capacity of an ecosystem to cope with disturbance or stress – is fundamental to any discussion of biodiversity and an important component of ecological integrity. Ecosystems are complex, dynamic and adaptive systems that are rarely at equilibrium. Ecological resilience determines the amount of stress and alteration that can occur in an ecosystem without it losing its defining characteristics, as well as the speed with which it recovers. A resilient ecosystem can better withstand shocks and rebuild itself without changing into a different state that is controlled by a different set of processes. When ecosystems become simplified through the elimination of components or processes, they become increasingly vulnerable to biophysical or human-induced events.

Trend data for B.C. show that declines in biodiversity are occurring at the genetic, species and ecosystem levels and that the integrity of key and special elements of biodiversity is being lost. Meanwhile, major gaps in our knowledge of the province's biodiversity hinder our capacity to understand and respond to this situation. Without immediate and effective action, British Columbia's remarkable biological richness may be lost.

4.2 Development of the Major Findings

The numbered major findings that follow provide a synthesis of the status assessment presented in Sections 2 and 3. Development of the major findings was guided by three principles: that the findings be supported by this report; that they add value to the report (e.g., by pointing out convergence of themes, places, etc.); and that they cover the full scope of the report.

The process of developing the major findings was iterative. The Technical Subcommittee of Biodiversity BC initiated the process and then sought input from scientific experts and direction from the Biodiversity BC Steering Committee.

The order in which the major findings are presented in Section 4.3 follows the structure of this report, rather than representing any prioritization. The findings related to ecosystem, species and genetic diversity focus on elements within each of these levels of organization that are of current conservation concern. The other findings are not limited to elements of conservation concern. All of the supporting information provided for each major finding is referenced in corresponding parts of Sections 1 to 3.

4.3 The Major Findings

ECOSYSTEM DIVERSITY

Ecosystems are made up of plants, animals and microorganisms, all interacting with the abiotic environment and integrated by ecological processes that play a critical role in shaping them. Ecosystems that maintain all of their component parts and processes are the most resilient.

Ecosystems can be described and assessed at a range of scales. The broadest scale used in this report is land cover, which classifies areas (excluding human-dominated and water) as forest, alpine, glacier, wetland and grassland. The primary scale used in this report is biogeoclimatic zones, which are broad geographic areas sharing similar climate and vegetation. Within B.C. there are 16 biogeoclimatic zones: 12 forested (Coastal Western Hemlock, Coastal Douglas-fir, Spruce–Willow–Birch, Boreal White and Black Spruce, Sub-Boreal Pine–Spruce, Sub-Boreal Spruce, Mountain Hemlock, Engelmann Spruce–Subalpine Fir, Montane Spruce, Interior Cedar–Hemlock, Interior Douglas-fir and Ponderosa Pine[a]); three alpine (Boreal Altai Fescue Alpine, Coastal Mountain-heather Alpine and Interior Mountain-heather Alpine); and one grassland (Bunchgrass). Major Drainage Areas were used as the basis for additional broad-scale analysis focusing on freshwater ecosystems.

The finest scale used in this report is ecological communities, of which 611 have been described in the province to date. Ecological community classification is incomplete for some biogeoclimatic zones, most notably the alpine zones, but the current list represents a majority of the province's ecological communities.

Freshwater and terrestrial ecosystems overlap with the marine realm in estuaries and intertidal areas.

1. **At the broad scale, four biogeoclimatic zones, representing approximately 5% of British Columbia's land base, are of provincial conservation concern.**

B.C.'s three dry-forest biogeoclimatic zones (Coastal Douglas-fir, Interior Douglas-fir and Ponderosa Pine) and one grassland zone (Bunchgrass) have been assessed as being of conservation concern. Nine of the province's forested zones and the three alpine zones are not currently assessed as being of conservation concern. The alpine zones are expected to change dramatically in response to climate change and, in many places, will disappear entirely, along with the species that presently inhabit them.

[a] The Ponderosa Pine biogeoclimatic zone consists of a mix of forest and grassland, but is generally dominated by trees.

2. **At the fine scale, more than half of the ecological communities described in British Columbia are of provincial conservation concern.**

Ecological communities of conservation concern are found in every one of the province's biogeoclimatic zones. The Coastal Western Hemlock zone has the greatest number of communities of concern. The highest percentages of communities of concern occur in the four biogeoclimatic zones of conservation concern and in the Coastal Western Hemlock zone.

3. **British Columbia has a majority of the global range for six of the 16 biogeoclimatic zones that occur in the province.**

Two of B.C.'s biogeoclimatic zones – the Sub-boreal Pine–Spruce and the Sub-boreal Spruce – occur nowhere else in the world. The other four zones that have more than half of their global range in B.C. are the Coastal Douglas-fir, Interior Cedar–Hemlock, Montane Spruce and Mountain Hemlock. Five of these zones are relatively intact; the exception is the Coastal Douglas-fir zone.

4. **The Coastal Douglas-fir biogeoclimatic zone is the rarest biogeoclimatic zone in British Columbia and is of great conservation concern.**

The Coastal Douglas-fir zone has the highest density of species that are of both provincial and global conservation concern of any B.C. biogeoclimatic zone. It also has the highest proportion of areas covered by roads or other linear development and has experienced the highest level of ecosystem conversion. Within this zone, almost all of the forests have been logged since European contact, only about 10% of the Garry oak meadows remain and wetlands are under severe pressure.

5. **Low-elevation grassland communities are the rarest land cover type in British Columbia and are concentrated in the biogeoclimatic zones of conservation concern.**

Grasslands occupy less than 1% of the provincial land base, but are home to a disproportionate number of species of conservation concern. They are located primarily in the Bunchgrass, Ponderosa Pine and Interior Douglas-fir biogeoclimatic zones. A large percentage of the grasslands in these biogeoclimatic zones have been lost due to ecosystem conversion and fire suppression, are being degraded by motorized recreation and livestock grazing, and are being impacted by alien species. In the north, grasslands occur at low elevations in the Boreal White and Black Spruce zone, on warm, dry, south-facing slopes. These already-rare grasslands are becoming rarer due to climate change, as warmer, wetter conditions result in encroachment by woody plants.

6. Significant areas of wetlands in British Columbia have been converted or degraded, particularly in the two Major Drainage Areas of greatest conservation concern.

Wetlands are among the most biologically diverse and productive of all ecosystems. They provide habitat for many species and fulfill a broad range of ecological functions. Although they cover only a small area of the provincial land base, their contribution to biodiversity conservation is greatly disproportionate to their size. B.C. has nine Major Drainage Areas, and wetlands are particularly impacted in the two that are of greatest conservation concern – those of the Columbia and Fraser rivers. The Fraser River alone drains roughly one-quarter of the province. In the Lower Fraser Valley, which extends from the Strait of Georgia inland to Hope and from the north shore mountains to the U.S. border, more than half of the original wetland area has disappeared. In the south Okanagan, which is part of the Columbia River drainage, about 85% of the original wetland area has disappeared.

PHOTO: MAX LINDENTHALER.

7. Estuaries are of concern in British Columbia because of their rarity and the level of human impacts to them.

Estuaries occur where freshwater systems meet the sea. Even though they account for less than 3% of the province's coastline, an estimated 80% of all coastal wildlife relies on estuary habitat. The Fraser River estuary is one of B.C.'s most important areas for seasonal concentrations of birds. Estuaries have experienced significant degradation as a result of human activities and are highly vulnerable to projected sea-level rise due to climate change.

DIVERSITY OF SPECIES

Species are genetically distinct groups of organisms that are capable of successfully interbreeding. Species interact within ecosystems, performing essential ecological functions. Only about 3,800 species have been assessed to date in British Columbia, but the actual number of species in the province may well exceed 50,000 (not including single-celled organisms). Some parts of the province (primarily unroaded and unsettled areas) have not been surveyed and some taxonomic groups remain largely unstudied. The highest species richness documented in B.C. occurs in the areas with the largest human populations.

PHOTO: JASON DOUCETTE.

8. Of the species assessed to date in British Columbia, 43% are of provincial conservation concern and these are concentrated in the four biogeoclimatic zones of conservation concern.

The number of species of provincial conservation concern is increasing as more species are assessed and as populations of previously secure species decline. Species currently known to be of provincial conservation concern include a high proportion of mosses, reptiles and turtles, and ferns and fern allies. There is a generally declining trend in provincial conservation status for three of the best-studied taxonomic groups: vascular plants of highest conservation concern, mammals and freshwater fish. A disproportionate number of B.C.'s species of conservation concern are concentrated in southern, low-elevation areas. Six percent of the species assessed to date in B.C. are also of global conservation concern.

9. British Columbia is known to have a majority of the global range for 99 species.

Of the species assessed to date, 3% have a majority of their global range in B.C. Of the 99 species that have a majority of their global range in B.C., 15 are found nowhere else and 30 are of global conservation concern. Most of B.C.'s species of conservation concern are shared with other jurisdictions.

GENETIC DIVERSITY

Genetic variation within species facilitates adaptation to changing environments, and B.C. has a disproportionately high level of genetic diversity relative to its species diversity. The province's glacial history and varied climate and topography (including many coastal islands) have fostered the evolution of local adaptations by creating unique local conditions and reducing dispersal between populations. As a result, many species occur in the province as complexes of geographically distinct subspecies, which differ from each other in appearance, environmental tolerances and/or behaviour, as well as in genetic make-up.

Due to B.C.'s large size and biophysical variability, the province is home to many species that are at the edge of their range. Such populations are often genetically distinct from populations at the core of a species' range. B.C. also has a high density of hybrid zones, where divergent groups overlap and some species hybridize as a result of landscape change and historic expansion and contraction of species ranges. These hybrid zones contribute to genetic diversity in both terrestrial and freshwater ecosystems in B.C.

10. British Columbia has a high level of genetic diversity within species, which is critical for adaptation and resilience.

Currently, 457 subspecies, ecotypes, populations and varieties of plants and animals are identified as being of provincial conservation concern in B.C. and 38 of these are found nowhere else. Genetic diversity within species is critical for their persistence in changing environments. For example, there are more than 400 genetically distinct populations among five species of Pacific salmon. This variability has allowed these species to use all available stream systems in B.C. and provides resilience to salmon and the functions they perform.

KEY AND SPECIAL ELEMENTS OF BIODIVERSITY

Key elements are pieces of the biodiversity puzzle that are essential and/or have a disproportionate influence on ecosystem function. They may be components, structures or functions. Special elements are components of biodiversity that are uncommon and, in some cases, found nowhere else. They include seasonal concentrations of species, special communities and noteworthy features.

11. The flow of water in lakes, streams, wetlands and groundwater systems is being seriously impacted in British Columbia by dams, water diversions, logging, stream crossings and climate change.

Dams and water diversions directly affect lakeshore, streamside and aquatic ecosystems and the organisms that live in them. The disruption of connectivity in stream systems can prevent fish passage and the flow of nutrients and sediments. Groundwater–surface water interactions determine the minimum flow for many streams in winter, when surface water is locked up as snow and ice, and during periods when there is no precipitation. Climate change is already having noticeable effects on streamflow patterns in some areas of B.C., and projected changes associated with warmer temperatures will likely affect all freshwater systems within the province.

12. The natural disturbance processes that shape British Columbia's forests are being disrupted by human activities.

Forests are the dominant land cover type in B.C. The province's forested ecosystems have been shaped by topography and climate, as well as by natural disturbance regimes (which are themselves influenced by topography and climate). The landscape structure of forested ecosystems is influenced by the timing, frequency, magnitude and severity of disturbances, and by the prevailing type of disturbance (e.g., stand-replacing fires versus single-tree-replacing dynamics). Human activities can change all of these key factors. In B.C.'s temperate rainforests, logging of old-growth stands is the greatest concern. In the province's other forests, the major concerns are fire suppression, logging and monoculture replanting. In addition to disrupting natural disturbance processes, these human activities also have other impacts on biodiversity, such as effects on soils, hydrology and individual species. Climate change has already begun to exacerbate these impacts (most notably with the rapid expansion and intensification of the current mountain pine beetle outbreak owing in large part to the warming of winter minimum temperatures) and will continue to do so.

13. British Columbia's mainland coast features a number of interconnected key and special elements of biodiversity: intact temperate rainforest, an intact large mammal predator-prey system, glacially influenced streams and salmon-driven nutrient cycling.

British Columbia has approximately one-fifth of the world's remaining temperate rainforest, with the majority of the province's undeveloped rainforest located along the middle and northern sections of the mainland coast. The mainland coast is also the largest contiguous area in the province with intact large mammal predator-prey systems (i.e., all native large mammals are present), which are vital elements in many natural communities. Anadromous salmon play a critical role in nutrient cycling throughout their B.C. range, but this process is especially important on the mainland coast, because of the overlap with the three other special elements. Salmon integrate the terrestrial, freshwater and marine realms by serving as a key food source for many predators and scavengers and providing important nutrients to aquatic and terrestrial ecosystems. They are susceptible to cumulative impacts occurring across all three realms and impacts resulting from climate change are of particular concern. One way that climate change is expected to affect salmon is through impacts on glacier-fed streams. In the short term, melting glaciers will likely discharge more water into some B.C. streams and rivers, which may damage salmon habitat. In the longer term, salmon may be affected by reduced water volume, and possibly temperature change, in glacier-fed streams and rivers, especially during the summer months.

14. The majority of British Columbia has intact or relatively intact predator-prey systems, but a major threat to them is motorized access and associated human activities.

B.C. is globally significant for its richness of large carnivore and ungulate species and the fact that most of the province has intact, or mostly intact, large mammal predator-prey systems, which provide critical ecosystem services. Large mammal predator-prey systems are directly impacted by the disturbance and fragmentation associated with motorized access, including access for off-road vehicles. Roads fragment populations, reduce gene flow and provide access that can result in increased direct mortality due to hunting, poaching, motor vehicle collisions and wildlife-human conflicts. Motorized access also causes disturbance, which displaces species from their habitats.

15. British Columbia has many significant seasonal concentrations of species that are vulnerable to human impacts.

Seasonal concentrations of species are vulnerable to human and non-human impacts. In B.C., seasonal concentrations often involve migratory species, including birds travelling along the Pacific Flyway and salmon migrating through coastal marine waters. Migratory species are affected by conditions throughout their range and B.C. has a responsibility for species that migrate through the province. Many estuaries along the B.C. coast and wetlands in the interior provide critical habitat for seasonal concentrations of migrating shorebirds, waterfowl and other birds. Other seasonal concentrations of species include seabird nesting colonies on coastal islands and pre-nesting or wintering aggregations. Island seabird populations are particularly threatened by alien species.

PHOTO: LAUREN NICHOLL.

THREATS TO BIODIVERSITY

The most significant stresses on biodiversity in B.C. are ecosystem conversion (the direct and complete conversion of natural ecosystems to landscapes for human uses), ecosystem degradation (change to the structure of a natural system, which impacts the ecosystem's composition and function) and alien species (species that occur outside their native range due to human introduction), followed by environmental contamination, species disturbance and species mortality.

The most significant categories of human activity that impact biodiversity in B.C. are climate change and specific practices associated with agriculture, recreation, urban and rural development, forestry, transportation and utility corridors, oil and gas development and water development. Specific practices associated with grazing, industrial development, mining and aquaculture also have important impacts on biodiversity in the province. Note that it is not these economic sectors, but some specific practices undertaken by people involved in the sectors, that impact biodiversity.

Although these factors may operate separately, losses to biodiversity generally originate from more than one source. Multiple impacts can affect biodiversity at a magnitude greater than the sum of the individual impacts, can be cumulative over time and can trigger cascading impacts on other components of biodiversity.

16. Ecosystem conversion from urban/rural development and agriculture has seriously impacted British Columbia's biodiversity, especially in the three rarest biogeoclimatic zones.

Although only about 2% of the province's land base has been converted to human uses, the magnitude of conversion is dramatically higher in the three rarest biogeoclimatic zones: Coastal Douglas-fir, Bunchgrass and Ponderosa Pine. Ecosystem conversion related to agriculture is most intensive in areas with rich soil, such as floodplains and valley bottoms. Urban and rural development is concentrated in these same areas, particularly in the lower Fraser River Valley, on southeastern Vancouver Island and in the Okanagan. The most immediate impact of urban and rural development is the conversion of natural landscapes to buildings, parking lots and playing fields, resulting in loss of species and ecosystems, along with impairment of ecosystem functions.

17. Ecosystem degradation from forestry, oil and gas development, and transportation and utility corridors has seriously impacted British Columbia's biodiversity.

Forestry-related activities affect species and ecosystems in various ways, including habitat fragmentation, simplification of forest communities, alteration of age-class distribution, tree species distribution and stand structure, and loss of key habitat elements such as wildlife trees and coarse woody debris. Ecosystem degradation associated with terrestrial oil and gas exploration and extraction is mainly concentrated in the Boreal White and Black Spruce biogeoclimatic zone in the northeast corner of the province. Ecosystem degradation associated with transportation corridors, seismic lines and other linear features includes fragmentation, alteration of the hydrology of water courses and increased sedimentation in water bodies. Areas of the province with high densities of transportation and utility corridors include the Coastal Douglas-fir, Ponderosa Pine, Bunchgrass and Interior Douglas-fir zones.

18. Alien species are seriously impacting British Columbia's biodiversity, especially on islands and in lakes.

Alien species can have many impacts, including alteration of forest fire cycles, nutrient cycling and hydrology, displacement of populations of native plants and animals, competition for resources, predation, disease introduction, and facilitation of the spread of other non-native species. Climate change and ecosystem conversion and degradation facilitate the invasion of alien species. Although alien species invasion is often a secondary impact, it can be a major independent impact in isolated systems, such as islands and lakes, which often have significant genetic and species-level diversity.

19. Climate change is already seriously impacting British Columbia and is the foremost threat to biodiversity.

The impacts of climate change on biodiversity in B.C. are predicted to be both extensive and intensive, and will be exacerbated by non-climate factors related to human activity, such as land-use changes, pollution and resource use. Although measured trends and observed responses clearly indicate that climate change is underway, the full extent of its impact is yet to be felt. It is expected to be the greatest overriding threat to biodiversity in the future. Some species will be lost, while the ranges of others will change. B.C.'s proportion of the global range of many species may increase due to northward shifts in distributions resulting from climate change; this is already occurring for some species. This trend may be accentuated by the tendency for species to collapse to the edge of their distributions. All of B.C.'s biogeoclimatic zones will be either changed or eliminated as a result of climate change.

PHOTO: DAVE LEWIS.

20. The cumulative impacts of human activities in British Columbia are increasing and are resulting in the loss of ecosystem resilience.

The cumulative impacts of human activities are greater than the sum of their individual effects. Compromised ecosystems and populations are more vulnerable to impacts than those that are pristine. For example, it is expected that climate change will have its greatest impact in areas where biodiversity has been already affected by other stresses. The density of roads and other linear development features in an area is the single best index of the cumulative impact of human activities on biodiversity. In B.C., the highest densities of roads are found in the four biogeoclimatic zones of highest conservation concern: Coastal Douglas-fir, Ponderosa Pine, Bunchgrass and Interior Douglas-fir.

21. Connectivity of ecosystems in British Columbia is being lost and, among other impacts, this will limit the ability of species to shift their distributions in response to climate change.

The degree of connectivity and the characteristics of linkages in natural landscapes vary, depending on topography, hydrology and natural disturbance regime. Human activities reduce connectivity and cause fragmentation through ecosystem conversion and degradation, disturbance, spread of alien species, direct mortality and environmental contamination. Linear features such as roads, hydro transmission corridors, seismic lines, pipelines and railways impact biodiversity in numerous ways, but particularly affect connectivity when they are built along valley bottoms, and when they cross streams, preventing the movement of terrestrial and aquatic

PHOTO: ISTOCK.

organisms. Besides limiting the ability of species to shift their distributions in response to climate change or habitat change, loss of connectivity also makes populations more vulnerable to extirpation as a result of chance events or the damaging effects of genetic drift and inbreeding.

KNOWLEDGE AND CAPACITY

There is a substantial and ever-growing body of knowledge about biodiversity in British Columbia, which includes scientific publications, species checklists, computer databases and individual expertise. However, there is also much that is not known. Capacity refers to the ability to fill the many knowledge gaps and integrate new and existing information.

22. Gaps in our knowledge of biodiversity in British Columbia create major challenges for effective conservation action.

Every species contributes, though not equally, to ecosystem function and resilience. However, approximately 92% of B.C.'s species (not including single-celled organisms) have not been assessed for their conservation status and the global ranks for many species that have been assessed are out of date. The ecology of most species and the distributions of all but a very few are poorly understood. Coarse-scale ecosystem classifications are complete in B.C., but information at a finer ecosystem scale is incomplete, as is ecosystem information from neighbouring jurisdictions. Trend monitoring is extremely limited and data on distribution and population size are lacking for many species. Information about impacts on biodiversity is generally incomplete or out of date.

23. The capacity to address some of the gaps in our knowledge of biodiversity in British Columbia is being impacted by the loss of already limited taxonomic expertise.

Thousands, if not tens of thousands, of species in B.C. have not been scientifically described or are not documented as being present in the province. Species groups for which such information is particularly lacking include most of the invertebrates and non-vascular plants. This taxonomic knowledge gap is currently being exacerbated by an 'extinction of experience' as the scientists with the knowledge, skills and inclination to do the work required to fill the gaps are retiring and often are not being replaced.

Glossary

Abiotic: non-living chemical and physical factors in the environment, including solar radiation, water, atmospheric gases, soil and physical geography.

Adaptation: any feature of an organism that substantially improves its ability to survive and leave more offspring. Also, the process of a species' or a population's genetic variability changing due to natural selection in a manner that improves its viability.

Adaptive divergence: divergence as a result of adaptive change.

Alien species: a species occurring in an area outside its historically known natural range as a result of intentional or accidental dispersal by humans (i.e., movement of individuals) or direct human activities that remove a natural barrier (e.g., creation of a fish ladder to allow fish to move past a waterfall). Also known as an *exotic* or *introduced* species.

Allele: a form of a gene.

Anadromous: fish species that spawn (breed and lay eggs) in freshwater environments, but spend at least part of their adult life in a marine environment.

Arthropod: invertebrate with external skeleton and jointed segmental appendages.

Benthic: the bottom substrate of an aquatic environment.

Beringia: the entire region between the Kolyma River in eastern Siberia and the Mackenzie River in the Canadian Northwest Territories, including the intervening continental shelf where it is shallower than approximately 200 m.

Biodiversity: the variety of species and ecosystems on earth and the ecological processes of which they are a part, including ecosystem, species and genetic diversity components.

Biofilm: a thin (0.01–2 mm) yet dense surface layer of microbes, organic detritus and sediment in a mucilaginous matrix of extracellular polymeric substances held together with non-carbohydrate components secreted by microphytobenthos and benthic bacteria; found in some intertidal areas.

Biogeoclimatic Ecosystem Classification [BEC]: a multilevel, integrated system of ecological classification utilizing climate, vegetation and soils data to produce a classification of ecosystems.

Biogeoclimatic zone: the broadest classification in the Biogeoclimatic Ecosystem Classification, representing large geographical areas that share similar climate and vegetation.

Biome: a major regional ecosystem, characterized by its distinctive vegetation, a particular plant formation and associated animals, microbes and physical environment (e.g., grasslands, tundra, savannah). A biome is a subdivision of a continent on the basis of major differences in the life form of the vegetation, where life forms reflect the regional climates and soils.

Bivalve: having a shell composed of two parts (valves).

Bryophyte: primitive plant in the plant phylum Bryophyta, lacking a vascular system and typically growing in moist habitats.

Cambium: a layer of actively dividing cells situated between xylem and phloem of a woody plant. As the cells develop, they add a new layer of woody material on the inner side of the root or stem (mainly xylem) and a new layer of bark (phloem and associated tissues) on the outer side.

Census population size: the actual number of individuals in a population.

Climate change: a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended time period (typically decades or longer).

Climate envelope: describes the area of suitable climate for a species or ecosystem in terms of temperature and precipitation. Climate envelope models determine the current distribution of the species or ecosystem, then map the location of this same envelope under a climate change scenario.

Coarse woody debris [CWD]: large pieces of wood, generally greater than 10 cm in diameter, on or near the forest floor, including sound or rotting logs, stumps and large branches that have fallen or been cut. In aquatic environments, this material is called *large woody debris* (LWD) or *large organic debris*.

Community: an integrated group of living organisms inhabiting a given part of an ecosystem.

Composition: the identity and variety of an ecological system. Descriptors of composition are typically lists of species resident in an area or an ecosystem.

Conifer: a cone-bearing tree having needles or scale-like leaves; usually evergreen.

Connectivity: the degree to which the habitat or terrain is linked so as to facilitate the movement of individuals of a species from one place to another.

Conservation concern: globally or provincially critically imperilled (G1 or S1), imperilled (G2 or S2), or vulnerable (G3 or S3). Species of global conservation concern are ranked G1 to G3. Species of provincial conservation concern are ranked S1 to S3.

Conservation status: a measure of the risk of regional extirpation or global extinction for an element of biodiversity, population, subspecies and ecosystem.

Cryptogamic crust: a thin layer of lichens, moss, liverworts, algae, fungi and bacteria found in undisturbed semi-arid ecosystems. Also known as *microbial, microfloral, microphytic* or *cryobiotic crust*.

Cumulative impact: changes to the environment that are caused by a human action in combination with other past, present and future human actions.

Decomposition: the breakdown of dead plant and animal matter, into their inorganic constituents, such as carbon and nitrogen.

Detritivore: an organism that feeds solely on non-living organic material.

Dicot [dicotyledon]: a flowering, vascular plant that has two cotyledons (primary embryonic leaves) in its seed.

Disjunct: disjoined or separated from the normal range.

Dispersal: movement of individual organisms to different localities.

DNA [Deoxyribonucleic Acid]: a long organic molecule composed of nucleotides in a linear order that contributes the genetic information of cells; capable of replicating itself and of synthesizing ribonucleic acid (RNA).

Duff: decaying vegetable matter that covers forest ground.

Ecological community: a recurring plant community with a characteristic range in species composition, specific diagnostic species, and a defined range in habitat conditions and physiognomy or structure.

Ecosystem: is a dynamic complex of plant, animal and microorganism communities and their abiotic environment, all interacting as a functional unit.

Ecosystem conversion: replacement of natural communities with human-dominated systems (e.g., intensive agriculture) or physical works (e.g., mines, urban areas).

Ecosystem degradation: direct change to the structure of natural systems (e.g., through forest harvesting or water diversion).

Ecotype: a distinct entity of an organism that is closely linked (in its characteristics) to the ecological surroundings it inhabits.

Ectomycorrhizal: see Mycorrhizae.

Effective population size [N_e]: a quantity that estimates the number of individuals contributing genes to future generations.

Endemic: found only in a specified geographic region.

Endomycorrhizal: see Mycorrhizae.

Environmental contamination: occurs when substances are released intentionally, accidentally or as a by-product, into natural systems.

Enzyme: a protein molecule produced in living cells that accelerates the rate of reactions without being consumed in that reaction.

Ephemeral: lasting for a brief period of time (e.g., a seasonal pond).

Estuary: a partially enclosed body of coastal water, where salt water is measurably diluted by mixing with river runoff.

Eutrophication: a process by which a water body becomes rich in dissolved nutrients, often leading to algal blooms, low dissolved oxygen and changes in community composition. Occurs naturally, but can be accelerated by human activities that increase nutrient inputs to the water body.

Evolutionarily significant unit: a population within a species that has very different behavioural and phenological traits based on genetic uniqueness.

Extinct: no longer living.

Extirpation: the elimination of a species or subspecies from a specified area, but not from its entire global range.

Fen: a nutrient-medium peatland ecosystem dominated by sedges and brown mosses, where mineral-bearing groundwater is within the rooting zone of plants.

Fire regime: the way in which fire interacts in an environment.

Function[s]: the result of ecological and evolutionary processes (e.g. nutrient cycling is a function that involves processes such as photosynthesis, herbivory, predation and decomposition).

Fungi: single-celled, multinucleate or multicellular organisms that lack chlorophyll and vascular tissues; includes yeasts, moulds, smuts and mushrooms.

Gene: the functional unit of heredity; the part of the DNA molecule that encodes a single enzyme or structural protein unit.

Gene flow: the transfer of genes from one population or locality to another.

Genetic drift: a change in the genetic composition of a population resulting from random events.

Genetic variability: the number and relative abundance of genes within a species or population.

Genotype: genetic basis of a trait in an organism.

Geographically marginal: a species or population that is at the edge of its range. Also known as *peripheral*.

Georgia Basin: the geographical area that encompasses the Straits of Georgia and Juan de Fuca and the land around them (i.e., eastern Vancouver Island, the lower mainland and the Pacific mountain ranges).

Groundwater: water in the soil and underlying geological strata.

Habitat: the natural environment in which an organism normally lives.

Herbivore: an organism that obtains nutrition and energy by eating plants.

Herbivory: plant-feeding.

Holocene: an epoch of the Quaternary period, spanning the interval after the last glaciation, typically from 10,000 years ago to the present.

Hybrid suture zone: geographic zone where hybridization occurs.

Hybridization: crossing of individuals from genetically different strains, populations or species.

Hyphae: fine, threadlike, tubular and often branched filaments of fungal cells that make up the mycelium, or fruiting body, of a fungus.

Hyporheic zone: the saturated sediment zone between groundwater and surface waters.

Impervious surface [impervious area]: an area covered by impenetrable materials such as asphalt, concrete, brick and stone, which seal surfaces, repel water and prevent precipitation and meltwater from infiltrating soils. Impervious areas are usually constructed surfaces (e.g., rooftops, sidewalks, roads, parking lots). Compacted soils can also be highly impervious.

Impoundment: the confinement of water by a dam.

Intertidal: the area between the mean high tide line and the mean low tide line, or zero tide, where the benthic substrate is regularly exposed through tidal action.

Invasive alien species: alien species that threaten biodiversity due to their ability to spread and out-compete or otherwise impact native species.

Invertebrate: an animal without a backbone.

Karst: landscapes derived from soluble bedrock; typically limestone, but also dolomite, marble and gypsum.

Key element: organisms, groups of organisms, and ecological processes known to play essential and/or disproportionately large roles in the functioning of ecosystems.

Keystone species: a species with an effect on its environment and associated species disproportionate to its relative abundance and biomass.

Large woody debris [LWD]: see Coarse woody debris.

Lichen: an organism consisting of an outer fungal body enclosing photosynthetic algae.

Liverwort: any of a class (Hepaticae) of bryophytic plants characterized by a thalloid gametophyte or sometimes an upright leafy gametophyte that resembles a moss.

Macroalgae: macroscopic algae, commonly known as seaweed.

Macrophyte: a large aquatic plant.

Major Drainage Area [MDA]: an area that drains all precipitation received as either runoff or base flow (groundwater sources) into a particular river or set of rivers. Also known as a *drainage basin*, *catchment area* or *watershed*.

Marl: soft calcium carbonate usually mixed with varying amounts of clay and other impurities.

Megafauna: a general term for the large terrestrial vertebrates inhabiting a specified region.

Migration: movement from one place of residence to another on a regular basis.

Mollusc: a taxonomic group of invertebrate organisms that includes clams, mussels, snails and slugs.

Monocot [monocotyledon]: a flowering, vascular plant that has a single cotyledon (primary embryonic leaf) in its seed.

Morphological: relating to the form and structure of living organisms.

Mutation: changes to the DNA sequence of the genetic material of an organism.

Mycorrhizae: mutually beneficial associations between the hyphae of a fungus and the roots of a plant. In ectomycorrhizal associations, the fungus grows on the outer surface of the plant roots. In endomycorrhizal associations, the fungus penetrates the roots.

Native species: a species that naturally occurs in an area as a result of its own movements (unaided by direct human actions allowing it to move past a natural barrier).

Natural disturbance: a natural event that directly alters the structure of ecosystems (e.g., fire, flood, insect outbreak, landslide).

Natural selection: the process by which favorable heritable traits become more common in successive generations of a population of reproducing organisms, and unfavorable heritable traits become less common, due to the differential contribution of offspring to the next generation by various genetic types within populations.

Nematodes: non-segmented roundworms in the phylum Nematoda.

Non-vascular plant: a plant without specialized tissues for conducting water and nutrients.

Nutrient cycling: circulation or exchange of elements, such as nitrogen and carbon dioxide, between non-living and living parts of the environment.

Obligate: restricted to a particular set of environmental conditions, without which an organism cannot survive.

Patch: in landscape ecology, a particular unit with identifiable boundaries that differs from its surroundings in one or more ways.

Pelagic: pertaining to the open ocean.

Peripheral: See Geographically marginal.

Phenotype: physical manifestation of a trait in an organism, determined by genotype and environment.

Phenotypic: relating to phenotype.

Photosynthesis: the conversion of light energy into chemical energy by living organisms.

Pleistocene: the first epoch of the Quaternary period after the Tertiary period and Pliocene epoch and before the Holocene epoch, spanning the interval from 1.7 million years ago to 10,000 years ago.

Pollination: the process in which pollen is transferred from an anther of male plant to a receptive stigma of a female plant.

Population: a group of individuals with common ancestry that are much more likely to mate with one another than with individuals from another such group.

Predator-prey system: a system involving interactions between predators and their prey. An *intact* predator-prey system is one in which all of the native species are present, and with no alien species that plays a role as either predator or prey relative to the others. A *relatively intact* predator-prey system is one that is missing only one species, and with no alien species that plays a role as either predator or prey relative to the others, and where the loss of the species has not substantially altered the importance of predator-prey interactions to the populations of the remaining species.

Primary consumer: an organism that gets its energy from primary producers (e.g., plants, algae).

Primary production: the production of organic compounds from atmospheric or aquatic CO_2, primarily through the process of photosynthesis.

Processes: actions or events that shape ecosystems, such as disturbances, predation and competition.

Refugium [pl. refugia]: an area that remained unchanged while areas surrounding it changed markedly (e.g., an area that remained ice-free while surrounding areas were glaciated).

Relict species: the remnants of a formerly widespread species, typically now found in very restricted or isolated areas.

Riparian: a zone of transition from an aquatic to a terrestrial system, dependent upon surface or subsurface water. Riparian areas may be located adjacent to lakes, estuaries, rivers, or ephemeral, intermittent or perennial streams.

Salmonid: a fish belonging to the family Salmonidae.

Seral stages: in a forestry context, the series of plant community conditions that develop during ecological succession from bare ground (or major disturbances) to the climax stage. Three main stages are typically recognized: early-seral, mid-seral and late-seral.

Special element: elements of biodiversity that are of global significance either because they are important habitat for seasonal concentrations of species or because they are uncommon or even unique on a global scale owing to their unusual ecological characteristics.

Speciation: the formation of new species.

Species: in most living organisms, each species represents a complete, self-generating, unique ensemble of genetic variation, capable of interbreeding and producing fertile offspring.

Species disturbance: the alteration of the behaviour of species due to human activities.

Species mortality: the direct killing of individual orgasms.

Species richness: the number of species within a specified area.

Steppe: vegetation dominated by grasses and occurring where the climate is too dry to support tree growth.

Structure: the physical organization or pattern of a system (e.g., the size and spacing of trees in a landscape).

Subspecies: a geographically defined aggregate of local populations that differs from other such subdivisions of a species; the lowest taxonomic rank given a formal scientific name.

Succession: a series of dynamic, non-seasonal changes in ecosystem structure, function, and species composition in a given area over time.

Taxon [pl. taxa]: any one of the categories used in naming and classifying organisms (e.g., phylum, class, order, family, genus, species, subspecies, variety).

Taxonomic group: a group of organisms at the same level of organization in biological classification.

Topography: the shape of the surface of the earth.

Transpiration: the evaporation of water from the aerial parts of plants, especially the leaves, but also stems, flowers and roots.

Trophic: pertaining to food or eating.

Tundra: a level or rolling treeless plain characteristic of Arctic and subarctic regions; consists of black, mucky soil with a permanently frozen subsoil, and a dominant vegetation of mosses, lichens, herbs and dwarf shrubs. Also, a similar region confined to mountainous areas above timberline.

Ungulate: a hoofed mammal.

Vascular plant: a plant with specialized tissues for conducting water and nutrients.

Vertebrate: an animal with a backbone.

Appendix A.

HISTORIC SPECIES IN B.C.

SPECIES GROUP	SCIENTIFIC NAME	COMMON NAME
Mammals	*Lepus townsendii*	White-tailed jackrabbit
Non-Marine Molluscs	*Deroceras hesperium*	Evening fieldslug
	Fisherola nuttalli	Shortface lanx
	Fluminicola fuscus	Ashy pebblesnail
	Fossaria vancouverensis	[no common name]
	Musculium partumeium	Swamp fingernailclam
	Planorbella columbiensis	Caribou rams-horn
	Sphaerium occidentale	Herrington fingernailclam
	Valvata humeralis	Glossy valvata
	Valvata tricarinata	Threeridge valvata
	Vertigo elatior	Tapered vertigo
Vascular Plants	*Atriplex alaskensis*	Alaskan orache
	Epilobium pygmaeum	Smooth spike-primrose
	Ericameria bloomeri	Rabbitbrush goldenweed
	Eriogonum pauciflorum	Small-flower wild buckwheat
	Gilia sinuata	Shy gilia
	Leucanthemum arcticum	Arctic daisy
	Parrya nudicaulis	Northern parrya
	Pleuricospora fimbriolata	Fringed pinesap
	Prenanthes racemosa	Glaucous rattlesnake-root
	Ranunculus lobbii	Lobb's water-buttercup
	Senecio hydrophilus	Alkali-marsh butterweed
	Polypodium sibiricum	Siberian polypody
	Elymus virginicus	Virginia wild rye
	Piptatherum canadense	Canada ryegrass
	Poa laxa	Mt. Washington bluegrass
	Poa nervosa	Coastal bluegrass
Non-vascular Plants	*Bryum tenuisetum*	[no common name]

SOURCE: Prepared for this report with data from the B.C. Conservation Data Centre.
NOTE: Historic species are those for which there is no verified record of their presence in B.C. in the past 40 years. They are possibly extinct or extirpated.

APPENDIX B.

MAJOR TAXA OF EXTANT, NATIVE, FREE-LIVING TERRESTRIAL AND FRESHWATER ORGANISMS IN B.C., WITH TABULAR SUMMARY OF THE AVAILABILITY OF UP-TO-DATE SPECIES CHECKLISTS, HANDBOOKS OR SYSTEMATIC MONOGRAPHS, COMPUTERIZED GEO-REFERENCED DISTRIBUTIONAL DATABASES, AND LOCAL (BRITISH COLUMBIA) TAXONOMIC/SYSTEMATIC EXPERTISE.

TAXA	COMMON NAME	UP-TO-DATE CHECKLIST OF SPECIES	HANDBOOK OR SYSTEMATIC MONOGRAPH	COMPUTERIZED GEO-REFERENCED DISTRIBUTIONAL DATABASE	LOCAL TAXONOMIC/ SYSTEMATIC EXPERTISE
Superkingdom PROKARYA	prokaryotes				
Kingdom BACTERIA	bacteria, blue-green algae	blue-green bacteria (Cyanobacteria) only			
Superkingdom EUKARYA	eukaryotes				
Kingdom PROTOCTISTA	protozoans, diatoms, algae, slime molds	green algae (Chlorophyta) only			
Kingdom ANIMALIA	animals				
Phylum PORIFERA	sponges	x			
Phylum CNIDARIA	hydras	x			
Phylum PLATYHELMINTHES	flatworms	x			
Phylum NEMERTINA	ribbon worms				
Phylum NEMATODA	roundworms				
Phylum NEMATOMORPHA	horsehair worms				
Phylum ROTIFERA	rotifers				
Phylum GASTROTRICHA	gastrotrichs				
Phylum CHELICERATA					
Class ARACHNIDA					
Order SOLPUGIDA	sun spiders	x		x	
Order SCORPIONIDA	scorpions	x		x	x
Order ARANEAE	spiders	x	part	part	x
Order PSEUDOSCORPIONIDA	pseudoscorpions				
Order OPILIONES	harvestmen				
Subclass ACARI	mites, ticks	part			
Phylum MANDIBULATA					
Subphylum MYRIAPODA					

CONTINUED ON PAGE 233

APPENDIX B. CONTINUED

TAXA	COMMON NAME	UP-TO-DATE CHECKLIST OF SPECIES	HANDBOOK OR SYSTEMATIC MONOGRAPH	COMPUTERIZED GEO-REFERENCED DISTRIBUTIONAL DATABASE	LOCAL TAXONOMIC/ SYSTEMATIC EXPERTISE
Class DIPLOPODA	millipedes	x			
Class CHILOPODA	centipedes				
Class PAUROPODA	pauropods	x			
Class SYMPHYLA	symphylans	x			
Subphylum HEXAPODA					
Class PROTURA	proturans	x			
Class COLLEMBOLA	springtails				x
Class DIPLURA	diplurans				
Class INSECTA	insects				
Order MICROCORYPHIA	bristletails				
Order EPHEMEROPTERA	mayflies	x			x
Order ODONATA	dragonflies, damselflies	x	x	x	x
Order PLECOPTERA	stoneflies	x	x	x	
Order MANTODEA	mantids	x	x	x	x
Order NOTOPTERA	grylloblattids	x	x	x	
Order ORTHOPTERA	grasshoppers & allies	x	x		
Order PSOCOPTERA	book & bark lice	x	x		
Order HEMIPTERA	true bugs	x	part	Heteroptera only	x
Order THYSANOPTERA	thrips	x			
Order MEGALOPTERA	alder & dobson flies	x		x	
Order RAPHIDIOPTERA	snakeflies	x	x	x	
Order NEUROPTERA	lacewing & allies	x	x	x	
Order COLEOPTERA	beetles	x	part	Carabidae only	Carabidae and aquatics only
Order MECOPTERA	scorpionflies	x	x		x
Order DIPTERA	true flies	a few families	part		Asilidae, Ceratopogonidae, Chaoboridae, Culicidae, Dixidae only

CONTINUED ON PAGE 234

APPENDIX B. CONTINUED

TAXA	COMMON NAME	UP-TO-DATE CHECKLIST OF SPECIES	HANDBOOK OR SYSTEMATIC MONOGRAPH	COMPUTERIZED GEO-REFERENCED DISTRIBUTIONAL DATABASE	LOCAL TAXONOMIC/ SYSTEMATIC EXPERTISE
Order LEPIDOPTERA	butterflies & moths	x	butterflies only	butterflies only	x
Order TRICHOPTERA	caddisflies	x			
Order HYMENOPTERA	bees, wasps, ants & allies	a few families	ants only		ants only
Phylum CRUSTACEA					
Class BRANCHIOPODA	fairy shrimps & water fleas	part			Cladocera only
Class OSTRACODA	seed shrimps	x			
Class COPEPODA	copepods	part	part	diaptomids only	
Class MALACOSTRACA					
Order AMPHIPODA	scuds	x			
Order ISOPODA	isopods				
Order DECAPODA	crayfish	x			
Phylum ANNELIDA	annelid worms				
Class POLYCHAETA	polychaete worms				
Class OLIGOCHAETA	earth worms	x			
Class HIRUDINEA	leeches	x			
Phylum MOLLUSCA	molluscs				
Class BIVALVIA	clams	x			
Class GASTROPODA	snails, slugs	part	part		
Phylum TARDIGRADA	water bears				
Phylum BRYOZOA	moss animals				
Phylum CRANIATA	vertebrates				
Class CYCLOSTOMATA	lamprey	x	x	x	x
Class OSTEICHTHYES	bony fishes	x	x	x	x
Class AMPHIBIA	amphibians	x	x	x	x
Class REPTILIA	reptiles	x	x	x	x
Class AVES	birds	x	x	passerines only	x
Class MAMMALIA	mammals	x	x	x	x
Kingdom FUNGI	fungi				

CONTINUED ON PAGE 235

APPENDIX B. CONTINUED

TAXA	COMMON NAME	UP-TO-DATE CHECKLIST OF SPECIES	HANDBOOK OR SYSTEMATIC MONOGRAPH	COMPUTERIZED GEO-REFERENCED DISTRIBUTIONAL DATABASE	LOCAL TAXONOMIC/ SYSTEMATIC EXPERTISE
Phylum ZYGOMYCOTA	zygomycetes				
Phylum BASIDIOMYCOTA	smuts, rusts, jelly fungi, mushrooms, etc. (basidiomycetes)	part		part	part
Phylum ASCOMYCOTA	yeasts, truffles, lichens (ascomycetes)	part	lichens only	part	x
Kingdom PLANTAE	plants				
Phylum BRYOPHYTA	mosses	x	x	part	x
Phylum HEPATOPHYTA	liverworts	x		part	x
Phylum ANTHOCEROPHYTA	hornworts	x			
Phylum LYCOPHYTA * (= LYCOPODIOPHYTA)	club mosses	x	x	x	x
Phylum SPHENOPHYTA * (= EQUISETOPHYTA)	horsetails	x	x	x	x
Phylum FILICINOPHYTA * (= PTERIDOPHYTA)	ferns	x	x	x	
Phylum CONIFEROPHYTA *	conifers (gymnosperms)	x	x	x	x
Phylum ANTHOPHYTA * (ANGIOSPERMOPHYTA)	flowering plants (angiosperms)	x	x	x	x

SOURCE: Prepared for this report.
NOTES: Major classification follows Margulis, L. and K.V. Schwartz. 1998. Five Kingdoms. An Illustrated Guide to the Phyla of Life on Earth. Third Edition. W.H. Freeman and Co., New York, NY. 520pp. The classification is detailed in some phyla to show the differing extent of knowledge in the larger taxa. Non-vascular plant phyla are marked with an asterisk (*).

Notes

1 Canadian Endangered Species Conservation Council. 2006. Wild Species 2005: The General Status of Species in Canada. Minister of Public Works and Government Services Canada, Ottawa, ON.

2 B.C. Ministry of Environment, Lands and Parks. 2000. Mountain Goat in British Columbia: Ecology, Conservation and Management. 6pp. Available at: www.env.gov.bc.ca/wld/documents/mtngoat.pdf.

3 Mountain Caribou Technical Advisory Committee. 2002. A Strategy for the Recovery of Mountain Caribou in British Columbia. B.C. Ministry of Water, Land and Air Protection, Victoria, BC. 73pp. Available at: wlapwww.gov.bc.ca/wld/documents/mtcaribou_rcvrystrat02.pdf.

4 Hatfield, T. 1999. Stickleback Species Pairs. B.C. Ministry of Environment, Lands and Parks, Conservation Data Centre, Victoria, BC. Wildlife at Risk brochure. 6pp.

5 Molnar, J., M. Marvier and P. Kareiva. 2004. The sum is greater than the parts. Conservation Biology 18: 1670-1671.

6 Environment Canada. 2005. Canadian Biodiversity Strategy: Canada's Response to the Convention on Biological Diversity. Biodiversity Convention Office, Hull, PQ. 85pp. Available at: www.cbin.ec.gc.ca/strategy/default.cfm?lang=e.

7 Vold, T. 2008. Ecological Concepts, Principles and Application to Conservation. Biodiversity BC, Victoria, BC. 24pp. Available at: www.biodiversitybc.org.

8 See endnote 5.

9 Peterson, G., C.R. Allen and C.S. Holling. 1998. Ecological resilience, biodiversity and scale. Ecosystems 1: 6-18.

10 See endnote 7.

11 World Resources Institute. 2003. Ecosystems and Human Well-Being: A Framework For Assessment. Millennium Ecosystem Assessment and Island Press, Washington, DC. 212pp. Available at: www.millenniumassessment.org/en/Framework.aspx.

12 Hilborn, R., T.P. Quinn, D.E. Schindler and D.E. Rogers. 2003. Biocomplexity and fisheries sustainability. Proceedings of the National Academy of Sciences 100(11): 6564-6568.

13 Haas, G.R. 2001. The evolution through natural hybridization of the Umatilla dace (Pisces: *Rhinichthys umatilla*), and their associated ecology and systematics. PhD thesis, University of British Columbia, Vancouver, BC.

14 Rieseberg, L.H. and J.H. Willis. 2007. Plant speciation. Science 317: 910-914.

15 Carroll, A.L., J. Régnière, J.A. Logan, S.W. Taylor, B.J. Bentz and J.A. Powell. 2006. Impacts of climate change on range expansion by the mountain pine beetle. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Initiative Working Paper 2006-14.

16 Rooney, T.P. 2001. Deer impacts on forest ecosystems: a North American perspective. Forestry 74: 201-208.

17 McShea, W.J. and J.H. Rappole. 1992. White-tailed deer as keystone species within forested habitats in Virginia. Virginia Journal of Science 43: 177-186.

18 McShea, W.J. and J.H. Rappole. 1997. Herbivores and the ecology of forest understory birds. Pp. 398-309 *in* W.J. McShea, H.B. Underwood and J.H. Rappole (eds.). Smithsonian Press, Washington, DC. 402pp.

19 D. Fraser, B.C. Ministry of Forests and Range, ppersonal communication.

20 Daily, G. (ed.). 1997. Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington, DC. 412pp.

21 Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. O'Neill, J. Paruelo, R.G. Raskin, P. Sutton and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature 387: 253-260.

22 Hågvar, S. 1998. Nature as an arena for the quality of life: psycho-spiritual values – the next main focus in nature conservation? The Environmentalist 19: 163-169.

23 Gobster, P.H. and R.B. Hull (eds.). 2000. Restoring Nature: Perspectives from the Social Sciences and Humanities. Island Press, Washington, DC. 322pp.

24 Garibaldi, A. and N. Turner. 2004. Cultural keystone species: implications for ecological conservation and restoration. Ecology and Society 9(3): 1-18. Available at: www.ecologyandsociety.org/vol9/iss3/art1.

25 Hennon, P.E., D.V. D'Amore, S. Zeglen and M. Grainger. 2005. Yellow-cedar decline in the North Coast Forest District of British Columbia. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Juneau, AK. Research Note PNW-RN-549. 16pp.

26 Hebda, R.J. 2006. Silviculture and climate change. Canadian Silviculture November 2006: 6-8.

27 Buchmann, S.L. and G.P. Nabhan. 1996. The Forgotten Pollinators. Island Press, Washington, DC. 292pp.

28 United Nations. 1997. United Nations Conference on Environment and Development (1992). U.N. Department of Public Information. Available at: www.un.org/geninfo/bp/enviro.html.

29 Environment Canada. no date. Canadian Biodiversity Information Network. Available at: www.cbin.ec.gc.ca/strategy/prov.cfm?lang=e.

30 Turner, N.J., H.V. Kuhnlein and K.N. Egger. 1985. The cottonwood mushroom (*Tricholoma populinum* Lange): a food resource of the Interior Salish Indian Peoples of British Columbia. Canadian Journal of Botany 65: 921-927.

31 Turner, N.J. and A. Davis. 1993. "When everything was scarce": the role of plants as famine foods in northwestern North America. Journal of Ethnobiology 13(2): 1-28.

32 Turner, N.J. 1995. Food Plants of Coastal First Peoples. Royal British Columbia Museum, Victoria, BC and UBC Press, Vancouver, BC. 164pp.

33 Turner, N.J. 2006. Food Plants of Interior First Peoples. Royal British Columbia Museum, Victoria, BC. 228pp.

34 Turner, N.J. 1998. Plant Technology of British Columbia First Peoples. UBC Press, Vancouver, BC and Royal British Columbia Museum, Victoria, BC. 255pp.

35 Hunn, E.S., N.J. Turner and D.H. French. 1998. Ethnobiology and subsistence. Pp. 525-545 *in* D.E. Walker (ed.). Plateau, Vol. 12, Handbook of North American Indians. Smithsonian Institution, Washington, DC. 808pp.
36 Alestine, A., A. Karst and N.J. Turner. 2006. Arctic and subarctic plants. Pp. 222-235 *in* D.H. Ubelaker, D. Stanford, B. Smith and E.J.E. Szathmary (eds.). Environment, Origins and Population, Vol. 3, Handbook of North American Indians. Smithsonian Institution, Washington, DC. 1160pp.
37 Turner, N.J. and F.H. Chambers. 2006. Northwest coast and plateau plants. Pp. 251-262 *in* D.H. Ubelaker, D. Stanford, B. Smith and E.J.E. Szathmary (eds.). Environment, Origins and Population, Vol. 3, Handbook of North American Indians. Smithsonian Institution, Washington, DC. 1160pp.
38 Turner, N.J. 1988. "The importance of a rose": evaluating the cultural significance of plants in Thompson and Lillooet Interior Salish. American Anthropologist 90(2): 272-290.
39 Turner, N.J. 2005. The Earth's Blanket: Traditional Teachings for Sustainable Living. Douglas and McIntyre, Vancouver, BC and University of Washington Press, Seattle, WA. 298pp.
40 See endnote 24.
41 Holm, B. 1965. Northwest Coast Indian Art: An Analysis of Form. University of Washington Press, Seattle, WA.
42 Holm, B. 1990. Art. Pp. 602-632 *in* W. Suttles (ed.). Northwest Coast, Vol. 7, Handbook of North American Indians. Smithsonian Institution, Washington, DC.
43 MacDonald, G.F. 1996. Haida Art. Douglas and McIntyre, Vancouver, BC and Canadian Museum of Civilization, Hull, PQ. 242pp.
44 Turner, N.J. 1997. "Le fruit de l'ours": les rapports entre les plantes et les animaux dans les langues et les cultures amérindiennes de la Côte-Ouest. Pp. 31-48 *in* P. Beaucage (ed.). Recherches Amérindiennes au Québec 27 (3-4). Special Edition on Des Plantes et des Animaux: Visions et Pratiques Autochtones. Université de Montréal, Montreal, PQ.
45 See endnote 24.
46 D. Hay, Fisheries and Oceans Canada (Retired), personal communication.
47 Turner, N.J., L.C. Thompson, M.T. Thompson and A.Z. York. 1990. Thompson Ethnobotany: Knowledge and Usage of Plants by the Thompson Indians of British Columbia. Royal British Columbia Museum. Memoir No. 3. 335pp.
48 Turner, N.J. 2001. "Doing it right": issues and practices of sustainable harvesting. BC Journal of Ecosystems and Management 1(1). Available at: www.forrex.org/publications/jem/.
49 See endnote 39.
50 Deur, D. and N.J. Turner (eds.). 2005. "Keeping it Living": Traditions of Plant Use and Cultivation on the Northwest Coast of North America. University of Washington Press, Seattle, WA and UBC Press, Vancouver, BC. 384pp.
51 Turner, N.J., M.B. Ignace and R. Ignace. 2000. Traditional ecological knowledge and wisdom of aboriginal peoples in British Columbia. Ecological Applications 10(5): 1275-1287.
52 Senos, R., F. Lake, N. Turner and D. Martinez. 2006. Traditional ecological knowledge and restoration practice in the Pacific Northwest. Pp. 393-426 *in* D. Apostol and M. Sinclair (eds.). Encyclopedia for Restoration of Pacific Northwest Ecosystems. Island Press, Washington, DC. 506pp.
53 See endnote 39.
54 Turner, N. J. and F. Berkes. 2006. Coming to understanding: developing conservation through incremental learning. Human Ecology 34(4): 495-513.
55 Turner, N.J. and J.C. Thompson (eds.). 2006. Plants of the Gitga'at People. 'Nwana'a lax Yuup. Hartley Bay, BC: Gitga'at Nation and Coasts Under Stress Research Project (R. Ommer, P.I.). Cortex Consulting, Victoria, BC. 335pp.
56 See endnote 47.
57 Turner, N.J. and D.C. Loewen. 1998. The original "free trade": exchange of botanical products and associated plant knowledge in northwestern North America. Anthropologica XL: 49-70.
58 Turner, N.J., I.J. Davidson-Hunt and M. O'Flaherty. 2003. Living on the edge: ecological and cultural edges as sources of diversity for social-ecological resilience. Human Ecology 31(3): 439-463.
59 N. Turner, University of Victoria, personal communication.
60 Hebda, R.J. and E. Irving. 2004. On the origin and distribution of Magnolias: tectonics, DNA, and climate change. Timescales of the Paleomagnetic Field Geophysical Monograph Series (AGU) 145: 43-57.
61 Clague, J.J. 1989. Cordilleran Ice Sheet. Pp. 40-42 *in* R.J. Fulton (ed.). Quaternary Geology of Canada and Greenland. (Geology of North America Vol. K-1/Geology of Canada No. 1.) Geological Survey of Canada, Ottawa, ON. 839pp.
62 Hebda, R.J. and C. Whitlock. 1997. Environmental history of the coastal temperate rain forest of northwest North America. Pp. 225-254 *in* P.K. Schoonmaker, B. von Hagen and E.C. Wolf (eds.). The Rain Forests of Home: Profile of a North American Bioregion. Island Press, Covelo, CA. 452pp.
63 See endnote 60.
64 Wilson, M.V. 1996. Fishes from Eocene Lakes of the Interior. *In* R. Ludvigsen (ed.). Life in Stone: A Natural History of British Columbia's Fossils. UBC Press, Vancouver, BC. 310pp.
65 Graham, A. 1999. Late Cretaceous and Cenozoic History of North American Vegetation (North of Mexico). Oxford University Press, Oxford, UK. 350pp.
66 Ibid.
67 See endnote 61.
68 Harington, C.R. 1975. Pleistocene muskoxen (*Symbos*) from Alberta and British Columbia. Canadian Journal of Earth Sciences 12: 903-919.
69 Whitlock, C. and R.J. Bartlein. 1997. Vegetation and climate change in northwest North America during the past 125 kyr. Nature 388: 57-61.
70 Armstrong, J.E., J.J. Clague and R.J. Hebda. 1985. Late Quaternary geology of the Fraser Lowland, southwestern British Columbia. Pp. 15-1 to 25 *in* D. Tempelman-Kluit (ed.). Field Guides to Geology and Mineral Deposits in the Southern Canadian Cordillera. Geological Association of Canada, Vancouver, BC.

71 Fedje, D.W. and R.W. Mathewes (eds.). 2005. Haida Gwaii: Human History and Environment from the Time of the Loon to the Time of the Iron People. UBC Press, Vancouver, BC. 448pp.
72 Harington, C.R. (ed.). 2001. Annotated Bibliography of Quaternary Vertebrates of Northern North America with Radiocarbon Dates. University of Toronto Press, Toronto, ON. 360pp.
73 Zazula, G.D., C.E. Schweger, A.B. Beaudoin and G.H. McCourt. 2006. Macrofossil and pollen evidence for full glacial steppe within and ecological mosaic along the Bluefish River, eastern Beringia. Quaternary International 142-143: 2-19.
74 R. Hebda, Royal British Columbia Museum, personal communication.
75 Mathewes, R.W. 1979. A paleoecological analysis of Quadra Sand at Point Grey, British Columbia, based on indicator pollen. Canadian Journal of Earth Sciences 16: 847-858.
76 Lian, O.B., R.W. Mathewes and S.R. Hicock. 2001. Paleoenvironmental reconstruction of the Port Moody Interstade, a non-glacial interval in southwestern British Columbia about 18,000 14C years BP. Canadian Journal of Earth Sciences 38: 943-952.
77 Carlson, C.C. and K. Klein. 1996. Late Pleistocene salmon of Kamloops Lake. Pp. 274-280 *in* R. Ludvigsen (ed.). Life in Stone: A Natural History of British Columbia's Fossils. UBC Press, Vancouver, BC. 310pp.
78 Marr, K.L., G.A. Allen and R.J. Hebda. In press. Refugia in the Cordilleran ice sheet of western North America: chloroplast DNA diversity in the Arctic-alpine plant *Oxyria digyna*. Journal of Biogeography. OnlineEarly version available at: www.blackwell-synergy.com/toc/jbi/0/0.
79 Hebda, R.J. and J.C. Haggarty (eds.). 1997. Brooks Peninsula: An Ice Age Refugium on Vancouver Island. B.C. Parks, Victoria, BC. Occasional Paper No. 5. 461pp.
80 See endnote 71.
81 See endnote 78.
82 Heinrichs, M.L., R.J. Hebda and I. Walker, I. 2001. Holocene vegetation and natural disturbance in the Engelmann Spruce–Subalpine Fir biogeoclimatic zone at Mt. Kobau, British Columbia. Canadian Journal of Forest Research 31: 2183-2199.
83 Heinrichs, M.L., R.J. Hebda, I. Walker and S.L. Palmer. 2002. Postglacial paleoecology and inferred paleoclimate intervals in the Engelmann Spruce–Subalpine Fir forest of south-central British Columbia, Canada. Palaeogeography, Palaeoclimatology, Palaeoecology 148: 347-369.
84 See endnote 62.
85 See endnote 71.
86 See endnote 62.
87 Cannings, R. and S. Cannings. 1996. British Columbia: A Natural History. Greystone Books, Vancouver, BC. 310pp.
88 See endnote 62.
89 See endnote 82.
90 Walker, I.R. and M.G. Pellatt. 2003. Climate change in coastal British Columbia – a paleoenvironmental perspective. Canadian Water Resources Journal 28: 531-566.
91 See endnote 72.
92 Wagner, F.J.E. 1959. Palaeoecology of the marine Pleistocene faunas of southwestern British Columbia. Geological Survey of Canada Bulletin 52. 67pp.
93 Mathewes, R.W., L.E. Heusser and R.T. Patterson. 1993. Evidence for a Younger Dryas-like cooling event on the British Columbia coast. Geology 21: 101-104.
94 R. Hebda, Royal British Columbia Museum, unpublished data.
95 See endnote 93.
96 Lundelius, E.L. Jr., R.W. Graham, E. Anderson, J. Guilday, J.A. Holman, D. Steadman and S.D. Webb. 1983. Terrestrial vertebrate faunas. Pp. 311-353 *in* S.C. Porter (ed.). Late Quaternary Environments of the United States: Vol. 1, The Late Pleistocene. University of Minnesota, Minneapolis, MN.
97 Martin, P.S. and R.G. Klein. 1984. Quaternary Extinctions: A Prehistoric Revolution. University of Arizona Press, Tucson, AZ. 892pp.
98 Hebda, R.J. 1995. British Columbia vegetation and climate history with focus on 6 KA BP. Géographie Physique et Quaternaire 49: 55-79.
99 Brown, K.J. and R.J. Hebda. 2002. Origin, development, and dynamics of coastal temperate conifer rainforests of southern Vancouver Island, Canada. Canadian Journal of Forest Research 32: 353-372.
100 See endnote 79.
101 See endnote 82.
102 Pellatt, M., R.J. Hebda and R.W. Mathewes. 2001. High resolution Holocene vegetation history and climate from Hole 1034B, ODP Leg 169S, Saanich Inlet, Canada. Marine Geology 174: 211-226.
103 Brown, K.J. and R.J. Hebda. 2002. Ancient fires on southern Vancouver Island, British Columbia, Canada: a change in causal mechanisms at about 2,000 ybp. Environmental Archaeology 7: 1-12.
104 See endnote 98.
105 See endnote 82.
106 Clague, J.J., J.R. Harper, R.J. Hebda and D.E. Howes. 1982. Late Quaternary sea levels and crustal movements, coastal British Columbia. Canadian Journal of Earth Science 19: 597-618.
107 See endnote 98.
108 Mathewes, R.W. and M. King. 1989. Holocene vegetation, climate and lake level changes in the Interior Douglas-fir biogeoclimatic zone, British Columbia. Canadian Journal of Earth Sciences 26: 1811-1825.
109 See endnote 71.
110 See endnote 98.
111 See endnote 102.
112 Heinrichs, M.L., M.G. Evans, R.J. Hebda, I. Walker, S. L. Palmer and S.M. Rosenberg. 2004. Holocene climatic change and landscape response at Cathedral Provincial Park, British Columbia, Canada. Geographie Physique et Quaternaire 58: 123-139.
113 See endnote 98.

114 See endnote 106.
115 See endnote 99.
116 See endnote 103.
117 See endnote 98.
118 Rosenberg, S.M., I.R. Walker and R.W. Mathewes. 2003. Postglacial spread of hemlock (*Tsuga*) and vegetation history in Mount Revelstoke National Park, British Columbia, Canada. Canadian Journal of Botany 81: 139-151.
119 See endnote 112.
120 Pellatt, M.G. and R.W. Mathewes. 1997. Holocene tree line and climatic change on the Queen Charlotte Islands, Canada. Quaternary Research 48: 88-99.
121 Brown, K.J. and R.J. Hebda. 2003. Temperate rainforest connections disclosed through a late-Quaternary vegetation, climate, and fire history investigation from the Mountain Hemlock zone on southern Vancouver Island, British Columbia, Canada. Review of Palaeobotany and Palynology 123: 247-269.
122 See endnote 98.
123 See endnote 103.
124 Palmer, S.L., I.R. Walker, M.L.. Henrichs, R.J. Hebda and G.G.E. Scudder. 2002. Postglacial midge community change and Holocene paleotemperature reconstructions near treeline, southern British Columbia (Canada). Journal of Paleolimnology 28: 469-490.
125 See endnote 106.
126 Geddes, G. (ed.). 1975. Skookum Wawa: Writings of the Canadian Northwest. Oxford University Press, Toronto, ON. 336pp.
127 Menzies, C. 2000. First Nations of B.C.: Overview. Pp. 233-242 *in* D. Francis (ed.). Encyclopedia of British Columbia. Harbour Publishing, Madeira Park, BC. 806pp.
128 Lea, T. 2006. Historical Garry oak ecosystems of Vancouver Island, British Columbia, pre-European contact to the present. Davidsonia 17(2): 34-5. Available at: www.davidsonia.org/bc_garryoak.
129 Lea, T. 2007. Historical (pre-European settlement) ecosystems of the Okanagan and lower Similkameen valleys: applications for species at risk. Saving the Pieces – Restoring Species at Risk Symposium, June 14-16, 2007, Victoria, BC.
130 Hyman, J. (ed.). 1989. Robert Brown and the Vancouver Island Exploring Expedition. UBC Press, Vancouver, BC.
131 Sullivan, P.T. 1983. A preliminary study of historic and recent reports of grizzly bears, *Ursus arctos*, in the North Cascades area of Washington. Washington Department of Fish and Game, Olympia, WA. 32pp.
132 Spalding, D.J. 2000. The early history of woodland caribou (*Rangifer tarandus caribou*) in British Columbia. B.C. Ministry of Environment, Lands and Parks, Wildlife Branch, Victoria, BC. Wildlife Bulletin No. 100. 61pp.
133 Ricker, W.E. 1987. Effects of the fishery and of obstacles to migration on the abundance of Fraser River sockeye salmon (*Onorhynchus nerka*). Canadian Technical Report of Fisheries and Aquatic Science No. 1522.
134 Dunn, E.H., D.T.J. Hussell and D.A. Welsh. 1999. Priority-setting tool applied to Canada's landbirds based on concern and responsibility for species. Conservation Biology 13: 1404-1415.
135 Bunnell, F., L. Kremsater and I. Houde. 2006. Applying the Concept of Stewardship Responsibility in British Columbia. Biodiversity BC, Victoria, BC. 188pp. Available at: www.biodiversitybc.org.
136 Fisher, R.A., A.S. Corbet and C.B. Williams. 1943. The relation between the number of species and the number of individuals in a random sample of an animal population. Journal of Animal Ecology 12: 42-58.
137 Geneletti, D. 2003. Biodiversity impact assessment of roads: an approach based on ecosystem rarity. Environmental Impact Assessment Review 23: 343–365.
138 Meidinger, D. and J. Pojar. 1991. Ecosystems of British Columbia. B.C. Ministry of Forests, Research Branch, Victoria, BC. Special Report Series No. 6. 330pp. Available at: www.for.gov.bc.ca/hfd/pubs/Docs/Srs/Srs06.htm.
139 Ibid.
140 T. Button, B.C. Ministry of Environment, personal communication.
141 B.C. Ministry of Forests and Range. Biogeoclimatic Ecosystem Classification Program. Available at: www.for.gov.bc.ca/hre/becweb/.
142 See endnote 138.
143 B.C. Ministry of Forests and Range. No date. Zone and Provincial Classification Reports: Biogeoclimatic Zone Brochures. Available at: www.for.gov.bc.ca/hre/becweb/resources/classificationreports/provincial/index.html.
144 MacKenzie, W. 2006. The Ecology of the Alpine Zones. B.C. Ministry of Forests, Research Branch, Victoria, BC. Forest Research Brochure 83. 9pp. Available at: www.for.gov.bc.ca/hfd/pubs/Docs/Bro/Bro83.pdf.
145 Kremsater, L. 2007. Draft S Ranks and Surrogate G Ranks for BEC Zones and Draft S Ranks for Ecoprovinces and Major Drainage Areas of B.C.: Preliminary Rankings for Informing the Biodiversity Status Report and Action Plan. Biodiversity BC, Victoria, BC. 64pp. Available at: www.biodiversitybc.org.
146 Hamann, A. and T. Wong. 2006. Potential effects of climate change on ecosystems and tree species distribution in British Columbia. Ecology 87(11): 2773-2786.
147 See endnote 145.
148 B.C. Conservation Data Centre. 2007. BC Species and Ecosystems Explorer. Available at: www.env.gov.bc.ca/atrisk/toolintro.html.
149 C. Cadrin, B.C. Ministry of Environment, personal communication.
150 W. MacKenzie, B.C. Ministry of Forests and Range, personal communication.
151 C. Cadrin, B.C. Ministry of Environment, personal communication.
152 K. Yearsley, B.C. Ministry of Environment, personal communication.
153 D. Meidinger, B.C. Ministry of Forests and Range, personal communication.
154 See endnote 129.
155 Grasslands Conservation Council of B.C. 2007. Understanding grasslands. Available at: www.bcgrasslands.org/grasslands/understandinggrasslands.htm.
156 Garry Oak Ecosystem Recovery Team. 2004. Brochure. Available at: www.goert.ca/documents/GOERTbroch_Jan6-2004.pdf.

157 Erickson, W. 1993. Ecosystems at Risk in British Columbia: Garry Oak Ecosystems. B.C. Ministry of Environment, Land and Parks, Wildlife Branch, Victoria, BC. 6pp. Available at: wlapwww.gov.bc.ca/wld/documents/garryoak.pdf.
158 See endnote 128.
159 B.C. Ministry of Environment. 2007. Environmental Trends 2007. State of Environment Reporting Office, Victoria, BC. Available at: www.env.gov.bc.ca/soe/et07/index.html.
160 See endnote 156.
161 See endnote 157.
162 Hebda, R. 2004. Paleoecology, climate change and forecasting the future of species at risk. *In* T.D. Hooper (ed.). Proceedings of the Species at Risk 2004 Pathways to Recovery Conference. March 2-6, 2004, Victoria, BC.
163 Ciruna, K.A., B. Butterfield, J.D. McPhail and B.C. Ministry of Environment. 2007. EAU BC: Ecological Aquatic Units of British Columbia. Nature Conservancy of Canada, Toronto, ON. 200pp plus DVD-ROM.
164 Environment Canada. No date. The world's water supply. Available at: www.ec.gc.ca/Water/images/nature/prop/a2f1e.htm.
165 B.C. Ministry of Water, Land and Air Protection. 2002. Status and Trends in Surface Water Quality. *In* Environmental Trends in British Columbia 2002. State of the Environment Reporting Office, Victoria, BC. Available at: www.env.gov.bc.ca/soerpt/6surfacewater/quality.html.
166 See endnote 145.
167 B.C. Ministry of Environment and Parks. 1988. The Guide to the Hierarchical Watershed Coding System for British Columbia. Water Management Branch, Victoria, BC. 33pp.
168 See endnote 145.
169 Precision Identification Biological Consultants. 1998. Wild, Threatened, Endangered and Lost Streams of the Lower Fraser Valley: Summary Report 1997. Fraser River Action Plan, Vancouver, BC. 58pp. Available at: www-heb.pac.dfo-mpo.gc.ca/maps/loststrm/loststreams_e.htm.
170 B.C. Ministry of Environment, Lands and Parks. 2000. Environmental Trends in British Columbia 2000. State of Environment Reporting Office, Victoria, BC. 53pp. Available at: www.env.gov.bc.ca/soerpt/files_to_link/etrends-2000.pdf.
171 Sloan, N.A., K. Vance-Borland and G.C. Ray. 2007. Fallen between the cracks: conservation linking land and sea. Conservation Biology 21(4): 897-898.
172 Integrated Land Management Bureau. Marine Planning Office website. Integrated Land Management Bureau, Victoria, BC. Available at: http://www.ilmb.gov.bc.ca/slrp/marine/index.html.
173 G. Jamison, Fisheries and Oceans Canada, personal communication.
174 Howes, D., J.R. Harper and E.H. Owens. 1994. British Columbia physical shore-zone mapping system. B.C. Resources Inventory Committee, Victoria, BC. 70pp.
175 Howes, D. 2001. BC biophysical shore-zone mapping system – a systematic approach to characterize coastal habitats in the Pacific Northwest. *In* T. Droscher (ed.). 2002. Proceedings of the 2001 at Puget Sound Research Conference. Puget Sound Action Team, Olympia, WA. 11pp. Available at: ilmbwww.gov.bc.ca/cis/rpts/pdf/BCBiophysicalShore-ZoneMapping.pdf.
176 Morris, M., D. Howes and P. Wainwright. 2006. Methodology for Defining B.C. Intertidal ShoreZone Habitats and Habitat Values for the B.C. Oil Spill Shoreline Sensitivity Model. B.C. Ministry of Agriculture and Lands, Victoria, BC. 47pp.
177 Boulanger, J. and A.G. MacHutchon. 2005. Black bear inventory plan for Haida Gwaii, British Columbia. B.C. Ministry of Water, Land and Air Protection, Biodiversity Branch, Victoria, BC. 55pp.
178 B.C. Ministry of Environment. 2006. Estuaries in British Columbia. Conservation Data Centre, Victoria, BC. Available at: www.env.gov.bc.ca/wld/documents/Estuaries06_20.pdf.
179 Ryder, J.L., J.K. Kenyon, D. Buffett, K. Moore, M. Ceh and K. Stipec. 2007. An integrated biophysical assessment of estuarine habitats in B.C. to assist regional conservation planning. Canadian Wildlife Service, Pacific and Yukon Region, Delta, BC. Technical Report Series No. 476.
180 Ibid.
181 Fraser River Estuary Management Program (FREMP). 2003. A Living, Working River: The Estuary Management Plan for the Fraser River. FREMP, Burnaby, BC. 88pp.
182 Groot, C. and L. Margolis. 1991. Pacific Salmon Life Histories. UBC Press, Vancouver, BC.
183 Kelsey, E. (ed.). 1999. The award-winning Pacific Estuary Conservation Program. The Nature Trust of B.C., Vancouver, BC.
184 Casillas, E. 1999. Role of the Columbia River estuary and plume in salmon productivity. Pp. 55-64 *in* G.A. Bisbal (ed.). Ocean Conditions and the Management of Columbia River Salmon. Proceedings of a symposium. Northwest Power and Conservation Council, Portland, OR.
185 Emmett, R., R. Llanso, J. Newton, R. Thom, M. Hornberger, C. Morgan, C. Levings, A. Copping and P. Fishman. 2000. Geographic signatures of North American west coast estuaries. Estuaries and Coasts 23(6): 765-792.
186 C. Cadrin, B.C. Ministry of Environment, personal communication.
187 T. Lea, B.C. Ministry of Environment, personal communication.
188 D. Clark, B.C. Ministry of Environment, personal communication.
189 See endnote 163.
190 C. Cadrin, B.C. Ministry of Environment, personal communication.
191 T. Lea, B.C. Ministry of Environment, personal communication.
192 Hebda, R.J. 1997. Impact of climate change on biogeoclimatic zones of British Columbia. Pp. 13:1-15 *in* E. Taylor and B. Taylor (eds.). Responding to Global Climate Change in British Columbia and Yukon: Vol. 1 of the Canada Country Study: Climate Impacts and Adaptation. Environment Canada, Vancouver, BC and B.C. Ministry of Environment, Lands and Parks, Victoria, BC.
193 T. Lea, B.C. Ministry of Environment, personal communication.
194 D. Filatow, B.C. Ministry of Environment, personal communication.

195 See endnote 87.
196 Warman, L. and G.G.E. Scudder. 2006. Species Richness and Summed Irreplaceability in B.C. Biodiversity BC, Victoria, BC. 36pp. Available at: www.biodiversitybc.org.
197 Willig, M.R. 2000. Latitudinal gradients in diversity. Pp. 701-714 *in* S. Levin (ed.). Encyclopedia of Biodiversity, Vol. 3. Academic Press, San Diego, CA.
198 Rahbek, C. 1995. The elevational gradient of species richness: a uniform pattern? Ecography 18(2): 200-205.
199 MacArthur, R.H. and E.O. Wilson. 1967. The Theory of Island Biogeography. Princeton University Press, Princeton, NJ. 224pp.
200 Anions, M. 2006. Global and Provincial Status of Species in British Columbia. Biodiversity BC, Victoria, BC. 16pp. Available at: www.biodiversitybc.org.
201 M. Anions, NatureServe Canada, personal communication.
202 Fraser, D.F. 2000. Going, gone, and missing in action: the extinct, extirpated and historic wildlife of British Columbia. Pp. 19-26 *in* L.M. Darling (ed.). Proceedings of a Conference on the Biology and Management of Species and Habitats at Risk, Kamloops, B.C., Feb. 15-19, 1999. Volume 1. B.C. Ministry of Environment, Lands and Parks, Victoria, BC and University College of the Cariboo, Kamloops, BC. 490pp.
203 Quayle, J.F. and L.R. Ramsay. 2005. Conservation status as a biodiversity trend indicator: recommendations from a decade of listing species at risk in British Columbia. Conservation Biology 19: 1306-1311.
204 Quayle, J.F., L.R. Ramsay and D.F. Fraser. 2007. Trends in the status of breeding bird fauna in British Columbia, Canada, based on the IUCN Red-list Index method. Conservation Biology: 21(5): 1241-1247.
205 See endnote 135.
206 Ibid.
207 Mittermeier, R.A., N. Myers, J.B. Thomsen, G.A.B. da Fonesca and S. Olivieri. 1998. Biodiversity hotspots and major tropical wilderness areas: approaches to setting conservation priorities. Conservation Biology 12(3): 516-520.
208 Myers, N., R.A. Mittermeier, C.G. Mittermeier, G.A.B. da Fonseca and J. Kent. 2000. Biodiversity hotspots for conservation priorities. Nature 403: 853-858.
209 Scudder, G.G.E. 1994. An annotated systematic list of the potentially rare and endangered freshwater and terrestrial invertebrates in British Columbia. Entomological Society of British Columbia, Occasional Paper 2.
210 See endnote 135.
211 See endnote 204.
212 Fraser, D.F. 2000. Species at the edge: the case for listing of "peripheral" species. Pp. 49-53 *in* L.M. Darling (ed.). Proceedings of a Conference on the Biology and Management of Species and Habitats at Risk, Kamloops, B.C., Feb. 15-19, 1999. Volume 1. B.C. Ministry of Environment, Lands and Parks, Victoria, BC and University College of the Cariboo, Kamloops, BC. 490pp.
213 Parmesan, C. and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421: 37-42.
214 Root, T.L., J.T. Price, K.R. Hall, S.H. Schneider, C. Rosenzweig and J.A. Pounds. 2003. Fingerprints of global warming in wild animals and plants. Nature 421: 57-60.
215 Elias, S.A. 1994. Quaternary Insects and their Environments. Smithsonian Institution Press, Washington, DC and London, UK. 284pp.
216 Hitch, A.T. and P.L. Leberg. 2007. Breeding distribution of North American bird species moving north as a result of climate change. Conservation Biology 21: 534-539.
217 Walther, G.R., E. Post, P. Convey, A. Menzel, C. Parmesan, T.J.C. Beebee, J.M. Fromentin, O. Hoegh-Guldberg and F. Bairlein. 2002. Ecological responses to recent climate change. Nature 416: 389-395.
218 Lomolino, M.V. and R. Channell. 1995. Splendid isolation: patterns of range collapse in endangered mammals. Journal of Mammalogy 76: 335-347.
219 See endnote 1.
220 J. Quayle, B.C. Ministry of Environment, personal communication.
221 Ohlson, D. 2007. Overlap: Investigations and Review. Biodiversity BC, Victoria, BC. 55pp.
222 R. Butler, Environment Canada, personal communication.
223 Blancher, P.J., B. Jacobs, A. Couturier, C.J. Beardmore, R. Dettmers, E.H. Dunn, W. Easton, E.E. Iñigo-Elias, T.D. Rich, K.V. Rosenberg and J.M. Ruth. 2006. Making Connections for Bird Conservation: Linking States, Provinces and Territories to Important Wintering and Breeding Grounds. Partners in Flight Technical Series No. 4. Available at: www.partnersinflight.org/pubs/ts/04-Connections.
224 Donaldson, G.M., C. Hyslop, R.I.G. Morrison, H.L. Dickson and I. Davidson. 2000. Canadian Shorebird Conservation Plan. Canadian Wildlife Service, Environment Canada, Ottawa, ON. 34pp.
225 Butler, R.W. and R.W. Campbell. 1987. The Birds of the Fraser River Delta: Populations, Ecology and International Significance. Canadian Wildlife Service, Ottawa, ON. Occasional Paper No. 65. 73pp.
226 Important Bird Areas Canada. 2002. Baynes Sound/Lambert Channel-Hornby Island Waters. Available at: www.ibacanada.com/cpm_baynessound.html.
227 A. Breault, Environment Canada, personal communication.
228 Environment Canada. 2005. Black brant geese: an indicator of wildlife sustainability in the Georgia Basin. Available at: www.ecoinfo.ec.gc.ca/env_ind/region/brantgeese/brantgeese_e.cfm.
229 Campbell R.W., N.K. Dawe, I. MacTaggart-Cowan, J.M. Cooper, G.W. Kaiser and M.C.E. McNall. 1990. The Birds of British Columbia, Vol. 2: Non-Passerines – Diurnal Birds of Prey through Woodpeckers. UBC Press, Vancouver, BC. 636pp.
230 Pacific Coast Joint Venture. 2005. Pacific Coast Joint Venture: BC – Strategic Plan and Biological Foundation. B.C. Steering Committee. Unpublished report. 77pp.
231 Breault, A. 2006. 2006 Waterfowl Breeding Population Survey of the British Columbia Interior Plateau. Environment Canada. Unpublished report.

232 Cooper J.M. 1996. Status of the Sandhill Crane in British Columbia. B.C. Ministry of Environment, Lands and Parks, Wildlife Branch, Victoria, BC. Wildlife Bulletin No. B-83. 40pp.
233 Acorn J. and I. Sheldon. 2006. Butterflies of British Columbia. Lone Pine Publishing, Edmonton, AB. 360pp.
234 Eder, T. and D. Pattie. 2001. Mammals of British Columbia. Lone Pine Publishing, Edmonton, AB. 296pp.
235 B.C. Conservation Data Centre. 2008. BC Species and Ecosystems Explorer: *Acipenser medirostris* – Species Summary. Available at: www.env.gov.bc.ca/atrisk/toolintro.html.
236 Wilson, W.H. 1994. Western Sandpiper (*Calidris mauri*). *In* A. Poole (ed.). The Birds of North America Online. Cornell Lab of Ornithology, Ithaca, NY. Available at: bna.birds.cornell.edu/bna/species/090.
237 Butler, R.W., F.S. Delgado, H. De La Cueva, V. Pulido and B.K. Sandercock. 1996. Migration routes of the Western Sandpiper. Wilson Bulletin 108(4): 662-672.
238 Kuwae, T., P.G. Beninger, P. Decottignies, K.J. Mathot, D.R. Lund and R.W. Elner. 2008. Biofilm grazing in a higher vertebrate: the western sandpiper, *Calidris mauri*. Ecology 89: 599-606.
239 Ibid.
240 Fernandez, G., N. Warnock, D.B. Lank and J.B. Buchanan. 2006. Conservation Plan for the Western Sandpiper Version 1.0. Manomet Center for Conservation Science, Manomet, MA.
241 Cheesman, O.D. and R.S. Key. 2007. The extinction of experience: a threat to insect conservation? Pp. 322-348 *in* A.J.A. Stewart, T.R. New and O.T. Lewis (eds.). Insect Conservation Biology. Proceedings of the Royal Entomological Society's 23rd Symposium. CAB International, Wallingford, UK.
242 See endnote 87.
243 D. Fraser, B.C. Ministry of Environment, personal communication.
244 McPhail, J.D. 2007. Freshwater Fishes of British Columbia. University of Alberta Press, Edmonton, AB. 620pp.
245 Burg, T.M., A.J. Gaston, K. Winker and V.L. Freisen. 2005. Rapid divergence and postglacial colonization in western North American Steller's jays (*Cyanocitta stelleri*). Molecular Ecology 14: 3745-3755.
246 O'Neill, M.B., D.W. Nagorsen and R.J. Baker. 2005. Mitochondrial DNA variation in water shrews (*Sorex palustris, Sorex bendirii*) from western North America: implications for taxonomy and phylogeography. Canadian Journal of Zoology 83: 1469-1475.
247 Demboski, J.R. and J. Sullivan. 2003. Extensive mtDNA variation within the yellow-pine chipmunk, *Tamias amoenu* (Rodentia: Sciuridae), and phylogeographic inferences for northwest North America. Molecular Phylogenetics and Evolution 26: 389-408.
248 Fleming, M.A. and J.A. Cooke. 2002. Phylogeography of endemic ermine (*Mustela erminea*) in southeast Alaska. Molecular Ecology 11: 795-807.
249 Cook, J.A. and S.O. MacDonald. 2001. Should endemism be a focus of conservation efforts along the North Pacific Coast of North America? Biological Conservation 97: 207-213.
250 Rundle, H.D., L. Nagel, J.W. Boughman and D. Schluter. 2000. Natural selection and parallel speciation in sticklebacks. Science 287: 306-308.
251 See endnote 244.
252 See endnote 245.
253 See endnote 246.
254 See endnote 248.
255 See endnote 249.
256 Weir, J.T. and D. Schluter. 2007. The latitudinal gradient in recent speciation and extinction rates of birds and mammals. Science 315: 1574-1576.
257 Wilson, A.G., P. Arcese and F. Bunnell. 2007. The status of genetic diversity in British Columbia. Biodiversity BC, Victoria, BC. 27pp. Available at: www.biodiversitybc.org.
258 Rice, K.J. and N.C. Emery. 2003. Managing microevolution: restoration in the face of global change. Frontiers in Ecology and the Environment 1(9): 469-478.
259 Berteaux, D., D. Reale, A.G. McAdam and S. Boutin. 2004. Keeping pace with fast climate change: can Arctic life count on evolution? Integrative and Comparative Biology 44(2): 140-151.
260 Frankel, O.H. 1974. Genetic conservation – our evolutionary responsibility. Genetics 1: 53-65.
261 Lande, R. and G.F. Barrowclough. 1987. Effective population size, genetic variation, and their use in population management. *In* M.E. Soulé (ed.). Viable Populations for Conservation. Cambridge University Press, New York, NY. 642pp.
262 Irvine, J.R. and G.A. Fraser. 2008. Canada's Wild Pacific Salmon Policy and the Maintenance of Diversity. American Fisheries Society Symposium 49: 391-398.
263 Frankham, R. 1995. Conservation genetics. Annual Review of Genetics 29: 305-327.
264 Frankham, R., D.A. Briscoe and J.D. Ballou. 2002. Introduction to Conservation Genetics. Cambridge University Press, New York, NY. 642pp.
265 Keller, L.F. and D.M. Waller. 2002. Inbreeding effects in wild populations. Trends in Ecology and Evolution 17(5): 230-241.
266 Frankham, R. 1995. Effective population size adult population size ratios in wildlife – a review. Genetical Research 66(2): 95-107.
267 Franklin I.R. 1980. Evolutionary change in small populations. Pp.135-148 *in* M.E. Soulé and B.A. Wilcox (eds.). Conservation Biology: An Evolutionary-Ecological Perspective. Sinauer Associates, Inc., Sunderland, MA. 395pp.
268 Lande, R. 1995. Mutation and conservation. Conservation Biology 9(4): 782-791.
269 See endnote 264.
270 Garcia-Ramos, G. and M. Kirkpatrick. 1997. Genetic models of adaptation and gene flow in peripheral populations. Evolution 51(1): 21-28.
271 Gapare, W.J. and S.N. Aitken. 2005. Strong spatial genetic structure in peripheral but not core populations of Sitka spruce [*Picea sitchensis* (Bong.) Carr.]. Molecular Ecology 14(9): 2659-2667.
272 See endnote 135.

273 Guppy, C.S. and J.H. Shepard. 2001. Butterflies of British Columbia: Including Western Alberta, Southern Yukon, the Alaska Panhandle, Washington, Northern Oregon, Northern Idaho, and Northwestern Montana. UBC Press, Vancouver, BC. 413pp.
274 Brown, J.H. and A.C. Gison. 1983. Biogeography. C.V. Morsby Co., St. Louis, MO. 643pp.
275 Byun, S.A., B. Koop, T.E. Reimchen. 1997. North American black bear mtDNA phylogeography: implications for morphology and the Haida Gwaii refugium controversy. Evolution 51: 1647-1653.
276 Marshall, H.D. and K. Ritland. 2002. Genetic diversity and differentiation of Kermode bear populations. Molecular Ecology 11(4): 685-697.
277 Backhouse, F. 2000. Extinct and Extirpated Species. B.C. Ministry of Environment, Lands and Parks, Wildlife Branch. 6pp.
278 Roca, A.L., N. Georgiadis, J. Pecon-Slattery and S.J. O'Brien. 2001. Genetic evidence for two species of elephant in Africa. Science 293(5534): 1473-1477.
279 Adams, R.P. 2007. *Juniperus maritima*, the seaside juniper, a new species from Puget Sound, North America. Phytologia 89(3): 263-283.
280 Toews, D.P.L and D.E. Irwin. In Press. Cryptic speciation in a Holarctic passerine revealed by genetic and bioacoustic analyses. Molecular Ecology. Abstract available at: www.blackwell-synergy.com/doi/abs/10.1111/j.1365-294X.2008.03769.x.
281 Stockton, S.A., S. Allombert, A.J. Gaston and J-L. Martin. 2005. A natural experiment on the effects of high deer densities on the native flora of coastal temperate rain forests. Biological Conservation 126(1): 118-128.
282 See endnote 244.
283 Ibid.
284 Rausch, R.L., J.E. Feagin and V.R. Rausch. 2007. *Sorex rohweri* sp. nov. (Mammalia, Soricidae) from northwestern North America. Mammalian Biology 72: 93-105.
285 Cannings, S.G. and J. Ptolemy. 1998. Rare Freshwater Fish of British Columbia. B.C. Ministry of Environment, Victoria, BC. 214pp.
286 See endnote 250.
287 See endnote 78.
288 Runck, A.M. and J.A. Cook. 2005. Postglacial expansion of the southern red-backed vole (*Clethrionomys gapperi*) in North America. Molecular Ecology 14: 1445-1456.
289 See endnote 244.
290 See endnote 77.
291 Northcote, T.G. 1998. Inland waters and aquatic habitats. *In* G.G.E. Scudder and I.M. Smith (eds.). Assessment of Species Diversity in the Montane Cordillera Ecozone. Ecological Monitoring and Assessment Network, Burlington, ON. Available at: www.naturewatch.ca/eman/reports/publications/99_montane/intro.html.
292 Northcote, T.G. and P.A. Larkin. 1989. The Fraser River: a major salmonine productive system. Pp. 174-202 *in* D. Dodge (ed.). Proceedings of the International Large River Symposium. Canadian Special Publications Fisheries and Aquatic Sciences 106.
293 Beacham, T.D., J.R. Candy, K.J. Supernault, T. Ming, B. Deagle, A. Schulze, D. Tuck, K.H. Kaukinen, J.R. Irvine, K.M Miller and R.E. Withler. 2001. Evaluation and application of microsatellite and major histocompatibility complex variation for stock identification of coho salmon in British Columbia. Transactions of the American Fisheries Society 130: 1116-1149.
294 Dyke, A.S. 2004. An outline of North American deglaciation with emphasis on central and northern Canada. Pp. 373-424 *in* J. Ehlers and P.L. Gibbard (eds). Quaternary glaciations, extent and chronology. Part 11: North America. Elsevier, Amsterdam.
295 Haas, G.R. and J.D. McPhail. 1991. The post-Wisconsinan glacial biogeography of bull trout (*Salvelinus confluentus*): a multivariate morphometric approach for conservation biology and management. Canadian Journal of Fisheries and Aquatic Sciences 58: 2189-2203.
296 Foote, C.J., J.W. Clayton, C.C. Lindsey and R.A. Bodaly. 1992. Evolution of lake whitefish (*Coregonus clupeiformis*) in North America during the Pleistocene: evidence for a Nahanni glacial refuge race in the northern Cordillera region. Canadian Journal of Fisheries and Aquatic Sciences 49: 760-768.
297 Wilson, C.C. and P.D.N. Hebert. 1998. Phylogeography and postglacial dispersal of lake trout (*Salvelinus namaycush*) in North America. Canadian Journal of Fisheries and Aquatic Sciences 55: 1010-1024.
298 Stamford, M.D. and E.B. Taylor. 2004. Phylogeographical lineages of Arctic grayling (*Thymallus arcticus*) in North America: divergence, origins and affinities with Eurasian *Thymallus*. Molecular Ecology 13: 1533-1549.
299 See endnote 244.
300 Rieseberg. L.H. 1997. Hybrid origins of plant species. Annual Review of Ecology and Systematics 28: 359-389.
301 Hegarty, M.J. and S.J. Hiscock. 2005. Hybrid speciation in plants: new insights from molecular studies. New Phytologist 165(2): 411-423.
302 Remington, C.L. 1968. Suture zones of hybrid interaction between recently joined biota. Evolutionary Biology 2: 321-428.
303 Swenson, N.G. and D. Howard. 2005. Clustering of contact zones, hybrid zones, and phylogeographic breaks in North America. American Naturalist 166: 581-591.
304 Short, L.L. 1965. Hybridization in the flickers (Colaptes) of North America. Bulletin of the American Museum of Natural History 129(4): 307-428.
305 Ruegg, K.C. and T.B. Smith. 2002. Not as the crow flies: a historical explanation for circuitous migration in Swainson's thrush (*Catharus ustulatus*). Proceedings of the Royal Society of London B 269: 1375-1381.
306 Clegg, S.M., J.F. Kelly, M. Kimura and T.B. Smith. 2003. Combining genetic markers and stable isotopes to reveal population connectivity and migration patterns in a Neotropical migrant, Wilson's warbler (*Wilsonia pusilla*). Molecular Ecology 12: 819-830.
307 Brower, L.P. 1959. Speciation in butterflies of the *Papilio glaucus* group. I. Morphological relationships and hybridization. Evolution 13: 40-63.

308 See endnote 244.
309 See endnote 257.
310 Avise, J.C. 2000. Phylogeography: The History and Formation of Species. Harvard University Press, Cambridge, MA. 447pp.
311 Rissler, L.J., R.J. Hijmans, C.H. Graham, C. Moritz and D.B. Wake. 2006. Phylogeographic lineages and species comparisons in conservation analyses: a case study of California herpetofauna. American Naturalist 167: 655–666.
312 See endnote 132.
313 Thomas, D.C. and D.R. Gray. 2002. Update COSEWIC status report on the woodland caribou *Rangifer tarandus caribou* in Canada. Pp. 1-98 *in* COSEWIC Assessment and Update Status Report on the Woodland Caribou *Rangifer tarandus caribou* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, ON.
314 B.C. Mountain Caribou Science Team. 2005. Mountain Caribou in British Columbia: A Situation Analysis. B.C. Ministry of Agriculture and Lands, Integrated Land Management Bureau, Victoria, BC. 9pp. Available at: http://ilmbwww.gov.bc.ca/sarco/mc/files/Mountain_Caribou_Situation_Analysis.pdf .
315 Hatter, I. 2006. Mountain caribou 2006 survey results, subpopulation trends and extinction risk. B.C. Ministry of Environment, Victoria, BC. Draft for technical review. 19pp. Available at: http://ilmbwww.gov.bc.ca/sarco/mc/files/MC_2006_Populaton_Survey.pdf .
316 See endnote 314.
317 Integrated Land Management Bureau. 2007. Mountain caribou recovery actions: backgrounder. B.C. Ministry of Agriculture and Lands, Victoria, BC. 2pp. Available at: ilmbwww.gov.bc.ca/sarco/mc/files/MC_Recovery_Implementation_Plan_Backgrounder_20071016.pdf.
318 Schwartz, M.K., G. Luikart and R.S. Waples. 2007. Genetic monitoring as a promising tool for conservation and management. Trends in Ecology and Evolution 22(1): 25-33.
319 Simberloff, D., J.A. Farr, J. Cox and D.W. Mehlman. 1992. Movement corridors: conservation bargains or poor investments? Conservation Biology 6(4): 493-504.
320 D. Irwin, University of British Columbia, personal communication.
321 P. Arcese and A. Wilson, University of British Columbia; C. Pruett, University of Oklahoma; K. Winker, University of Alaska - Fairbanks; and L. Keller, University of Zurich, personal communications.
322 DeWoody, J.A. and J.C. Avise. 2000. Microsatellite variation in marine, freshwater and anadromous fishes compared with other animals. Journal of Fish Biology 56(3): 461-473.
323 See endnote 244.
324 K. Hyatt, Fisheries and Oceans Canada, personal communication.
325 Ward, R.D., D.O.F. Skibinski and M. Woodwark. 1992. Protein heterozygosity, protein structure, and taxonomic differentiation. Evolutionary Biology 26: 73-159.
326 Clarke, T.E., D.B. Levin, D.H. Kavanaugh and T.E. Reimchen. 2001. Rapid evolution in the *Nebria gregaria* group (Coleoptera: Carabidae) and the paleogeography of the Queen Charlotte Islands. Evolution 55(7): 1408-1418.
327 P. Arcese, University of British Columbia, personal communication.
328 E. Elle, Garry Oak Ecosystem Recovery Team, personal communication.
329 Adapted from Bunnell, F.L. In progress. The neglected majority.
330 Marshall, V.G. 2001. Sustainable forestry and soil fauna diversity. Ecoforestry Spring issue: 29-34.
331 Lindner D.L., H.H. Burdsall and G.R. Stanosz. 2006. Species diversity of polyporoid and corticioid fungi in northern hardwood forests with differing management histories. Mycologia 98: 195-217.
332 Marshall, V.G., H. Setala and J.A. Trofymow. 1998. Collembolan succession and stump decomposition in Douglas-fir. Northwest Science 72: 84-85.
333 Varese, G.C., P. Gonthier and G. Nicolotti. 2003. Long-term effects on other fungi are studied in biological and chemical stump treatments in the fight against *Heterobasidion annosum* Coll. Mycologia 95: 379-387.
334 Forsyth, R.G. 2006. Terrestrial Snails and Slugs of British Columbia. E-Fauna BC. Available at: www.geog.ubc.ca/biodiversity/efauna/LandSnails.html.
335 Lesica, P., B. McCune, S.V. Cooper and W.S. Hong. 1991. Differences in lichen and bryophyte communities between old-growth and managed second-growth forests in the Swan Valley, Montana. Canadian Journal of Botany 69: 1745-1755.
336 McCune, B., R. Rosentreter, J.M. Ponzetti and D.C. Shaw. 2000. Epiphyte habitats in an old conifer forest in western Washington, USA. Bryologist 103: 417-427.
337 Nadkarni, N.M., M.C. Merwin and J. Nieder. 2001. Forest canopies, plant diversity. Pp. 27-40 *in* S. Levin, ed. Encyclopedia of Biodiversity. Vol. 3. Academic Press, San Diego, CA.
338 Rhoades, F.M. 1995. Nonvascular epiphytes in forest canopies: worldwide distribution, abundance and ecological roles. Pp. 353-408 *in* M.D. Lowman, M.D. and N.M. Nadkarni (eds.). Forest Canopies. Academic Press, San Diego, CA. 624pp.
339 Newmaster, S.G., R. Belland, A. Arsenault and D.H. Vitt. 2003. Patterns of bryophyte diversity in humid coastal and inland cedar-hemlock forests of British Columbia. Environmental Reviews 11: S159-S189.
340 Binkley, D. and R.L. Graham. 1981. Biomass, production, and nutrient cycling of mosses in an old-growth Douglas-fir forest. Ecology 62: 1387-1389.
341 McCune, B. 1993. Gradients in epiphytic biomass in three *Pseudotsuga-Tsuga* forests of different ages in Oregon and Washington. Bryologist 96: 405-411.
342 Bunnell, F.L., T. Spribille, I. Houde, T. Goward and C. Björk. 2008. Lichens on down wood in logged and unlogged forest stands. Canadian Journal of Forest Research 38(5): 1033-1041.
343 Harwell, M.A., V. Myers, T. Young, A. Bartuska, N. Gassman, J.H. Gentile, C.C. Harwell, S. Appelbaum, J. Barko, B. Causey, C. Johnson, A. McLean, R. Smola, P. Templet and S. Tosini. 1999. A framework for an ecosystem integrity report card. BioScience 49: 543-556.
344 Tischendorf, L. and L. Fahrig. 2000. On the usage and measurement of landscape connectivity. Oikos 90(1): 7-19.

345 Andren H. 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. Oikos 71(3): 355-366.
346 Courtney, S.P., J.A. Blakesley, R.E. Bigley, M.L. Cody, J.P. Dumbacher, R.C. Fleischer, A.B. Franklin, J.F. Franklin, R.J. Gutiérrez, J.M. Marzluff and L. Sztukowski. 2004. Scientific evaluation of the status of the Northern Spotted Owl. Sustainable Ecosystems Institute, Portland, OR. 508pp. Available at: www.sei.org/owl/finalreport/OwlFinalReport.pdf.
347 McLellan, B.N. and D.M. Shackleton. 1988. Grizzly bears and resource-extraction industries: effects of roads on behaviour, habitat use and demography. Journal of Applied Ecology 25(2): 451-460.
348 S. Desjardins, University of British Columbia Okanagan, personal communication. Observed average dispersal distances for Behr's hairstreak (*Satyrium behrii*) in the Okanagan Valley were 120 m in 2005 (warm and dry) and 80 m in 2006 (cool and rainy); maximum dispersal was 1.2 km (one individual). Average for the Mormon metalmark (*Apodemia mormo*) was 360 m.
349 Fahrig, L. and G. Merriam. 1985. Habitat patch connectivity and population survival. Ecology 66(6): 1762-1768.
350 Keller, L.F. and D.M. Waller. 2002. Inbreeding effects in wild populations. Trends in Ecology and Evolution 17(5): 230-241.
351 Watters, G.T. 1996. Small dams as barriers to freshwater mussels (*Bivalvia, Unionoida*) and their hosts. Biological Conservation 75: 79-85.
352 Weaver, J.L., P.C. Paquet and L.F. Ruggiero. 1996. Resilience and conservation of large carnivores in the Rocky Mountains. Conservation Biology 10(4): 964-976.
353 Preisler, H.K., A.A. Ager and M.J. Wisdom. 2006. Statistical methods for analysing responses of wildlife to human disturbance. Journal of Applied Ecology 43: 164–172.
354 Seip, D.R., C.J. Johnson and G.S. Watts. 2006. Displacement of mountain caribou from winter habitat by snowmobiles. Journal of Wildlife Management 71: 1539-1544.
355 Adapted from B.C. Ministry of Environment. 2007. Ecosystems: Trends in Number of Road Crossings of Streams. *In* Environmental Trends 2007. State of Environment Reporting Office, Victoria, BC. Available at: www.env.gov.bc.ca/soe/et07/06_ecosystems/stream_crossings.html.
356 Data source: National Forest Inventory Photo Database. Analysed by B.C. Ministry of Forests and Range, Forest Analysis and Inventory Branch, Victoria, BC.
357 Thompson, R. and C. Mount. 2007. Fish passage and culverts: why did the fish cross the road? Poster presented to B.C. Ministry of Environment Ecosystem Program Meeting, Sun Peaks, BC.
358 Apps, C. 1997. Identification of grizzly bear linkage zones along the Highway 3 corridor of southeastern British Columbia and southwestern Alberta. Unpublished report prepared for B.C. Ministry of Environment, Lands and Parks and World Wildlife Fund Canada and U.S.A.
359 Apps, C.D. 2001. Grizzly bear population linkage zones in the Sea to Sky Planning Area of southwestern British Columbia. Unpublished report prepared for B.C. Ministry of Water, Land and Air Protection, Surrey, BC.
360 Alexander, S. and J. Gailus. 2005. A GIS-Based Approach to Restoring Connectivity Across Banff's Trans-Canada Highway. Yellowstone to Yukon Conservation Initiative, Canmore, AB. Technical Report No. 4. 36pp. Available at: www.rockies.ca/downloads/COMPLETE TCH Report.pdf.
361 Apps, C.D., J.L. Weaver, P.C. Paquet, B. Bateman and B.N. McLellan. 2007. Carnivores in the southern Canadian Rockies: core areas and connectivity across the Crowsnest Highway. Wildlife Conservation Society Canada, Toronto, ON. Conservation Report No. 3. 109pp. Available at: www.wcscanada.org/media/file/crowsnest_web.pdf.
362 Clayoquot Sound Scientific Panel. 1995. Sustainable ecosystem management in Clayoquot Sound: planning and practices. B.C. Ministry of Environment, Victoria, BC. Report 5. Available at: srmwww.gov.bc.ca/rmd/specialprojects/clayquot/archive/reports/Panel.htm.
363 Price, K. and D. McLennan. 2001. Hydroriparian Ecosystems of the North Coast. Background report prepared for the North Coast Land and Resource Management Plan. 90pp.
364 Howard, S. In Progress. An Application of the Hydroriparian Planning Guide in Six British Columbia Coastal Watersheds. Masters thesis, Simon Fraser University, Burnaby, BC.
365 See endnote 363.
366 Wylynko, D. (ed.). 1999. Prairie wetlands and carbon sequestration: assessing sinks under the Kyoto Protocol. International Institute for Sustainable Development, Winnipeg, MB. 45pp. Available at: www.iisd.org/wetlands/wrkshp_summ.pdf.
367 See endnote 87.
368 Bunnell, F.L. and L.A. Dupuis. 1995. Riparian habitats in British Columbia: their nature and role. Pp. 7-21 *in* K.H. Morgan and M.A. Lashmar (eds.). Riparian habitat management and research. Special Publication of the Fraser River Action Plan, Canadian Wildlife Service, Delta, B.C.
369 B.C. Ministry of Water, Land and Air Protection. 2006. Riparian Areas Regulation Implementation Guidebook. B.C. Ministry of Water, Land and Air Protection, Biodiversity Branch, Victoria, BC. 87pp. Available at: www.env.gov.bc.ca/habitat/fish_protection_act/riparian/documents/ImplementationGuidebook.pdf.
370 Poole, G.C. and C.H. Berman. 2001. An ecological perspective on in-stream temperature: natural heat dynamics and mechanisms on human-caused thermal degradation. Environmental Management 27: 787-802.
371 Naiman, R, H. Decamos and M.E. McClain. 2005. Riparia – Ecology, Conservation and Management of Streamside Communities. Elsevier Academic Press, Burlington, MA. 448pp.
372 See endnote 363.
373 See endnote 368.
374 Cannings, R.A., R.J. Cannings and S.G. Cannings. 1987. Birds of the Okanagan Valley, British Columbia. Royal British Columbia Museum, Victoria, BC. 420pp.

375 Partners in Flight British Columbia and Yukon. 2003. Canada's Great Basin Landbird Conservation Plan, Version 1.0. Partners in Flight British Columbia and Yukon, Delta, BC. 100pp.
376 Abele, S.C., V.A. Saab and E.O. Garton. 2004. Lewis's Woodpecker (*Melanerpes lewis*): a technical conservation assessment. USDA Forest Service, Rocky Mountain Research Station, Bozeman, MT. 50pp. Available: www.fs.fed.us/r2/projects/scp/assessments/lewisswoodpecker.pdf.
377 J. Hobbs, B.C. Ministry of Environment, personal communication.
378 See endnote 371.
379 Iverson, K. and C. Cadrin. 2003. Sensitive Ecosystems Inventory: Central Okanagan, 2000–2001. Vol. 1: Methodology, Ecological Descriptions, Results and Conservation Tools. Canadian Wildlife Service, Pacific and Yukon Region, Delta, BC. Technical Report Series No. 399.
380 See endnote 87.
381 See endnote 129.
382 See endnote 363.
383 Reese-Hansen, L. and E. Parkinson. 2006. Evaluating and Designing Fisheries Sensitive Watersheds (FSW): An Overview of B.C.'s New FSW Procedure. Draft report prepared for the B.C. Ministry of Environment, Victoria, BC.
384 See endnote 371.
385 Gilbertson, R.L. and L. Ryvarden. 1986. North American polypores, Vol. 1. Fungiflora, Oslo, Norway. 433pp.
386 Miller, R.M., D.R. Reinhardt and J.D. Jastrow. 1995. External hyphal production of vesicular-arbuscular mycorrhizal fungi in pasture and tallgrass prairie communities. Oecologia 103: 17-23.
387 Pacific Forestry Centre. 2007. Beneficial fungi affected by harvesting regime and rotation. Information Forestry, April 2007. Canadian Forest Service, Victoria, BC.
388 Molles, M.C. 2002. Nutrient cycling and retention. Pp. 432-451 *in* Ecology, Concepts and Applications. McGraw-Hill. 640pp.
389 Ibid.
390 Holt, R. and T. Hatfield. 2007. Key Elements of Biodiversity in British Columbia: Some Examples From the Terrestrial and Freshwater Aquatic Realm. Biodiversity BC, Victoria, BC. 70pp. Available at: www.biodiversitybc.org.
391 Buchmann, S.L. and G.P. Nabhan. 1996. The Forgotten Pollinators. Island Press, Washington, DC. 312pp.
392 Losey, J.E. and M. Vaughan. 2006. The economic value of ecological services provided by insects. Bioscience 56: 311-323.
393 Larsen, T.H., N. Williams and C. Kremen. 2005. Extinction order and altered community structure rapidly disrupt ecosystem functioning. Ecology Letters 8: 538-547.
394 Black, S.H., N. Hodges, M. Vaughan and M. Shepherd. 2007. Pollinators in natural areas: a primer on habitat management. The Xerces Society for Invertebrate Conservation, Portland, OR. 8pp. Available at: www.xerces.org/Pollinator_Insect_Conservation/Managing_Habitat_for_Pollinators.pdf.
395 E. Elle, Garry Oak Ecosystem Recovery Team, personal communication.
396 Garry Oak Recovery Team. 2006. Research Colloquium 2006: Abstracts of Presentations. Available at: www.wnps.org/ecosystems/west_lowland_eco/documents/GOERTResearchColloquium2006Proceedings.pdf.
397 National Research Council. 2006. Status of Pollinators in North America. National Academies Press, Washington, DC. 307pp.
398 Kremen, C.N., M. Williams and R.W. Thorp. 2002 Crop pollination from native bees at risk from agricultural intensification. Proceedings of the National Academy of Sciences 99: 16812-16816.
399 Gates, J. 1995. Bees and pollination. Tree Fruit Leader 4(1). Available at: www.agf.gov.bc.ca/treefrt/newslett/bees_pollination.htm.
400 See endnote 398.
401 See endnote 397.
402 Terborgh, J., L. Lopez, P. Nuñez, M. Rao, G. Shahabuddin, G. Orihuela, M. Riveros, R. Ascanio, G.H. Adler, T.D. Lambert and L. Balbas. 2001. Ecological meltdown in predator-free forest fragments. Science 294: 1923-1926.
403 Stolzenburg, W. 2008. Where the wild things were: life, death and ecological wreckage in a land of vanishing predators. Bloomsbury USA, New York, NY. 240pp.
404 Laliberte, A.S. and W.J. Ripple. 2004. Range contractions of North American carnivores and ungulates. BioScience 54(2): 123-138.
405 Soulé, M.E., J.A. Estes, B. Miller and D.L. Honnold. 2005. Strongly interacting species: conservation policy, management, and ethics. Bioscience 55: 168-176.
406 Bergerud, A.T. and J.P. Elliott. 1998. Wolf predation in a multiple-ungulate system in northern British Columbia. Canadian Journal of Zoology 76: 1551-1569.
407 Bergerud, A.T. and J.P. Elliott. 1986. Dynamics of caribou and wolves in northern British Columbia. Canadian Journal of Zoology 64: 1515-1529.
408 Ripple, W.J., E.J. Larsen, R.A. Renkin and D.W. Smith. 2001. Trophic cascades among wolves, elk and aspen on Yellowstone National Park's northern range. Biological Conservation 102: 227-234.
409 Ripple, W.J. and R.L. Beschta. 2003. Wolf reintroduction, predation risk, and cottonwood recovery in Yellowstone National Park. Forest Ecology and Management 184: 299-313.
410 Berger, J., P.B. Stacey, L. Bellis and M.P. Johnson. 2001. A mammalian predator-prey imbalance: grizzly bear and wolf extinction affect avian neotropical migrants. Ecological Applications 11: 947-960.
411 Wiens, J.A. 1989. Spatial scaling in ecology. Functional Ecology 3: 385-397.
412 D. Fraser, B.C. Ministry of Environment, personal communication.
413 Allombert, S., A.J. Gaston and J-L. Martin. 2005. A natural experiment on the impact of overabundant deer on songbird populations. Biological Conservation 126(1): 1-13.
414 Stockton, S.A., S. Allombert, A.J. Gaston and J-L. Martin. 2005. A natural experiment on the effects of high deer densities on the native flora of coastal temperate rain forests. Biological Conservation 126(1): 118-128.

415 Hobbs, N.T. 1996. Modification of ecosystems by ungulates. Journal of Wildlife Management 60: 695-713.
416 Singer, F.J., L.C. Zeigenfuss and D.T. Barnett. 2000. Elk, beaver and the persistence of willows in national parks: response to Keigley (2000). Wildlife Society Bulletin 28: 451-453.
417 Singer, F.J., L.C. Zeigenfus, R.G. Cates and D.T. Barnett. 1998. Elk, multiple factors, and the persistence of willows in national parks. Wildlife Society Bulletin 26: 419-428.
418 Forman, R.T.T. 2000. Estimate of the area affected ecologically by the road system in the United States. Conservation Biology 14: 31-35.
419 Wittmer, H.U., B.N. McLellan, R. Serrouya and C.D. Apps. 2007. Changes in landscape composition influence the decline of a threatened woodland caribou population. Journal of Animal Ecology 76:568-579.
420 B.C. Ministry of Water, Land and Air Protection. 2004. Accounts and Measures for Managing Identified Wildlife: Caribou – Version 2004. Biodiversity Branch, Victoria, BC. 29pp.
421 Mountain Caribou Technical Advisory Committee 2002. A Strategy for the Recovery of Mountain Caribou in British Columbia. B.C. Ministry of Water, Land and Air Protection, Victoria, BC. 73pp.
422 See endnote 419.
423 Dunster, J. and K. Dunster. 1996. Dictionary of Natural Resource Management. UBC Press, Vancouver, BC.
424 Polster, D.F. 1991. Natural Vegetation Succession and Sustainable Reclamation. Presentation to the Canadian Land Reclamation Association/ B.C. Technical and Research Committee on Reclamation, Kamloops, B.C., June 24–28, 1991. Available at: www.for.gov.bc.ca/nursery/fnabc/Proceedings/NatVegSuccsn.htm.
425 Pidwirny, M. and I.K. Barber. 2006. PhysicalGeography.net: Fundamentals (of Physical Geography) Online Textbook (2nd edition). University of British Columbia Okanagan. Available at: www.physicalgeography.net/about.html.
426 Whittle, C.A., L.C. Duchesne and T. Needham. 1997. The importance of buried seeds and vegetative propagation in the development of postfire plant communities. Environmental Review 5: 79-87.
427 Ryan, K.C. 2002. Dynamic interactions between forest structure and fire behavior in boreal ecosystems. Silva Fennica 36(1): 13-39.
428 Campbell, E.M. and J.A. Antos. 2003. Postfire succession in *Pinus albicaulis – Abies lasiocarpa* forests of southern British Columbia. Canadian Journal of Botany 81: 383-397.
429 Flannigan, M.D. and B.M. Wotton. 2007. Assessing Past, Current, and Future Fire Occurrence and Fire Severity in British Columbia. Canadian Forest Service. Available at: feu.scf.rncan.gc.ca/research/climate_change/activites/nat_bc_e.htm.
430 See endnote 426.
431 See endnote 428.
432 Keane, R.E., G.J. Cary, I.D. Davies, M.D. Flannigan, R.H. Gardner, S. Lavorel, J.M. Lenihan, C. Li and T.S. Rupp. 2004. A classification of landscape fire succession models: spatial simulations of fire and vegetation dynamics. Ecological Modelling 179: 3-27.
433 Stoffels, D. 2000. Natural Disturbance and Large Scale Vegetation Succession Scenarios for the Columbia Forest District Columbia Mountains Caribou Project. B.C. Ministry of Forests, Research Branch, Prince Rupert, BC. 23pp. Available at: www.for.gov.bc.ca/hre/LACH/pdf/land/lachm01.pdf.
434 Turner, J.S. and P.G. Krannitz. 2001. Conifer density increases in semi-desert habitats of British Columbia in the absence of fire. Northwest Science 75: 176-182.
435 See endnote 426.
436 See endnote 428.
437 DeLong, S.C. 1998. Natural disturbance rate and patch size distribution of forests in northern British Columbia: implications for forest management. Northwest Science 72: 35-48.
438 Gavin, D.G., L.B. Brubaker and K.P Lertzman. 2003. Holocene fire history of a coastal temperate rain forest based on soil charcoal radiocarbon dates. Ecology 84(1): 186-201.
439 Agee, J.K. 1994. Fire and weather disturbances in terrestrial ecosystems of the eastern Cascades. USDA Forest Service, Pacific Northwest Research Station, Portland, OR. General Technical Report PNW-GTR-320. 52pp. Available at: www.treesearch.fs.fed.us/pubs/6225.
440 See endnote 433.
441 See endnote 429.
442 Gayton, D.V. 2003. British Columbia grasslands: monitoring vegetation change. FORREX–Forest Research Extension Partnership, Kamloops, BC. FORREX Series 7. Available at: www.forrex.org/publications/forrexseries/series.asp.
443 Ibid.
444 Parminter, J. (co-author and co-editor). 1995. Biodiversity Guidebook – Forest Practices Code of British Columbia. B.C. Ministry of Forests and B.C. Ministry of Environment, Victoria, BC. 99pp. Available at: www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/biodiv/biotoc.htm.
445 B.C. Ministry of Agriculture, Food and Fisheries. 2004. Fire Effects on Rangeland. Fire Effects on Rangeland Factsheet Series No. 1. 4pp. Available at: www.agf.gov.bc.ca/range/publications/documents/fire1.pdf.
446 See endnote 426.
447 Keen, F.P. 1952. Insect enemies of western forests. United States Department of Agriculture Miscellaneous Publication 273. 280pp.
448 Ibid.
449 See endnote 426.
450 Parks Canada. 2000. Yoho National Park of Canada Management Plan: Summary of the Environmental Assessment. Available at: www.pc.gc.ca/docs/v-g/yoho/plan1/sec11/page1_e.asp.
451 See endnote 427.
452 See endnote 450.
453 McCullough, D.G., R.A. Werner and D. Neumann. 1998. Fire and insects in northern and boreal forest ecosystems of North America. Annual Review of Entomology 43: 107-127.

454 Drever, C.R., G. Peterson, C. Messier, Y. Bergeron and M. Flannigan. 2006. Can forest management based on natural disturbances maintain ecological resilience? Canadian Journal of Forest Research 36(9): 2285-2299.
455 Spies, T.A., M.A. Hemstrom, A. Youngblood and S. Hummel. 2006. Conserving old-growth forest diversity in disturbance-prone landscapes. Conservation Biology 20(2): 351-362.
456 Keane, R.E., G.J. Cary, I.D. Davies, M.D. Flannigan, R.H. Gardner, S. Lavorel, J.M. Lenihan, C. Li and T. S. Rupp. 2004. A classification of landscape fire succession models: spatial simulations of fire and vegetation dynamics. Ecological Modelling 17: 3-27.
457 See endnote 15.
458 Canadian Forest Service. 2007. Mountain Pine Beetle Biology. Available at: mpb.cfs.nrcan.gc.ca/biology/biology_e.html.
459 See endnote 15.
460 Safranyik, L. and A.L. Carroll. 2006. The biology and epidemiology of the mountain pine beetle in lodgepole pine forests. The mountain pine beetle: a synthesis of biology, management, and impacts on lodgepole pine. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. 304pp.
461 Unger, L. 1993. Mountain pine beetle. Forest Pest Leaflet. Canada-BC Partnership Agreement on Forest Resource Development: FRDA II. Fo 29-6/76-1993E.
462 E. Lofroth, B.C. Ministry of Environment, personal communication. To date, no research has been done to investigate this possible outcome.
463 Martin, K., A. Norris and M. Drever. 2006. Effects of bark beetle outbreaks on avian biodiversity in the British Columbia interior: implications for critical habitat management. B.C. Journal of Ecosystems and Management 7: 10-24. Available at: www.forrex.org/publications/jem/ISS38/vol7_no3_art2.pdf.
464 Anonymous. 2007. Beetle studies investigate effects on forest hydrology. Natural Resources Canada. Information Forestry. 3pp.
465 Bunnell, F.L., K.A. Squires and I. Houde. 2004. Evaluating the effects of large-scale salvage logging for mountain pine beetle on terrestrial and aquatic vertebrates. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Initiative Working Paper 2004-2. Available at: warehouse.pfc.forestry.ca/pfc/25154.pdf.
466 Boon, S. 2006. Determining the impact of MPB-killed forest and elevated harvesting on snow accumulation and the projected impacts on melt and peak flow. Forest Investment Account (FIA) Report, FIA Project M065006 (2005/06). Abstract available at: www.for.gov.bc.ca/hfd/library/fia/html/FIA2006MRunp001.htm.
467 Forest Practices Board. 2007. The effect of mountain pine beetle attack and salvage harvesting on streamflows. Special Investigation. FPB/SIR/16. 27pp. Available at: www.fpb.gov.bc.ca/s_investigations.htm.
468 See endnote 463.
469 See endnote 15.
470 Wong, C., H. Sandmann and B. Dorner. 2004. Historical variability of natural disturbances in British Columbia: a literature review. FORREX–Forest Research Extension Partnership, Kamloops, BC. FORREX Series 12. Available at: www.forrex.org/publications/forrexseries/series.asp.
471 Ibid.
472 Huggard, D.J, W. Klenner and A. Vyse. 2000. Identifying and managing fauna sensitive to forest management: examples from the Sicamous Creek and Opax Mountain Silvicultural Systems Sites. Pp. 235-239 *in* L.M. Darling (ed). Proceedings of a Conference on the Biology and Management of Species and Habitats at Risk, Kamloops, B.C., Feb. 15-19, 1999. Volume 1. B.C. Ministry of Environment, Lands and Parks, Victoria, BC and University College of the Cariboo, Kamloops, BC. 490pp.
473 Nordyke, K.A. and S.W. Buskirk. 1991. Southern red-backed vole, *Clethrionomys gapperi*, populations in relation to stand succession and old-growth character in the central Rocky Mountains. Canadian Field-Naturalist 105: 330-34.
474 Maser, C. and Z. Maser. 1988. Mycophagy of red-backed voles *Clethrionomys californicus* and *Clethrionomys gapperi*. Great Basin Naturalist. 48(2): 269-273.
475 Holt, R. and T. Hatfield. 2007. Key Elements of Biodiversity in British Columbia: Some Examples From the Terrestrial and Freshwater Aquatic Realm. Biodiversity BC, Victoria, BC. 70pp. Available at: www.biodiversitybc.org.
476 Hayes, J.P. and S.P. Cross. 1987. Characteristics of logs used by western red-backed voles, *Clethrionomys californicus*, and deer mice, *Peromyscus maniculatus*. Canadian Field-Naturalist 101: 543-46.
477 Clarkson, D.A. and L.S. Mills. 1994. Hypogeous sporocarps in forest remnants and clearcuts in southwest Oregon. Northwest Science 68:259-65.
478 Ibid.
479 See endnote 390.
480 Fenger, M., T. Manning, J. Cooper, S. Guy and P. Bradford. 2006. Wildlife and Trees in British Columbia. Lone Pine Publishing, Edmonton, AB. 336pp.
481 Ibid.
482 Martin, K. and J.M. Eadie. 1999. Nest webs: a community wide approach to the management and conservation of cavity nesting birds. Forest Ecology and Management 115: 243-257.
483 See endnote 480.
484 Ibid.
485 Simard, S. and A. Vyse. 2006. Trade-offs between competition and facilitation: a case study of vegetation management in the interior cedar-hemlock forests of southern British Columbia. Canadian Journal of Forest Research 36(10): 2486-2496.
486 Sachs, D.L. 1996. Simulation of the growth of mixed stands of Douglas-fir and paper birch using the FORECAST model. Pp. 152-158 *in* P. Comeau and K.D. Thomas (eds.). Silviculture of Temperate and Boreal Broadleaved-conifer Mixtures. B.C. Ministry of Forests, Research Branch, Victoria, BC. Land Management Handbook 36. 163pp.

487 Gerlach, J.P., P.B. Reich, K. Puettmann and T. Baker. 1997. Species, diversity, and density affect tree seedling mortality from *Armillaria* root rot. Canadian Journal of Forest Research 27: 1509-1512.
488 Arsenault, A. and T. Goward. 1999. The drip zone effect: new insights into the distribution of rare lichens. Pp. 767-768 *in* L.M. Darling (ed.). Proceedings of a Conference on the Biology and Management of Species and Habitats at Risk, Kamloops, B.C., Feb. 15-19, 1999. Volume 2. B.C. Ministry of Environment, Lands and Parks, Victoria, BC and University College of the Cariboo, Kamloops, BC. 520pp.
489 S. Simard, University of British Columbia, personal communication.
490 See endnote 390.
491 Holt, R.F. 2001. A Strategic Ecological Restoration Assessment (SERA) in the Forest Regions of British Columbia. Summary: Ecological Restoration Priorities by Region. Unpublished report prepared for B.C. Ministry of Environment, Habitat Branch, Victoria, BC.
492 Holt, R.F., G. Utzig, M. Carver and J. Booth. 2003. Biodiversity Conservation in BC: An Assessment of Threats and Gaps. Unpublished report prepared for B.C. Ministry of Environment, Biodiversity Branch, Victoria, BC. Available at: www.veridianecological.ca/publications/Veridian_Bio_Gaps_Report_final.pdf.
493 B.C. Conservation Data Centre. 2007. BC Species and Ecosystems Explorer. Available at: www.env.gov.bc.ca/atrisk/toolintro.html.
494 See endnote 129.
495 See endnote 390.
496 Lavkulich, L.M. and K.W.G. Valentine. 2007. The Soil Landscapes of British Columbia: Soil And Soil Processes. B.C. Ministry of Environment, Victoria, BC. Available at: www.env.gov.bc.ca/soils/landscape/2.2soil.html.
497 Millar, C.E., L.M. Turk and H.D. Foth. 1965. Fundamentals of Soil Science, 4th edition. Wiley, New York, NY. 491pp.
498 B.C. Ministry of Forests. 2002. Stand Level Components of Biodiversity: Module 3D – Forest Floor. Available at: www.for.gov.bc.ca/hfp/training/00001/module03/forest-floor.htm.
499 Alberta Environment. 2008. Land contamination. Available at: www.environment.alberta.ca/1015.html.
500 Atwood, L.B. and P.G. Krannitz. 1999. Effect of the microbiotic crust of the antelope brush (*Purshia tridentata*) shrub-steppe on soil moisture. Pp. 809-812 *in* L.M. Darling (ed.). Proceedings of a Conference on the Biology and Management of Species and Habitats at Risk, Kamloops, B.C., Feb. 15-19, 1999. Volume 2. B.C. Ministry of Environment, Lands and Parks, Victoria, BC and University College of the Cariboo, Kamloops, BC. 520pp.
501 Williston, P. 2000. A lust for crust: successional microbiotic crusts in British Columbia. Botanical Electronic News 251.
502 See endnote 426.
503 Harmon, M.E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R. Sedell, G.W. Lienkaemper, K. Cromack Jr. and K.W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research 15: 133-302.
504 B.C. Ministry of Forests. No date. Module 3: Stand Level Components of Biodiversity. Module 3C Coarse Woody Debris. Available on the internet at: www.for.gov.bc.ca/hfp/training/00001/module03/cwd.htm. Access date: October 10, 2007.
505 Caza, C.L. 1993. Woody debris in the forests of B.C.: a review of the literature and current research. B.C. Ministry of Forests, Victoria, BC. Land Management Report 78. 112pp.
506 Maser, C. and J.R. Sedell (eds.). 1994. From the forest to the sea: the ecology of wood in streams, rivers, estuaries, and oceans. St. Lucie Press, FL.
507 B.C. Ministry of Forests. 2007. State of Cutblocks: Resource Stewardship Monitoring for Stand-level Biodiversity 2005. Forest Practices Branch, Victoria, BC. FREP Report 7. 14pp. Available at: www.for.gov.bc.ca/hfp/frep/site_files/reports/FREP_Report_07.pdf.
508 Densmore, N., J. Parminter and V. Stevens. 2004. Coarse woody debris: inventory, decay modelling, and management implications in three biogeoclimatic zones. BC Journal of Ecosystems and Management 5(2): 14-29. Available at: www.forrex.org/publications/jem/jem.asp?issue=26.
509 Durst, J.D. and J. Ferguson. 2000. Large woody debris: an annotated bibliography. Alaska Department of Fish and Game, Habitat and Restoration Division. 60pp. Available at: forestry.alaska.gov/pdfs/3Lit-LWD8-11.pdf.
510 Deil, U. 2005. A review on habitats, plant traits and vegetation of ephemeral wetlands – a global perspective. Phytocoenologia 35(2-3): 533-705.
511 Meyer, J.L, L.A. Kaplan, D. Newbold, D.L. Strayer, C.J. Woltemade, J.B. Zedler, R. Beilfuss, Q. Carpenter, R. Semlitsch, M.C. Watzin and P.H. Zedler. 2003. Where Rivers Are Born: The Scientific Imperative for Defending Small Streams and Wetlands. Sierra Club and American Rivers. 26pp. Available at: www.americanrivers.org/site/PageServer?pagename=AR7_Publications.
512 Naugle, D.E., R.R. Johnson, M.E. Estey and K.F. Higgins. 2000. A landscape approach to conserving wetland bird habitat in the prairie pothole region of eastern South Dakota. Wetlands 20: 588-604.
513 Maret, T.J., J.D. Snyder and J.P. Collins. 2006. Altered drying regime controls distribution of endangered salamanders and introduced predators. Biological Conservation 127: 129-138.
514 Batzer, D.P. and S.A. Wissinger. 1996. Ecology of insect communities in nontidal wetlands. Annual Review of Entomology 41: 75-100.
515 Brock, M.A., D.L. Nielsen, D.L., R.L., Shiel, J.D. Green and J.D. Langley. 2003. Drought and aquatic community resilience: the role of eggs and seeds in sediments of temporary wetlands. Freshwater Biology 48: 1207-1218.
516 B.C. Ministry of Environment, Lands and Parks. 1993. State of the Environment Report for British Columbia. B.C. Ministry of Environment, Lands and Parks, Victoria, BC and Environment Canada, Communications, Pacific and Yukon Region, North Vancouver, BC. 127pp. Available at: www.env.gov.bc.ca/soe/.
517 Ibid.

518 Boyle, C.A., L. Lavkulich, H. Schreier and E. Kiss. 1997. Changes in land cover and subsequent effects on Lower Fraser Basin ecosystems from 1827 to 1990. Environmental Management 21(2): 185-196.
519 Moore, K. and K. Roger. 2003. Urban and Agricultural Encroachment onto Fraser Lowland Wetlands – 1989 to 1999. *In* Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference. Puget Sound Action Team, Olympia, WA.
520 Prentice, A.C. and W.S. Boyd. 1988. Intertidal and Adjacent Upland Habitat in Estuaries Located on the East Coast of Vancouver Island: A Pilot Assessment of Their Historical Changes. Canadian Wildlife Service, Pacific and Yukon Region, Delta, BC. Technical Report Series No. 38.
521 Axys Environmental Consulting Ltd. 2005. Redigitizing of Sensitive Ecosystems Inventory Polygons to Exclude Disturbance Areas: A Summary Report. Prepared for Canadian Wildlife Service, Pacific and Yukon Region, Delta, BC.
522 National Wetlands Working Group. 1988. Wetlands of Canada. Environment Canada, Sustainable Development Branch, Ottawa, ON and Polyscience Publications Inc., Montreal, PQ. Ecological Land Classification Series No. 24. 452pp.
523 See endnote 192.
524 Wilson, S.J. and R.J. Hebda. 2008. Mitigating and adapting to climate change through the conservation of nature. The Land Trust Alliance of British Columbia, Saltspring Island, BC. 58pp.
525 Mackenzie, W.H. and J.R. Moran. 2004. Wetlands of B.C.: a guide to identification. Land Management Handbook 5. B.C. Ministry of Forests, Research Branch, Victoria, BC. 297pp. Available at: www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/Lmh52.htm.
526 Ibid.
527 Howie, S. 2002. A look at Burns Bog. Davidsonia 13(4): 76-94.
528 Hebda, R.J., K. Gustavson, K. Golinski and A.M. Calder. 2000. Burns Bog Ecosystem Review. Synthesis Report for Burns Bog, Fraser River Delta, South-western British Columbia, Canada. Environmental Assessment Office, Victoria, BC. 271pp.
529 Rydin, H. and J.K. Jeglum. 2006. The Biology of Peatlands. Oxford University Press, Oxford, UK. 360pp.
530 Andrus, R.E. 1986. Some aspects of *Sphagnum* ecology. Canadian Journal of Botany 64: 416-426.
531 Greater Vancouver Regional District. 2007. Burns Bog Ecological Conservancy Area Draft Management Plan. 29pp. Available at: www.gvrd.bc.ca/board/archive2007/agendas/gvrd/may/E6.1.pdf.
532 Cannings, S.G. and R.A. Cannings. 1994. The Odonata of the northern Cordilleran peatlands of North America. Memoirs of the Entomological Society of Canada 169: 89-110.
533 See endnote 528.
534 See endnote 527.
535 Smith, C., J. Morissette, S. Forest, D. Falk and E. Butterworth. 2007. Synthesis of Technical Information on Forest Wetlands in Canada. National Council for Air and Stream Improvement, Inc., Research Triangle Park, NC. Technical Bulletin No. 938.
536 Rochefort, L. 2000. *Sphagnum*: a keystone genus in habitat restoration. Bryologist 103(3): 503-508.
537 Andrus, R.E. 1986. Some aspects of *Sphagnum* ecology. Canadian Journal of Botany 64: 416-426.
538 See endnote 390.
539 Keddy, P.A. and A.A. Reznicek. 1986. Great Lakes vegetation dynamics: the role of fluctuating water levels and buried seeds. Journal of Great Lakes Research 12: 25-36.
540 Turner, M.A., D.B. Huebert, D.L. Findlay, L.L. Hendzel, W.A. Jansen, R.A. Bodaly, L.M. Armstrong and S.E.M. Kasian. 2005. Divergent impacts of experimental lake-level draw down on planktonic and benthic plant communities in a boreal forest lake. Canadian Journal of Fisheries and Aquatic Sciences 62: 991-1003.
541 Fraley, J. and J. Decker-Hess. 2006. Effects of stream and lake regulation on reproductive success of kokanee in the Flathead River system, Montana, U.S.A. Regulated Rivers: Research and Management 1(3): 257-265.
542 Andrusak, H., S. Matthews, I. McGregor, K. Ashley, R. Rae, A. Wilson, J. Webster, G. Andrusak, L. Vidmanic, J. Stockner, D. Sebastian, G. Scholten, P. Woodruff, , G. Wilson, , B. Jantz, D. Bennett, H. Wright, R. Withler and S. Harris. 2005. Okanagan Lake Action Plan Year 9 (2004) Report. B.C. Ministry of Environment, Biodiversity Branch, Victoria, BC. Fisheries Project Report No. RD 111.
543 Hecky, R.E. and R.H. Hesslein. 1995. Contributions of benthic algae to lake food webs as revealed by stable isotope analysis. Journal of the North American Benthological Society 14: 631-653.
544 Rorslett, B. 1989. An integrated approach to hydropower impact assessment. Hydrobiologia 175: 65-82
545 Hellsten, S., M. Marttunen, R. Palomaki, J. Riihimaki and E.A. Alasaarela. 1996. Towards an ecologically based regulation practice in Finnish hydroelectric lakes. Regulated Rivers: Research and Management 12: 535-545.
546 Paller, M.H. 1997. Recovery of a reservoir fish community from drawdown related impacts. North American Journal of Fisheries Management 17: 726-733.
547 See endnote 540.
548 Magee, T.K. and M.E. Kentula. 2005. Response of wetland plant species to hydrologic conditions. Wetlands Ecology and Management 13: 163-181.
549 See endnote 540.
550 Wilcox, D.A., and J.E. Meeker. 1991. Disturbance effects on aquatic vegetation in regulated and unregulated lakes in northern Minnesota. Canadian Journal of Botany 69:1542-1551.
551 Cooke, G.D. 1980. Lake level drawdown as a macrophyte control technique. Water Resources Bulletin 16: 317-322.
552 James, W.F., J.W. Barko, H.L. Eakin and D.R. Helsel. 2001. Changes in sediment characteristics following drawdown of Big Muskego Lake, Wisconsin. Archiv Für Hydrobiologie 151: 459-474.
553 Kadlec, J.A. 1962. Effects of a drawdown on a waterfowl impoundment. Ecology: 267-281.
554 Cohen, Y. and P. Radomski. 1993. Water level regulations and fisheries in Rainy Lake and the Namakan Reservoir. Canadian Journal of Fisheries and Aquatic Sciences 50: 1934-1945.

555 See endnote 546.
556 See endnote 540.
557 Montgomery, D.R. and J.M. Buffington. 1997. Channel-reach morphology in mountain drainage basins. GSA Bulletin 109: 596-611.
558 Gomi, T., R.C. Sidle and J.S Richardson. 2002. Understanding processes and downstream linkages of headwater systems. BioScience 52: 905-916.
559 See endnote 557.
560 See endnote 558.
561 T. Johnson, B.C. Ministry of Environment, personal communication.
562 Sophocleous, M. 2002. Interactions between groundwater and surface water: the state of the science. Hydrogeology Journal 10: 52-67.
563 Hynes, H.B.N. 1983. Groundwater and stream ecology. Hydrobiologia 100: 93-99.
564 Harvey, B.C., R.J. Nakamoto and J.L. White. 2006. Reduced streamflow lowers dry-season growth of rainbow trout in a small stream. Transactions of the American Fisheries Society 135: 998-1005.
565 Bradford, M.J., G.C. Taylor and J.A. Allan. 1997. Empirical review of coho salmon smolt abundance and the prediction of smolt production at the regional level. Transactions of the American Fisheries Society 126: 49-64.
566 Baxter, J.S. and J.D. McPhail. 1999. The influence of redd site selection, groundwater upwelling, and over-winter incubation temperature on survival of bull trout (*Salvelinus confluentus*) from egg to alevin. Canadian Journal of Zoology 77: 1233-1239.
567 Bradford, M.J., J.A. Grout and S. Moodie. 2001. Ecology of juvenile chinook salmon in a small non-natal stream of the Yukon River drainage and the role of ice conditions on their distribution and survival. Canadian Journal of Zoology 79: 2043-2054.
568 Torgersen, C.E., D.M. Price, H.W. Li and B.A. McIntosh. 1999. Multiscale thermal refugia and stream habitat associations of chinook salmon in northeastern Oregon. Ecological Applications 9: 301-319.
569 See endnote 566.
570 Lorenz, J.M. and J.H. Eiler. 1989. Spawning habitat and redd characteristics of sockeye salmon in the glacial Taku River, British Columbia and Alaska. Transactions of the American Fisheries Society 118: 495-502.
571 Leman, V.N. 1993. Spawning sites of chum salmon, *Oncorhynchus keta*: microhydrological regime and viability of progeny in redds (Kamchatka River basin). Journal of Ichthyology 33: 104-117.
572 Curry, R.A., J. Gehrels, D.L.G. Noakes and R. Swainson. 1994. Effects of river flow fluctuations on groundwater discharge through brook trout, *Salvelinus fontinalis*, spawning and incubation habitats. Hydrobiologia 277: 121-134.
573 Garrett, J.W., D.H. Bennett, F.O. Frost and R.F. Thurow. 1998. Enhanced incubation success for kokanee spawning in groundwater upwelling sites in a small Idaho stream. North American Journal of Fisheries Management 18: 925-930.
574 See endnote 568.
575 Geist, D.R. 2000. Hyporheic discharge of river water into fall chinook salmon (*Oncorhynchus tshawytscha*) spawning areas in the Hanford Reach, Columbia River. Canadian Journal of Fisheries and Aquatic Sciences 57: 1647-1656.
576 Boulton, A.J., S. Findlay, P. Marmonier, E.H. Stanley and H.M. Valett. 1998. The functional significance of the hyporheic zone in streams and rivers. Annual Review of Ecology and Systematics 29: 59-81.
577 Stanford, J.A. and J.V. Ward. 1988. The hyporheic habitat of river ecosystems. Nature 335: 64-66.
578 See endnote 576.
579 Edwards, R.T. 1998. The hyporheic zone. *In* R.J. Naiman and R.E. Bilby (eds.). River Ecology and Management. Springer, New York, NY. 705pp.
580 Pillipow, R. and C. Williamson. 2004. Goat River bull trout (*Salvelinus confluentus*) biotelemetry and spawning assessments 2002–2003. BC Journal of Ecosystems and Management 4(2): 1-9. Available at: www.forrex.org/publications/jem/jem.asp?issue=24.
581 Smerdon, B. and T. Redding. 2006. Groundwater: more than water below the ground! Streamline Watershed Management Bulletin 10(2): 1-6.
582 B.C. Ministry of Water, Land and Air Protection. 2002. Status and Trends in Groundwater Supply. *In* Environmental Trends in British Columbia 2002. State of the Environment Reporting Office, Victoria, BC. Available at: www.env.gov.bc.ca/soerpt/7groundwater/wells.html.
583 Ibid.
584 Sophocleous, M. 2000. From safe yield to sustainable development of water resources – the Kansas experience. Journal of Hydrology 235: 27-43.
585 See endnote 562.
586 Stanford, J.A. and J.V. Ward. 1993. An ecosystem perspective of alluvial rivers: connectivity and the hyporheic corridor. Journal of the North American Benthological Society 12: 48-60.
587 Brunke, M. and T. Gonser. 1997. The ecological significance of exchange processes between rivers and groundwater. Freshwater Biology 37: 1-33.
588 Ibid.
589 Allen, D.M., D.C. Mackie and M. Wei. 2004. Groundwater and climate change: a sensitivity analysis for the Grand Forks aquifer, southern British Columbia, Canada. Hydrogeology Journal 12: 270-290.
590 Scibek, J. 2005. Modelling the impacts of climate change on groundwater: a comparative study of two unconfined aquifers in southern British Columbia and northern Washington State. M.Sc. thesis, Simon Fraser University, Burnaby, BC.
591 Booth, D.B., D. Hartley and R. Jackson. 2002. Forest cover, impervious-surface area, and the mitigation of stormwater impacts. Journal of the American Water Resources Association 38: 835-845.
592 Wang, L., J. Lyons and P. Kanehl. 2002. Impacts of urbanization on stream habitat and fish across multiple spatial scales. Environmental Management 28: 255-266.
593 Boulton, A.J., M.R. Scarsbrook, J.M. Quinn and G.P. Burrell. 1997. Land-use effects on the hyporheic ecology of five small streams near Hamilton, New Zealand. New Zealand Journal of Marine and Freshwater Research 31: 609-622.

594 See endnote 584.
595 Pearson, M.P., T. Hatfield, J.D. McPhail, J.S. Richardson, J.S. Rosenfeld, H. Schreier, D. Schluter, D.J. Sneep, M. Stejpovic, E.B. Taylor and P.M. Wood. 2006. Recovery Strategy for Nooksack Dace (*Rhinichthys cataractae*) in Canada [Proposed]. Species at Risk Act Recovery Strategy Series. Fisheries and Oceans Canada, Vancouver, BC. 31pp.
596 Hyatt, K., M.S. Johannes and M. Stockwell. 2006. Appendix I: Pacific Salmon. *In* B.G. Lucas, S. Verrin, and R. Brown (eds.). Ecosystem Overview: Pacific North Coast Integrated Management Area (PNCIMA). Canadian Technical Report of Fisheries and Aquatic Science 2667. 101pp.
597 Cederholm, C.J., D.H. Johnson, R.E. Bilby, L.G. Dominguez, A.M. Garrett, W.H. Graeber, E.L. Greda, M.D. Kunze, B.G. Marcot, J.F. Palmisano, R.W. Plotnikoff, W.G. Pearcy, C.A. Simenstad and P.C. Trotter. 2000. Pacific Salmon and Wildlife—Ecological Contexts, Relationships, and Implications for Management. Special Edition Technical Report. Prepared for D.H. Johnson and T.A. O'Neil (Managing directors), Wildlife-Habitat Relationships in Oregon and Washington. Washington Department of Fish and Wildlife, Olympia, WA. 768pp.
598 Wilkinson, C.E., M.H. Hocking and T.E. Reimchen. 2005. Uptake of salmon-derived nitrogen by mosses and liverworts in Coastal British Columbia. Oikos 108: 85-98.
599 Wipfli, M.S., J.P. Hudson and J.P. Caouette. 1998. Influence of salmon carcasses on stream productivity: response of biofilm and benthic macroinvertebrates in southeastern Alaska, U.S.A. Canadian Journal of Fisheries and Aquatic Sciences 55: 1503-1511.
600 Wipfli, M.S., J.P. Hudson, J.P. Caouette, and D.T. Chaloner. 2003. Marine subsidies in freshwater ecosystems: salmon carcasses increase the growth rates of stream-resident salmonids. Transactions of the American Fisheries Society 132: 371-381.
601 Moore, J.W. and D.E. Schindler. 2004. Nutrient export from freshwater ecosystems by anadromous sockeye salmon (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences 61: 1582-1589.
602 Scheuerell, M.D., P.S. Levin, R.W. Zabel, J.G. Williams and B.L. Sanderson. 2005. A new perspective on the importance of marine-derived nutrients to threatened stocks of Pacific salmon (*Onchorhynchus* spp.). Canadian Journal of Fisheries and Aquatic Sciences 62: 961-964.
603 B.C. Ministry of Environment. 2006. Fisheries. Technical paper for British Columbia's Coastal Environment: 2006. State of Environment Reporting Office, Victoria, BC. 57pp. Available at: www.env.gov.bc.ca/soe/bcce/04_fisheries/technical_paper/fisheries.pdf.
604 Slaney, T.L., K.D. Hyatt, T.G. Northcote and R.J. Fielden. 1996. Status of anadromous salmon and trout in British Columbia and Yukon. Fisheries 21: 20-35.
605 Larkin, G.A. and P.A. Slaney. 1997. Implications of trends in marine-derived nutrient influx to south coastal British Columbia salmonid production. Fisheries 22: 16-24.
606 Himmer, S. and J. Boulanger. 2003. Trends in grizzly bears utilizing salmon streams in the Owikeno Lake system: 1998–2002. Report prepared for Western Forest Products and the B.C. Ministry of Water, Land and Air Protection, William's Lake, BC. 32pp.
607 Austin, M. 2000. B.C. bears in trouble. International Bear News. 9(2): 13.
608 See endnote 606.
609 Bradford, M.J. and Irvine, J.R. 2000. Land use, fishing, climate change, and the decline of Thompson River, British Columbia, coho salmon. Canadian Journal of Fisheries and Aquatic Sciences 57: 13-16.
610 B.C. Ministry of Environment. 2006. Fisheries. Technical paper for British Columbia's Coastal Environment: 2006. State of Environment Reporting Office, Victoria, BC. 57pp. Available at: www.env.gov.bc.ca/soe/bcce/04_fisheries/technical_paper/fisheries.pdf.
611 Morrison, J., M.C. Quick and M.G.G. Foreman. 2002. Climate change in the Fraser River watershed: flow and temperature projections. Journal of Hydrology 263: 230-244.
612 Leith, R. and P. Whitfield. 1998. Evidence of climate change effects on the hydrology of streams in south-central B.C. Canadian Water Resources Journal 23: 219-230.
613 B.C. Ministry of Environment. 2002. What is the Relationship Between Climate and Migration Success of Sockeye Salmon? *In* Environmental Trends in British Columbia 2002. State of the Environment Reporting Office, Victoria, BC. Available at www.env.gov.bc.ca/soerpt/997climate/salmon.html.
614 Bonar, S.A., B.D. Bolding, M. Divens and W. Meyer. 2005. Effects of introduced fishes on wild juvenile coho salmon in three shallow Pacific Northwest lakes. Transactions of the American Fisheries Society 134: 641-652.
615 Fayram, A.H. and T.H. Sibley. 2000. Impact of predation by smallmouth bass on sockeye salmon in Lake Washington, Washington. North American Journal of Fisheries Management 20: 81-89.
616 Parmesan, C. and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421: 37-42.
617 Stefan, H.G., X. Fang and J.G. Eaton. 2001. Simulated fish habitat changes in North American lakes in response to projected climate warming. Transactions of the American Fisheries Society 130:459-477.
618 Welch, D.W., Y. Ishida and K. Nagasawa. 1998. Thermal limits and ocean migrations of sockeye salmon (*Oncorhynchus nerka*): long-term consequences of global warming. Canadian Journal of Fisheries and Aquatic Sciences 55: 937-948.
619 Nelitz, M., K. Wieckowski, D. Pickard, K. Pawley and D.R. Marmorek. 2007. Helping Pacific Salmon Survive the Impact of Climate Change on Freshwater Habitats. Pacific Fisheries Resource Conservation Council, Vancouver, BC. 122pp.
620 Walters, C.J. and M.J. Staley. 1987. Evidence against the existence of cyclic dominance in Fraser River sockeye salmon (*Oncorhynchus nerka*). Pp. 375-384 *in* H.D. Smith, L. Margolis and C.C. Wood (eds.). Sockeye salmon (*Oncorhynchus nerka*) population biology and future management. Canadian Special Publication of Fisheries and Aquatic Sciences 96.

621 Irvine, J.R. 2002. COSEWIC status report on the coho salmon *Oncorhynchus kisutch* (Interior Fraser population) in Canada, in COSEWIC assessment and status report on the coho salmon *Oncorhynchus kisutch* (Interior Fraser population) in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, ON. 34pp.
622 COSEWIC. 2003. COSEWIC assessment and status report on the sockeye salmon *Oncorhynchus nerka* (Cultus population) in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, ON. 57pp.
623 COSEWIC. 2003. COSEWIC assessment and status report on the Sockeye Salmon *Oncorhynchus nerka* (Sakinaw population) in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, ON. 35pp.
624 Krkošek, M., J.S. Ford, A. Morton, S. Lele, R.A. Myers and M.A. Lewis. 2007. Declining wild salmon populations in relation to parasites from farm salmon. Science 318: 1772-1775.
625 See endnote 596.
626 Ibid.
627 Brayshaw, T.C. 1996. Catkin-bearing Plants of British Columbia. Royal British Columbia Museum, Victoria, BC. 213pp.
628 Hoag, J.C., N. Melvin and D. Tilley. 2007. Wetland Plants: Their Function, Adaptation and Relationship to Water Levels. United States Department of Agriculture, Natural Resources Conservation Service Plant Materials Center, Aberdeen, ID. Riparian/Wetland Project Information Series No. 21. 15pp.
629 J. Penny, B.C. Conservation Data Centre, personal communication.
630 Broberg, C.L., J.H. Borden and L.M. Humble. 2002. Distribution and abundance of *Cryptorhynchus lapathi* on *Salix* spp. in British Columbia. Canadian Journal of Forest Research 32: 561-568.
631 Garbutt, R. and J.W.E. Harris. No date. Poplar and willow borer. Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Available at: www.pfc.cfs.nrcan.gc.ca/diseases/hforest/Pests/popwilbo_e.html.
632 Pandion Ecological Research. 2001. Wildlife-Habitat Relationships in the Columbia River Basin: A British Columbia Database for Terrestrial Vertebrate Species. B.C. Ministry of Forests, Research and Forest Practices Branch, Victoria, BC. Unpublished report. 50pp.
633 Pollock, M.M., R.J. Naiman, H.E. Erickson, C.A. Johnstone, J. Pastor and G. Pinay. 1995. Beaver as engineers: influences on biotic and abiotic characteristics of drainage basins. Pp. 117-126 *in* C.G. Jones and J. H. Lawton (eds.). Linking Species and Ecosystems. Chapman and Hall, New York, NY. 387pp.
634 Muller-Schwarze, D. and L. Sun. 2003. The Beaver: Natural History of a Wetlands Engineer. Comstock Books, Ithaca, NY. 208pp.
635 Butler, D.R. and G.P. Malanson. 2004. The geomorphic influences of beaver dams and failures of beaver dams. Geomorphology 71: 48-60.
636 Bailey, J.K. and T.G. Whitham. 2006. Interactions between cottonwood and beavers positively affect sawfly abundance. Ecological Entomology 31:294-297.
637 B.C. Ministry of Environment. No date. Beaver: Management Guidelines in British Columbia. Wildlife Branch, Victoria, BC. 6pp. Available at: wlapwww.gov.bc.ca/vir/pa/beaver_mgt.pdf.
638 Ibid.
639 See endnote 390.
640 Crawley, M.J. 1988. Herbivores and plant population dynamics. Pp. 1.67-1.92 *in* A.J. Davy, M.J. Hutchings and A.R. Watkinson (eds.). Plant Population Ecology. Blackwell, Oxford, UK.
641 Huntly, N. 1991. Herbivores and the dynamics of communities and ecosystems. Annual Review of Ecological Systems 22: 477-503.
642 Idestam-Almquist, J. 1998. Waterfowl herbivory on *Potamogeton pectinatus* in the Baltic Sea. Oikos 81(2): 323-328.
643 Rodrıguez-Villafane, C., E. Becares and M. Fernandez-Alaez. 2007. Waterfowl grazing effects on submerged macrophytes in a shallow Mediterranean lake. Aquatic Botany 86: 25-29.
644 Heck, K.L. Jr. and J.F. Valentine. 2006. Plant–herbivore interactions in seagrass meadows. Journal of Experimental Marine Biology and Ecology 330: 420-436.
645 Druehl, L. 2000. Pacific Seaweeds: A Guide to Common Seaweeds of the West Coast. Harbour Publishing, Madeira Park, BC. 190pp.
646 Polis, G.A. and S.D. Hurd. 1996. Linking marine and terrestrial food webs: allochtonous input from the ocean supports high secondary productivity on small islands and coastal land communities. American Naturalist 147: 396-423.
647 Bodkin, J.L. 1988. Effects of kelp forest removal on associated fish assemblages in central California. Journal of Experimental Marine Biology and Ecology 117: 227-238.
648 Ebeling, A.W. and D.R. Laur. 1988. Fish populations in kelp forest without sea otters: effects of severe storm damage and destructive sea urchin grazing. Pp. 169-191 *in* The Community Ecology of the Sea Otter. G.R. VanBlaricom and J.A. Estes (eds.). Ecological Studies, Vol. 65. Springer-Verlag, Heidelberg, Germany.
649 Laur, D.R., A.W. Ebeling and D.A. Coon. 1988. Effects of sea otter foraging on subtidal reef communities off central California. Pp. 151-168 *in* Community Ecology of the Sea Otter. G.R. VanBlaricom and J.A. Estes (eds.). Ecological Studies, Vol. 65. Springer-Verlag, Heidelberg, Germany.
650 Duggins, D.O. E.J. Eckman and A.T. Sewell. 1990. Ecology of understory kelp environments. II. Effects of kelp on recruitment of benthic invertebrates. Journal of Experimental Marine Biology and Ecology 143: 27-45.
651 Carr, M.H. 1991. Habitat selection and recruitment of an assemblage of temperate zone reef fishes. Journal of Experimental Marine Biology and Ecology 146: 113-137.
652 National Recovery Strategy Team. 2003. National Recovery Strategy for the Sea Otter (*Enhydra lutris*) in British Columbia [draft]. 52pp.
653 Watson, J. 2007. Continued support of sea otter research in BC. The Log: Friends of Ecological Reserves Newsletter. Autumn issue: 8.
654 Ibid.

655 Gillespie, G.E. 1999. Stock assessment and management framework for the proposed fishery for sea mussel (*Mytilus californianus*) in British Columbia. Pacific Scientific Advice Review Committee, Fisheries and Oceans Canada. PSARC Working Paper 99/116. 46pp.
656 D. Biffard, B.C. Ministry of Environment, personal communication.
657 See endnote 655.
658 Smith, J.R., P. Fong and R.F. Ambrose. 2006. Dramatic declines in mussel bed community diversity: response to climate change? Ecology 87(5): 1153-1161.
659 Reidman, M.L. and J.A. Estes. 1990. The Sea Otter (*Enhydra lutris*): Behavior, Ecology and Natural History. U.S. Fish and Wildlife Service. Biology Report 90(14). 126pp.
660 Sea Otter Recovery Team. 2007. Recovery Strategy for the Sea Otter (*Enhydra lutris*) in Canada. Fisheries and Oceans Canada, Vancouver, BC. 56pp.
661 Watson, J.C. 1993. The effects of the sea otter (*Enhydra lutris*) foraging on shallow rocky communities off northwestern Vancouver Island, British Columbia. Ph.D. dissertation, University of California, Santa Cruz. 169pp.
662 Lowry, I.F. and J.S. Pearce. 1973. Abalones and sea urchins in an area inhabited by sea otters. Marine Biology 23: 213-219.
663 Farr, A.C.M. and F.L. Bunnell. 1980. The sea otter in British Columbia – a problem or opportunity? Pp. 110-128 *in* R. Stace-Smith, L. Johns and P. Joslin (eds.). Threatened and Endangered Species and Habitats in British Columbia and the Yukon. Fish and Wildlife Branch, B.C. Ministry of Environment, Victoria, BC.
664 COSEWIC. 2007. COSEWIC assessment and update status report on the sea otter *Enhydra lutris* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, ON. 36pp.
665 See endnote 660.
666 The Royal Society. 2005. Ocean acidification due to increasing atmospheric carbon dioxide. The Royal Society, London. UK. Policy document 12/05. 60pp. Available at: royalsociety.org/document.asp?id=3249.
667 Orr, J.C., V.J. Fabry, O. Aumont, L. Bopp, S.C. Doney, R.A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joose, R.M. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R.G. Najjar, G.K. Plattner, K.B. Rodgers, D.L. Savine, J.L. Sarmiento, R. Schlitzer, R.D. Slater, I.J. Totterdell, M.F. Weirig, Y. Yamanaka and A. Yool. 2005. Anthroponenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature 437: 681-686.
668 Ibid.
669 Burns, W.C.G. 2008. Ocean acidification: a greater threat than climate change or overfishing? Terrain.org: A Journal of the Built and Natural Environments No. 21. Available at: www.terrain.org/articles/21/burns.htm.
670 Kozloff, E.N. 1996. Seashore Life of the Northern Pacific Coast. University of Washington Press, Seattle, WA. 378pp.
671 Fenger M.A. E.H. Miller, J.F. Johnson and E.J.R. Williams (eds.). 1993. Our Living Legacy: A Symposium on Biological Diversity. Royal British Columbia Museum, Victoria, BC. 392pp.
672 See endnote 645.
673 Morgan, J.A., A.B. Aguiar, S. Fox, M. Teichberg and I. Valiela. 2003. Relative influence of grazing and nutrient supply on growth of the green macroalga *Ulva lactuca* in estuaries of Waquiot Bay, Massachusetts. Biological Bulletin 205: 252-253.
674 D'Avanzo, C. and J.N. Kremer. 1994. Diel oxygen dynamics and anoxic events in an eutrophic estuary of Waquiot Bay, Massachusetts. Estuaries 17: 131-139.
675 Dunham J.S. and D.A. Duffus. 2001. Foraging Patterns of Gray Whales in Central Clayoquot Sound, British Columbia Canada. Marine Ecological Progress Series 223: 299-310.
676 See endnote 238.
677 Washington State Department of Ecology. No date. Puget Sound Shorelines: Shorebirds. Department of Ecology Shorelands Program and Puget Sound Water Quality Action Team, WA. Available at: www.ecy.wa.gov/programs/sea/pugetsound/species/shorebird.html.
678 McKindsey, C.W., M.R. Anderson, P. Barnes, S. Courtenay, T. Landry and M. Skinner. 2006. Effects of shellfish aquaculture and fish habitat. Canadian Science Advisory Secretariat, Department of Fisheries and Oceans.
679 See endnote 645.
680 Puget Sound Water Quality Action Team. 2001. Sound Facts: Eelgrass. 2pp.
681 Durance, C. 2002. Field Methods for Mapping and Monitoring Eelgrass Habitat in British Columbia: Draft 4. Canadian Wildlife Service, Delta BC. 38pp. Available at: www.stewardshipcentre.bc.ca/eelgrass/methods.pdf.
682 See endnote 680.
683 Wright, N. 2002. Eelgrass Conservation for the B.C. Coast: A Discussion Paper. B.C. Coastal Eelgrass Stewardship Project. 15pp. Available at: www.stewardshipcentre.bc.ca/eelgrass/discussionpaper.pdf.
684 Maser, C. and J.R. Sedell. 1997. Driftwood and how forestry affects the ocean. Pp. 106-108 *in* Ecoforestry: The Art and Science of Sustainable Forest Use. A. Drengson and D. Taylor (eds.). New Societies Publishers, Gabriola Island, BC. 312pp.
685 Levin, L.A., D.F. Boesch, A. Covich, C. Dahm, C. Erséus, K.C. Ewel, R.T. Kneib, A. Moldenke, M.A. Palmer, P. Snelgrove, D. Strayer and J.M. Weslawski. 2001. The function of marine critical transition zones and the importance of sediment biodiversity. Ecosystems 4: 430-451.
686 Ibid.
687 Hood, G.W. 2007. Large woody debris influences vegetation zonation in an oligohaline tidal marsh. Estuaries and Coasts 30(3): 441-450.
688 Maser, C., R.F. Tarrant, J.M. Trappe and J.F. Franklin (eds.). 1988. From the Forest to the Sea: A Story of Fallen Trees. USDA Forest Service, Portland, OR. PNW-GTR-229. 153pp.
689 Beckmann, L., M. Dunn and K. Moore. 1997. Effects of Climate Change on Coastal Systems in British Columbia and Yukon. Pp. 8-1 to 8-26 *in* E. Taylor and B. Taylor (eds.). Responding to Global Climate Change in British Columbia and Yukon: Volume I of the Canada Country Study: Climate Impacts and Adaptation. Environment Canada, Vancouver, BC.

690 See endnote 687.
691 See endnote 684.
692 See endnote 688.
693 See endnote 689.
694 Ibid.
695 See endnote 687.
696 See endnote 685.
697 Thomson, R.E. 1981. Oceanography of the British Columbia Coast. Canadian Special Publication of Fisheries and Aquatic Sciences 56. Ministry of Supply and Services Canada. 291pp.
698 See endnote 525.
699 Hubertz, J., X. Huang, V. Kolluru and J. Edinger. 2005. Physical Processes Affecting Estuarine Health. Pp. 19-32 *in* S.A. Bortone (ed.). Estuarine Indicators. CRC Press, New York, NY. 531pp.
700 Kjerfve, B. 1989. Estuarine Geomorphology and Physical Oceanography. Pp. 47-78 *in* J.W. Day Jr, C.A. Hall, W.M. Kemp and A. Yaez-Arancibia (eds.). Estuary Ecology. John Wiley and Sons, New York, NY. 582pp.
701 Emmett, R., R. Llanso, J. Newton, R. Thom, M. Hornberger, C. Morgan, C. Levings, A. Copping and P. Fishman. 2000. Geographic signatures of North American west coast estuaries. Estuaries 23: 765-792.
702 See endnote 697.
703 Ricklefs, R.E. 1990. Ecology (3rd edition). W.H. Freeman and Company, New York, NY. 896pp.
704 Fox, I.K. and J.P. Nowlan. 1978. The management of estuarine resources in Canada. Canadian Environment Advisory Council, Ottawa, ON. Report No. 6. 54pp.
705 Simenstad, C.A. 1983. The Ecology of Estuarine Channels of the Pacific Northwest Coast: A Community Profile. U.S. Fish and Wildlife Service Biological Services Program, National Wetlands Research Center, Lafayette, LA. FWS/OBS-83/05. 181pp.
706 Beck, M.W., K.L. Heck, K.W. Able, D.L. Childers, D.B. Eggleston, B.M. Gillanders, B. Halpern, C.G. Hays, K. Hoshino, T.J. Minello, R.J. Orth, P.F. Sheridan and M.P. Weinstein. 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. Bioscience 51(8): 633-641.
707 Butler, R.W., N.K. Dawe and D.E. Trethewey. 1989. The Birds of Estuaries and Beaches in the Strait of Georgia. Pp. 142-147 *in* K. Vermeer and R.W. Butler (eds.). The Ecology and Status of Marine and Shoreline Birds in the Strait of Georgia, British Columbia. Canadian Wildlife Service, Ottawa, ON. Special Publication. 186pp.
708 Butler, R.W. and R.W. Campbell. 1987. The birds of the Fraser River Delta: populations, ecology and international significance. Canadian Wildlife Service, Delta, BC. Occasional Paper No. 65. 73pp.
709 Butler, R. 2003. The Jade Coast: The Ecology of the North Pacific Ocean. Key Porter Books, Toronto, ON. 176pp.
710 British Columbia Nearshore Habitat Loss Work Group. 2001. A Strategy to Prevent Coastal Habitat Loss and Degradation in the Georgia Basin. Unpublished report. 56pp. Available at: www.env.gov.bc.ca/spd/ecc/docs/coastal.pdf.
711 See endnote 701.
712 Fraser River Estuary Study Steering Committee. 1978. Fraser River Estuary Study: Summary. B.C. Ministry of Environment, Victoria, BC and Fisheries and Environment Canada.
713 Campbell-Prentice, A. and W.S. Boyd. 1988. Intertidal and Adjacent Upland Habitat in Estuaries Located on the East Coast of Vancouver Island: A Pilot Assessment of their Historical Changes. Canadian Wildlife Service, Pacific and Yukon Region, Delta, BC. Technical Report Series No. 38. 75pp.
714 B.C. Ministry of Environment. 2006. Ecosystems at Risk: Estuaries in British Columbia. Available at: www.env.gov.bc.ca/wld/documents/Estuaries06_20.pdf.
715 Hagen, M.E. 1984. British Columbia Estuarine Information Catalogue. Vol. 1 - Vancouver Island – East. Lands Directorate, Environnent Canada, Vancouver BC. 146pp.
716 Hagen, M.E. 1984. British Columbia Estuarine Information Catalogue. Vol. 2 - Lower Mainland – Sunshine Coast. Lands Directorate, Environnent Canada, Vancouver BC. 215pp.
717 Remington, D. 1993. Coastal Wetlands Habitat Assessment and Classification for Northwestern B.C. Pacific Estuary Conservation Program. Unpublished report.
718 MacKenzie, W., D. Remington and J. Shaw. 2000. Estuaries on the North Coast of British Columbia: A Reconnaissance Survey of Selected Sites. B.C. Ministry of Environment, Lands and Parks, and Ministry of Forests, Research Branch. Unpublished Report.
719 Hunter, R.A., K.R. Summers and R.G. Davies. 1985. A Rating Scheme for British Columbia's Major Coastal Wetlands. Unpublished report prepared for B.C. Ministry of Environment. 29pp.
720 Ryder, J.L., J.K. Kenyon, D. Buffett, K. Moore, M. Ceh and K. Stipec. 2007. An Integrated Biophysical Assessment of Estuarine Habitats in British Columbia to Assist Regional Conservation Planning. Canadian Wildlife Service, Pacific and Yukon Region, Delta, BC. Technical Report Series No. 476. 141pp.
721 Howes. D., M. Morris and M. Zacharias. 1999. British Columbia Estuary Mapping System. Version 1.0. Resources Inventory Committee, B.C. Ministry of Sustainable Resource Management, Victoria, BC. 62pp. Available at: ilmbwww.gov.bc.ca/risc/pubs/coastal/estuary/index.htm.
722 Holt, R. 2007. Special Elements of Biodiversity in British Columbia. Biodiversity BC, Victoria, BC. 30pp. Available at: www.biodiversitybc.org.
723 IBA Canada. 2004. Important Bird Areas of Canada. Available at: www.ibacanada.com/.
724 R. Hebda, Royal British Columbia Museum, personal communication.
725 IBA Canada. 2003. Scott Islands Executive Summary. Available at: www.ibacanada.com/cpm_scott03.html.
726 Ban, S. and A.W. Trites. 2007. Quantification of terrestrial haul-out and rookery characteristics of Steller sea lions. Marine Mammal Science 23: 496-507.
727 COSEWIC. 2003. COSEWIC assessment and update status report on the Steller sea lion *Eumatopia jubatus* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, ON. www.sararegistry.gc.ca/virtual_sara/files/cosewic/sr_steller_sea_lion_e.pdf.

728 B.C. Conservation Data Centre. 2008. Occurrences For Steller Sea Lion Rookeries. B.C. Ministry of Environment, Victoria, BC. 5pp.
729 See endnote 727.
730 D. Biffard, B.C. Ministry of Environment, personal communication.
731 See endnote 727.
732 See endnote 596.
733 Ibid.
734 B. Holtby, Fisheries and Oceans Canada, personal communication.
735 K. Hyatt, Fisheries and Oceans Canada, personal communication.
736 B. Holtby, Fisheries and Oceans Canada, personal communication.
737 Harper, D., P. Slaney and G. Wilson. 2007. Lower Cheakamus River Habitat Compensation: Pilot Reach Bank-secured Large Wood Restoration. Report prepared for the Canadian National Railway Company. Report No. HR-CHEAK-BCK-CN-2007. 25pp. Available at: www.bccanoe.com/newsflash/Cheakamus_2007_LWD_restoration_Backgrounder_from_BCCF.pdf.
738 Arsenault, A. and T. Goward. 2000. Ecological characteristics of inland rain forests. Pp. 437-439 *in* L.M. Darling (ed.). Proceedings of a Conference on the Biology and Management of Species and Habitats at Risk, Kamloops, B.C., Feb. 15-19, 1999. Volume 1. B.C. Ministry of Environment, Lands and Parks, Victoria, BC and University College of the Cariboo, Kamloops, BC. 490pp.
739 Utzig, G. 2005. Inland temperate rainforest region. Map prepared for ForestEthics, Wildsight and Northwest Ecosystem Alliance. Available at: forestethics.org/img/original/intrain_final.jpg.
740 See endnote 738.
741 See endnote 438.
742 Brown, K.J. and R.J. Hebda. 2002. Origin, development, and dynamics of coastal temperate conifer rainforests of southern Vancouver Island, Canada. Canadian Journal of Forest Research 32: 353-372.
743 Holt, R.F. and D.J. MacKillop. 2006. Endangered Forests of the Inland Temperate Rainforest: An Inventory of Old-growth in Trout Lake and the Incomappleux. Prepared for the Columbia Basin Fish and Wildlife Compensation Program and ForestEthics. 47pp. Available at: www.fwcp.ca/version2/reports/pdfs/Endangered_Forests_of_the_Inland_Temperate_Rainforest.pdf.
744 B.C. Ministry of Environment. 2006. Register of Big Trees of British Columbia. Conservation Data Centre, Victoria, BC. Available at: www.env.gov.bc.ca/bigtree/docs/BigTreeRegistry.pdf.
745 Winchester, N. 1998. Severing the web: changing biodiversity in converted northern temperate ancient coastal rainforests. Northwest Science 72 (Special Issue No. 2): 124-126.
746 Lindo, Z. and N.N. Winchester. 2006. A comparison of microarthropod assemblages with emphasis on oribatid mites in canopy suspended soils and forest floors associated with ancient western redcedar trees. Pedobiologia 15(1): 31-41.
747 Arsenault, A. and T. Goward. 1998. Patterns of lichen diversity and distribution in old and young forests of the Interior Cedar-Hemlock Zone of British Columbia. Pp. 21-22 *in* Ecosystem Dynamics and Silviculture Systems in Interior Wet-belt ESSF and ICH Forests: Workshop Proceedings, June 10-12, 1997. University of Northern British Columbia, Prince George, BC. Available at: www.for.gov.bc.ca/hfd/pubs/RSI/FSP/Kamloops/Misc020.pdf.
748 Arsenault, A. and T. Goward. 2000. Inland old-growth rain forests: Safe havens for rare lichens. Pp. 759-766 *in* L.M. Darling (ed.). Proceedings of a Conference on the Biology and Management of Species and Habitats at Risk, Kamloops, B.C., Feb. 15-19, 1999. Volume 2. B.C. Ministry of Environment, Lands and Parks, Victoria, BC and University College of the Cariboo, Kamloops, BC. 520pp.
749 Smith, W. and P. Lee (eds.). 2000. Canada's Forests at a Crossroads: An Assessment in the Year 2000. World Resources Institute, Washington, DC. 114pp.
750 B.C. Parks. Kitlope Heritage Conservancy Protected Area. No date. B.C. Ministry of Environment, Victoria, BC. Available at: www.env.gov.bc.ca/bcparks/explore/parkpgs/kitlope.html.
751 See endnote 749.
752 Holt, R.F. 2004. Environmental Conditions Report for the Haida Gwaii / Queen Charlotte Islands Land Use Plan. Integrated Land Management Bureau, Victoria, BC. Available at: http://ilmbwww.gov.bc.ca/slrp/lrmp/nanaimo/qci/news/envconditionreport.html.
753 Holt, R.F. and G. Sutherland. 2003. Environmental Risk Assessment: Base Case: Coarse Filter Biodiversity – Final Report. Prepared for North Coast Land and Resources Management Plan, Integrated Land Management Bureau, Victoria, BC. 44pp. Available at: http://ilmbwww.gov.bc.ca/citbc/b-CoFiltFull-Holt-Mar03.pdf .
754 Holt, R.F. and A. MacKinnon. 2007. Central Coast LUP Environmental Risk Assessment: Ecosystem Protection, Condition and Trends. Unpublished report prepared for Integrated Land Management Bureau, Victoria, BC.
755 See endnote 748.
756 See endnote 405.
757 Morrison, J.C., W. Sechrest, E. Dinerstein, D.S. Wilcove and J.F. Lamoreux. 2007. Persistence of large mammal faunas as indicators of global human impacts. Journal of Mammalogy 88(6): 1363-1380.
758 Ibid.
759 Ibid.
760 See endnote 404.
761 McTaggart Cowan, I. 1987. Science and the Conservation of Wildlife in British Columbia. Pp. 85-106 *in* A. Murray (ed.). Our Wildlife Heritage: 100 Years of Wildlife Management. The Centennial Wildlife Society of British Columbia, Victoria, BC. 192pp.
762 See endnote 757.
763 See endnote 528.
764 Rydin, H. and J. Jeglum. 2006. The Biology of Peatlands. Oxford University Press, Oxford, UK and New York, NY.
765 R. Hebda, Royal British Columbia Museum, personal communication.

766 See endnote 284.
767 See endnote 764.
768 Whitfield, P.H., R.J. Hebda, J.K. Jeglum and S.A. Howie. 2006. Restoring the natural hydrology of Burns Bog, Delta, British Columbia: the key to the bog's ecological recovery. Pp. 58-70 *in* A. Chantler (ed.). Water Under Pressure. Proceedings of the Canadian Water Resources Association B.C. Branch Conference, October 25-27, 2006, Vancouver, BC.
769 B.C. Ministry of Forests. 2003. Karst management handbook for British Columbia. B.C. Ministry of Forests, Victoria, BC. 69pp. Available at: www.for.gov.bc.ca/hfp/publications/00189/Karst-Mgmt-Handbook-web.pdf.
770 B.C. Ministry of Forests. 2002. Karst Impact Analysis – Provincial Analysis. Unpublished report prepared for the Chief Forester.
771 See endnote 769.
772 Shaw, P. and M. Davis. 2000. Invertebrates from caves on Vancouver Island. Pp. 121-124 *in* L.M. Darling (ed.). Proceedings of a Conference on the Biology and Management of Species and Habitats at Risk, Kamloops, B.C., Feb. 15-19, 1999. Volume 1. B.C. Ministry of Environment, Lands and Parks, Victoria, BC and University College of the Cariboo, Kamloops, BC. 490pp.
773 Houde, I., S. Leech, F.L. Bunnell, T. Spribille and C. Björk. 2007. Old forest remnants contribute to sustaining biodiversity: the case of the Albert River Valley. BC Journal of Ecosystems and Management 8(3): 43-52.
774 Lewis T. and A. Inselberg. 2001. Survey of limestone species in the Holberg Operation. Prepared for Western Forest Products, Campbell River Office. Campbell River, BC.
775 Harding, K.A. and D.C. Ford. 1993. Impacts of primary deforestation upon limestone slopes in northern Vancouver Island, British Columbia. Environmental Geology 21: 137-143.
776 Baichtal, J.F. 1995. Evolution of Karst Management on the Ketchikan Area of the Tongass National forest: Development of an Ecologically Sound Approach. Pp. 190-202 *in* Proceedings of the 1993 National Cave Management Symposium, Carlsbad, NM.
777 Davis, M. 1995. Weymer/Green Creeks Cave/Karst Inventory. Unpublished report prepared by Island Karst Research for Pacific Forests Products Ltd., Duncan, BC.
778 Gascoyne, M., D.C. Ford and H.P. Schwarz. 1981. Late Pleistocene chronology and paleoclimate of Vancouver Island determined from cave deposits. Canadian Journal of Earth Sciences 18(11): 1643-1652
779 Lean, C.B., A.J. Latham and J. Shaw. 1995. Palaeosecular variation from a Vancouver-Island stalagmite and comparison with contemporary North American records. Journal of Geomagnetism and Geoelectricity 47(1): 71-87.
780 Forest Practices Board. 2007. Protecting karst in coastal B.C. Special Report FPB/SR/31. 10pp. Available at: www.fpb.gov.bc.ca/special/reports/SR31/Protecting_Karst_in_Coastal_BC.pdf.
781 See endnote 770.
782 See endnote 780.
783 Lee, J.S. and J.D. Ackerman. 2000. Freshwater Molluscs at Risk in British Columbia: Three Examples of "Risk". Pp. 67-73 *in* L.M. Darling (ed.). Proceedings of a Conference on the Biology and Management of Species and Habitats at Risk, Kamloops, B.C., Feb. 15-19, 1999. Volume 1. B.C. Ministry of Environment, Lands and Parks, Victoria, BC and University College of the Cariboo, Kamloops, BC. 490pp.
784 Stahl. K. and R.D. Moore. 2006. Influence of basin glacier coverage on trends in summer streamflow in British Columbia, Canada. Geophysical Research Abstracts 8: 1.
785 S. Bertram, Consultant, personal communication. See map at: http://tree.discovery.mala.bc.ca/student_pages/2005_fall/glacial_watersheds/bc_parks.html.
786 B.C. Ministry of Environment. 2002. Climate Change and Freshwater Ecosystems – Glaciers. *In* Indicators of Climate Change for British Columbia 2002. Environment Protection Division, Victoria, BC. Available at: www.env.gov.bc.ca/air/climate/indicat/glacier_id1.html.
787 Parks Canada. 2003. Time for Nature: Reservoirs of the Rockies. Available at: www.pc.gc.ca/canada/pn-tfn/itm2-/2003/au/index_e.asp.
788 See endnote 786.
789 See endnote 784.
790 Kruckeberg, A.R. 1969. Soil diversity and the distribution of plants, with examples from western North America. Madrono 20: 129-154. Cited in Ogilvie, R.T. 1998. Vascular Plants. *In* G.G.E. Scudder and I.M. Smith (eds.). Assessment of Species Diversity in the Montane Cordillera Ecozone. Ecological Monitoring and Assessment Network, Burlington, ON. Available at: www.naturewatch.ca/eman/reports/publications/99_montane/intro.html.
791 Overmann, J., K.J. Hall, T.G. Northcote and J.T. Beatty. 1999. Grazing of the copepod *Diaptomus connexus* on purple sulphur bacteria in a meromictic salt lake. Environmental Microbiology 1: 213-221.
792 Bahls, P.F. 1992. The status of fish populations and management of high mountain lakes in Western United States. Northwest Science 66: 183-193.
793 McGarvie Hirner, J.L. 1998. Relationship between trout stocking and amphibians in British Columbia's southern interior lakes. University of Victoria, School of Resource and Environmental Management, Victoria, BC. Report No. 406.
794 Rae, R. and D. Biffard. 2003. Are BC's Protected Areas Representing Freshwater Ecosystems? 5th International Science and Management of Protected Areas Association Conference. Available at: www.sampaa.org/PDF/ch7/7.1.pdf.
795 McPhail, J.D. and R. Carveth. 1993. A Foundation for Conservation: The Nature and Origin of the Freshwater Fish Fauna of British Columbia. B.C. Ministry of Environment, Lands and Parks, Fisheries Branch, Victoria, BC. 39pp. Available at: wlapwww.gov.bc.ca/wld/documents/techpub/rn323.pdf.
796 Laval, B., S.L. Cady, J.C. Pollack, C.P. McKay, J.S. Bird, J. P. Grotzinger, D.C. Ford and H.R. Bohm. 2000. Modern freshwater microbialite analogues for ancient dendritic reef structures. Nature 407: 626-629.
797 Ibid.
798 Ferris, F.G., J.B. Thompson and T.J. Beveridge. 1997. Modern freshwater microbialites from Kelly Lake, British Columbia, Canada. Palaios 12: 213-219.

799 Pike, W., D.S.S. Lim, B. Laval, G. Slater, D. Reid and C.P. McKay. 2008. Kelly Lake microbialites, another discovery in the Pavilion Lake region. Oral presentation at the Astrobiology Science Conference 2008, Santa Clara, CA, April 15-17, 2008.
800 Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-being: Biodiversity Synthesis. World Resources Institute, Washington, DC. 85pp. Available at: www.maweb.org/documents/document.354.aspx.pdf.
801 United Nations Environment Programme. 2001. Global biodiversity outlook. United Nations. Secretariat of the Convention on Biological Diversity. Available at: www.cbd.int/gbo1/gbo-pdf.shtml.
802 Committee on the Status of Endangered Wildlife in Canada. 2007. Canadian Species at Risk. Available at: www.cosewic.gc.ca/eng/sct0/rpt/dsp_booklet_e.htm.
803 World Conservation Union (IUCN). 2006. The IUCN Red List of Threatened Species: IUCN-CMP: The Conservation Measures Partnership. Available at: www.iucn.org/themes/ssc/sis/classification.htm.
804 Long, G. 2007. Biodiversity Safety Net Gap Analysis Biodiversity BC, Victoria, BC. 66pp. Available at: www.biodiversitybc.org.
805 Holt, R.F., G. Utzig, M. Carver, and J. Booth. 2003. Biodiversity Conservation in B.C. : An Assessment of Threats and Gaps. Veridian Ecological Consulting. South Slocan, B.C. pp. 55-56.
806 See endnote 145.
807 Didham, R.K., J.M. Tylianakis, M.A. Hutchison, R.M. Ewers and N.J. Gemmell. 2005. Are invasive species the drivers of ecological change? Trends in Ecology and Evolution 20:470-474.
808 MacDougall, A.S. and R. Turkington. 2005. Are invasive species the drivers or passengers of change in degraded ecosystems? Ecology 86:42-55.
809 Gayton, D. 2004. Native and non-native plant species in grazed grasslands of British Columbia's southern interior. BC Journal of Ecosystems and Management 5(1): 51-59. Available at: www.forrex.org/jem/2004/vol5/no1/art6.pdf.
810 See endnote 159.
811 Ibid.
812 Venter, O., N.N. Brodeur, L. Nemiroff, B. Belland, I.J. Dolinsek and J.W.A. Grant. 2006. Threats to endangered species in Canada. Bioscience 56: 903-910.
813 Stein, B.A., L.S. Kutner and J.S. Adams (eds.). 2000. Precious Heritage: The Status of Biodiversity in the United States. Oxford University Press, New York, NY. 399pp.
814 Noss, R.F. and R.L. Peters. 1995. Endangered Ecosystems: A Status Report on America's Vanishing Habitat and Wildlife. Defenders of Wildlife, Washington DC.
815 Baillie, J.E.M., C. Hilton-Taylor and S.N. Stuart (eds.). 2004. A Global Species Assessment. IUCN, Gland, Switzerland and Cambridge, UK.. Available at: www.iucn.org/bookstore/HTML-books/Red List 2004/completed/cover.html.
816 Vitousek, P.M., H.J.A. Mooney, J. Lubchneco and J.M. Melillo. 1977. Human domination of Earth's ecosystems. Science 277: 494-499.
817 Intergovernmental Panel on Climate Change (IPCC). 2001. Climate Change 2001: The Scientific Basis. (Contribution of Working Group I). *In* J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell and C.A. Johnson (eds.). Third Assessment Report of the IPCC. Cambridge University Press, Cambridge, UK and New York, NY. 881pp.
818 Bunnell, F.L., K.A. Squires, M.I Preston and R.W. Campbell. 2005. Towards a general model of avian response to climate change. Pp. 59-70 *in* Implications of Climate Change in B.C.'s Southern Interior Forests. 2005 Workshop, Columbia Mountains Institute of Applied Ecology, Revelstoke, BC. 166pp. Available at: www.cmiae.org/pdf/ImpofCCinforestsfinal.pdf.
819 See endnote 524.
820 See endnote 159.
821 See endnote 804.
822 See endnote 518.
823 See endnote 516.
824 See endnote 434.
825 C. Rankin and Associates. 2004. Invasive Alien Species Framework for BC: Identifying and Addressing Threats to Biodiversity. B.C. Ministry of Water, Land and Air Protection, Biodiversity Branch, Victoria, BC. 109pp. Available at: wlapwww.gov.bc.ca/wld/documents/alien_species_framework_BC_0205.pdf.
826 B.C. Ministry of Water, Land and Air Protection. 2002. Trends in Water Allocation Restrictions across British Columbia. *In* Environmental Trends in British Columbia 2002. State of the Environment Reporting Office, Victoria, BC. Available at: www.env.gov.bc.ca/soerpt/8surfacewateruse/allocations.html.
827 Blackman, B.G., D.A. Jesson, D. Ableson and T. Down. 1990. Williston Lake Fisheries Compensation Program Management Plan. Peace/Williston Fish and Wildlife Compensation Program. Report No. 58. 38pp. Available at: www.bchydro.com/pwcp/pdfs/reports/pwfwcp_report_no_058.pdf.
828 Northcote, T.G. 1993. A Review of Management and Enhancement Options for the Arctic Grayling (*Thymallus arcticus*) With Special Reference to Williston Reservoir Watershed in British Columbia. Peace/Williston Fish and Wildlife Compensation Program, Prince George, BC. PWFWCP Report No. 78. 69pp. Available at: www.bchydro.com/pwcp/pdfs/reports/pwfwcp_report_no_078.pdf.
829 Keddy, P.A. 2000. Wetland Ecology: Principles and Conservation. Cambridge University Press, Cambridge, UK. 628pp.
830 Summit Environmental Consultants Ltd. 2007. Nicola River Watershed Present and Future Water Demand Study. Nicola Watershed Community Round Table, Merritt, BC. Project 466-01.02. Available at: www.nicolawump.ca/downloads/4660102FinalReportJune1907.pdf.
831 See endnote 805.
832 Department of Fisheries and Oceans. 1998. Strategic Review of Fisheries Resources for the Thompson Nicola Habitat Management Area. Fraser River Action Plan, Vancouver, BC. 128pp.
833 Walthers, L.C. and J.C. Nener. 1997. Continuous Water Temperature Monitoring in the Nicola River, BC, 1994: Implications of High Measured Temperatures for Anadromous Salmonids.

Department of Fisheries and Oceans, Vancouver, BC. Canadian Technical Report of Fisheries and Aquatic Sciences 2158. 59pp.
834 Lauzier, R., T.J. Brown, I.V. Williams and L.C. Walthers. 1995. Water Temperature at Selected Sites in the Fraser River Basin During the Summers of 1993 and 1994. Canadian Data Report of Fisheries and Aquatic Sciences 956. 81pp.
835 Department of Fisheries and Oceans. 1999. Fraser River Basin Strategic Water Quality Plan – Thompson River Sub-Basin. Fraser River Action Plan, Vancouver, BC. Water Quality Series 02.
836 See endnote 830.
837 See endnote 833.
838 Walthers, L.C. and J.C. Nener. 1998. Water Temperature Monitoring in the Nicola River , BC, 1995: Implications of Measured Temperatures for Anadromous Salmonids. Department of Fisheries and Oceans, Vancouver , BC . Canadian Manuscript Report of Fisheries and Aquatic Sciences 2443. 58pp.
839 Walthers, L.C. and J.C. Nener. 2000. Water Temperature Monitoring in Selected Thompson River Tributaries, BC, 1996: Implications of Measured Temperatures for Anadromous Salmonids. Department of Fisheries and Oceans, Habitat and Enhancement Branch, Vancouver , BC . Canadian Technical Report of Fisheries and Aquatic Sciences 2306. 69pp.
840 See endnote 832.
841 Boeckh, I., V.S. Christie, A.H.J. Dorcey and H.J. Rueggeberg. 1991. Water use in the Fraser Basin. Pp. 181-200 *in* A. Dorcey and J.R. Griggs (eds.). Water in Sustainable Development: Exploring Our Common Future in the Fraser River Basin. Westwater Research Centre, University of British Columbia, Vancouver, BC.
842 B.C. Ministry of Water, Land and Air Protection. 2002. Trends in Water Allocation Restrictions in British Columbia. *In* Environmental Trends in British Columbia 2002. State of the Environment Reporting Office, Victoria, BC. Available at: www.env.gov.bc.ca/soerpt/8surfacewateruse/gallocations.html.
843 See endnote 825.
844 Ibid.
845 Menge, B.A. and G.M. Branch. 2001. Rocky intertidal communities. Pp. 221-250 *in* M.D. Bertness, S.D. Gaines and M.E. Hay (eds.). Marine Community Ecology. Sinauer Associates Inc., Sunderland, MA.
846 R. Hebda, Royal British Columbia Museum, personal communication.
847 Ciruna, K., L.A. Meyerson, A.T. Gutierrez and E. Watson. 2004. The Ecological and Socio-Economic Impacts of Invasive Alien Species on Inland Water Ecosystems. Report to the Convention on Biological Diversity. Convention on Biological Diversity. Available at: www.cbd.int/doc/ref/alien/ias-inland-waters-en.pdf.
848 Gayton. D. 2007. Major impacts to Biodiversity in British Columbia (excluding climate change). Biodiversity BC, Victoria, BC. 28pp. Available at: www.biodiversitybc.org.
849 Wind, E. 2005. Effects of non-native predators on aquatic ecosystems. Biodiversity Branch, B.C. Ministry of Water, Land and Air Protection, Victoria, BC. 118pp.
850 See endnote 825.
851 Voller, J. and R.S. McNay. 2007. Problem analysis: effects of invasive species on species at risk in British Columbia. FORREX Series 20. Available at: www.forrex.org/publications/forrexseries/series.asp.
852 See endnote 825.
853 See endnote 148.
854 Bosquet, Y. (ed.). 1991. Checklist of Beetles of Canada and Alaska. Research Branch, Agriculture Canada. Publication 1861/E:430.
855 Maw, H.E.L., R.G. Foottit, K.G.A. Hamilton and G.G.E. Scudder. 2000. Checklist of the Hemiptera of Canada and Alaska. NRC Research Press, Ottawa, ON. 220pp.
856 Foottit, R.G., S.E. Halberd, G.L. Miller, E. Maw and L.M. Russell. 2006. Adventive aphids (Hemiptera: Aphididae) of America north of Mexico. Proceedings of the Entomological Society of Washington 108: 583-610.
857 B.C. Ministry of Environment. 2007. Species Conservation. Technical paper for Environmental Trends 2007. State of Environment Reporting Office, Victoria, BC. Available at: www.env.gov.bc.ca/soe/et07/07_species_conserv/technical_paper/species_conservation.pdf.
858 Hatfield, T. and S. Pollard. 2007. Non-native Freshwater Fish Species in British Columbia: Biology, Biotic Effects, and Potential Management Actions. Freshwater Fisheries Society of B.C. and B.C. Ministry of Environment, Victoria, BC.
859 D. McPhail, University of British Columbia, Emeritus, personal communication.
860 See endnote 858.
861 Biodiversity BC. 2008. The Biodiversity Atlas of BC. Available at: www.biodiversitybc.org.
862 See endnote 805.
863 Bourne, N. 1982. Distribution, reproduction and growth of Manila clam, *Tapes philippinarum* (Adams and Reeve) in British Columbia. Journal of Shellfish Research 2: 47-54.
864 Hempel, P. (ed.). 2000. High altitude POPs and alpine predators. Environment Canada. Science and the Environment Bulletin. Nov./Dec. 2000. Available at: www.ec.gc.ca/science/sandenov00/article1_e.html.
865 Chandler, T. 2005. Maintaining British Columbia's Biological Diversity: Issues and Opportunities For Coordinated Action. Unpublished report prepared for B.C. Ministry of Water, Land and Air Protection.
866 B.C. Ministry of Environment. 2006. British Columbia's Coastal Environment: 2006. State of Environment Reporting Office, Victoria, BC. 57pp. Available at: www.env.gov.bc.ca/soe/bcce/.
867 Ibid.
868 Ibid.
869 Ibid.
870 Ibid.
871 Ryan, J.J., B. Patry, P. Mills and G. Beaudoin. 2002. Body burdens and food exposure in Canada for polybrominated diphenyl ethers (PBDEs). Organohalogen Compounds 51: 226-229.
872 See endnote 866.
873 See endnote 865.
874 Ibid.
875 See endnote 805.

876 See endnote 582.
877 Martin, T., E. Nygren, N. Dawe and G. Jamieson. 1996. Effects of disturbances of spring staging brant (*Branta bernicula nigricans*) in the Parksville-Qualicum Beach area of south-east Vancouver Island, B.C. Unpublished report prepared for Canadian Wildlife Service, Pacific and Yukon Region, Delta, BC.
878 See endnote 582.
879 B.C. Ministry of Environment, Lands and Parks. 1996. Ecoregions of British Columbia. Wildlife Branch, Victoria, BC.
880 See endnote 805.
881 See endnote 145.
882 See endnote 159.
883 See endnote 804.
884 See endnote 814.
885 Murdock, T.Q., A.T. Werner and D. Bronaugh. 2007. Preliminary Analysis of BC Climate Trends for Biodiversity. Biodiversity BC, Victoria, BC. 24pp. Available at: www.biodiversitybc.org.
886 Compass Resource Management. 2007. Major Impacts: Climate Change. Biodiversity BC, Victoria, BC. 41pp. Available at: www.biodiversitybc.org.
887 See endnote 138.
888 See endnote 817.
889 See endnote 98.
890 Zhang, Q-B. and R.J. Hebda. 2004. Radial growth patterns of *Pseudotsuga menziesii* along an elevational gradient on the central coast of British Columbia, Canada. Canadian Journal of Forest Research 34: 1946-1954.
891 See endnote 886.
892 See endnote 817.
893 Fischlin, A., G.F. Midgely, J.T. Price, R. Leemans, B. Gopal, C. Turley, M.D.A. Rounsevell, O.P. Dube, J. Tarazona and A.A. Velichko. 2007. Ecosystems, their properties, goods and services. Pp. 211-272 *in* M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.). Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK. 973pp.
894 Field, C.B., L.D. Mortsch, M. Brklacich, D.L. Forbes, P. Kovacs, J.A. Patz, S.W. Running and M.J. Scott. 2007. North America. Pp. 617-652 *in* M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.). Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK. 973pp.
895 See endnote 805.
896 See endnote 192.
897 See endnote 146.
898 See endnote 893.
899 Ibid.
900 See endnote 894.
901 See endnote 524.
902 See endnote 616.
903 See endnote 894.
904 Wilson, R.J., Z.G. Davies and C.D. Thomas. 2007. Insects and climate change: Process, patterns and implications for conservation. Pp. 245-279 *in* A.J.A. Stewart, T.R. New and O.T. Lewis (eds.). Insect Conservation Biology. CAB International, Wallingford, UK. 464pp.
905 Parmesan, C. 2005. Detection at multiple levels: *Euphydryas editha* and climate change. Pp. 56-60 *in* T.E. Lovejoy and L. Hannah (eds.). Climate Change and Biodiversity. Yale University Press, New Haven, CT. 440pp.
906 See endnote 15.
907 See endnote 818.
908 Bunnell, F.L. and K.A. Squires. 2005. Evaluating Potential Influence of Climate Change on Historical Trends in Bird Species. B.C. Ministry of Water, Land and Air Protection, Victoria, BC. Unpublished report. 48pp.
909 Hyatt, K.D., M.M. Stockwell and D.P. Rankin. 2003. Impact and adaptation response of Okanagan River sockeye salmon (*Onchorhynchus nerka*) to climate variation and change during freshwater migration: stock restoration and fisheries management implications. Canadian Water Resources Journal 28: 689-713.
910 Idler, D.R. and W.A. Clemens. 1959. The energy expenditures of Fraser River sockeye during the spawning migration to Chilko and Stuart lakes. International Pacific Salmon Fisheries Commission Progress Report 6. 80pp.
911 Gilhousen, P. 1980. Energy sources and expenditures in Fraser River sockeye salmon during their spawning migration. International Pacific Salmon Fisheries Commission Bulletin 23. 51pp.
912 Groot, C., W.C. Clarke and L. Margolis (eds.). 1995. Physiology of Pacific Salmon. UBC Press, Vancouver, BC. 515pp.
913 Quinn, T.P. and D.J. Adams.1996. Environmental changes affecting the migratory timing of American shad and sockeye salmon. Ecology 77: 1151-1162.
914 See endnote 244.
915 See endnote 582.
916 See endnote 866.
917 See endnote 582.
918 See endnote 866.
919 See endnote 885.
920 See endnote 893.
921 See endnote 886.
922 See endnote 817.
923 Pacific Climate Impacts Consortium (PCIC). No date. Royal B.C. Museum maps. PCIC, Victoria, BC. Available at: www.pacificclimate.org/impacts/rbcmuseum/.
924 See endnote 885.
925 See endnote 886.
926 Pacific Climate Impacts Consortium (PCIC). No date. Climate Overview. PCIC, Victoria, BC. Available at: www.pacificclimate.org/resources/climateimpacts/overview/.
927 See endnote 817.
928 See endnote 926.
929 See endnote 893.
930 See endnote 192.
931 Hebda, R.J. 1998. Atmospheric change, forests and biodiversity. Environmental Monitoring and Assessment 49: 195-212.
932 See endnote 146.
933 See endnote 886
934 Pacific Climate Impacts Consortium (PCIC). No date. Royal B.C. Museum maps and unpublished data. PCIC, Victoria, BC. Available at: www.pacificclimate.org/impacts/rbcmuseum/.

935 See endnote 931.
936 See endnote 524.
937 See endnote 146.
938 T. Lea, B.C. Ministry of Environment, personal communication.
939 See endnote 931.
940 See endnote 893.
941 Nelitz M., K. Wieckowski, D. Pickard, K. Pawley and D.R. Marmorek. 2007. Helping Pacific Salmon Survive the Impact of Climate Change on Freshwater Habitats: Pursuing Proactive and Reactive Adaptive Strategies. Pacific Fisheries Resource Conservation Council, Vancouver, BC. 122pp. Available at: fish.bc.ca/files/PFRCC-ClimateChange-Adaptation.pdf.
942 Tyedmers, P. and B. Ward. 2001. A Review of the Impacts of Climate Change on BC's Freshwater Fish Resources and Possible Management Responses. Fisheries Centre, University of British Columbia, Vancouver, BC. Research Report 9(7). Available at: www.fisheries.ubc.ca/publications/reports/report9_7.php.
943 See endnote 886.
944 B.C. Ministry of Environment. 2002. Salmon in the River. *In* Indicators of Climate Change for British Columbia 2002. Environmental Protection Division, Victoria, BC. Available at: www.env.gov.bc.ca/air/climate/indicat/salmonriv_id1.html.
945 Murdock, T., J. Fraser and C. Pearce. 2006. Preliminary Analysis of Climate Variability and Change in the Canadian Columbia River Basin: Focus on Water Resources. Pacific Climate Impacts Consortium, University of Victoria, Victoria, BC. 57pp. Available at: www.pacificclimate.org/publications/CBT.Assessment.pdf.
946 Nicholls, R.J., P.P. Wong, V.R. Burkett, J.O. Codignotto, J.E. Hay, R.F. McLean, S. Ragoonaden and C.D. Woodroffe. 2007. Coastal systems and low-lying areas. Pp. 315-356 *in* M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.). Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK. 973pp.
947 See endnote 942.
948 See endnote 886.
949 Palmer, S.L., I.R. Walker, M.L.. Henrichs, R. Hebda and G.G.E. Scudder. 2002. Postglacial midge community change and Holocene paleotemperature reconstructions near treeline, southern British Columbia (Canada). Journal of Paleolimnology 28: 469-490.
950 See endnote 98.
951 See endnote 192.
952 See endnote 98.
953 Rahmstorf, S., A. Cazenave, J.A. Church, J.E. Hansen, R.F. Keeting, D.E. Parker and R.C.J. Somerville. 2007. Recent climate observations compared to projections. Science 316: 709.
954 See endnote 886.
955 See endnote 524.
956 Clarke, A. 1993. Temperature and extinction in the sea: a physiologist's view. Paleobiology 19(4): 499-518.
957 See endnote 931.
958 See endnote 98.
959 See endnote 146.
960 Ibid.
961 Ibid.
962 Ibid.
963 See endnote 893.
964 See endnote 83.
965 See endnote 146.
966 See endnote 98.
967 Ibid.
968 See endnote 146.
969 See endnote 923.
970 See endnote 99.
971 See endnote 98.
972 See endnote 102.
973 See endnote 146.
974 See endnote 121.
975 See endnote 146.
976 See endnote 923.
977 See endnote 98.
978 Rosenberg, S.M., I.R. Walker and R.W. Mathewes. 2003. Postglacial spread of hemlock (*Tsuga*) and vegetation history in Mount Revelstoke National Park, British Columbia, Canada. Canadian Journal of Botany 81: 139-151.
979 See endnote 82.
980 See endnote 146.
981 See endnote 121.
982 J. Pojar, Consultant, personal communication.
983 Mooney, H.A. and R.J. Hobbs (eds.). 2000. Invasive Species in a Changing World. Island Press, Washington, DC.
984 McNeely, J.A., H.A. Mooney, L.E. Neville, P. Schei and J.K. Waage (eds.). 2001. A Global Strategy on Invasive Alien Species. IUCN Gland, Switzerland, and Cambridge, UK. 50pp. Available at: www.gisp.org/publications/brochures/globalstrategy.pdf.
985 See endnote 886.
986 See endnote 848.
987 Ibid.
988 Lee, M. and M. Hovorka. 2003. Invasive Alien Species in Canada. Canadian Wildlife Service, Ottawa, ON. Available at: www.hww.ca/hww2p.asp?id=220&cid=0.
989 See endnote 825.
990 B.C. Ministry of Forests and Range. 2007. State of British Columbia's Forests, 2006. Forest Practices Branch, Victoria, BC. 182pp. Available at: www.for.gov.bc.ca/hfp/sof/2006/pdf/sof.pdf.
991 See endnote 848.
992 Guynn, Jr., D.C., S.T. Guynn, T. Bently Wigley and D.A. Miller. 2004. Herbicides and forest biodiversity: what do we know and where do we go from here? Wildlife Society Bulletin 32(4): 1085-1092.
993 See endnote 990.
994 Newmaster, S.G., R.J. Belland, A. Arsenault and D.H. Vitt. 2003. Patterns of bryophyte diversity in humid coastal and inland cedar hemlock forests of British Columbia. Environmental Reviews 11(1): 159-185.
995 Winchester, N.N. 2006. Ancient temperate rainforest research in British Columbia: a tribute to Dr. Richard A. Ring. Canadian Entomologist 138: 72-83.
996 Blood, D.A. 1998. Marbled Murrelet. B.C. Ministry of Environment, Lands and Parks, Wildlife Branch, Victoria, BC. 6pp.
997 Winchester, N.N. and L.L. Fagan. 2000. Canopy arthropods of montane forests on Vancouver Island, British Columbia, Canada. Journal of Sustainable Forestry 10: 355-361.

998 See endnote 159.
999 See endnote 866.
1000 McPhee, M., P. Ward, J. Kirkby, L. Wolfe, N. Page, K. Dunster, N.K. Dawe and I. Nykwist. 2000. Sensitive Ecosystems Inventory: East Vancouver Island and Gulf Islands 1993 – 1997. Volume 2: Conservation Manual. Canadian Wildlife Service, Pacific and Yukon Region, Delta, BC. 284pp.
1001 See endnote 379.
1002 See endnote 848.
1003 Stanton-Kennedy, T. 2005. Calculating Impermeable Surface Area in the Prince George "Bowl." University of Northern British Columbia, Prince George, BC. Available at: www.gis.unbc.ca/courses/geog300/projects/2005/stanton/index.php.
1004 Olewiler, N. 2004. The Value of Natural Capital in Settled Areas of Canada. Ducks Unlimited Canada and Nature Conservancy of Canada. 36pp.
1005 B.C. Stats. 2007. British Columbia Population 1867 to 2007. Available at: www.bcstats.gov.bc.ca/DATA/pop/pop/bc1867on.csv.
1006 Sightline Institute. 2007. Cascadia Scorecard: Seven Key Trends Shaping the Northwest. Sightline Institute, Seattle, WA. 68pp. Available at: www.sightline.org/research/cascadia_scorecard/.
1007 B.C. Stats. 1997. First 1996 Census Release – Population and Dwellings. Ministry of Finance and Corporate Relations, Victoria, BC. Infoline 97-16. 5pp. Available at: www.bcstats.gov.bc.ca/releases/info1997/in9716.pdf.
1008 B.C. Stats. 2003. 2001 Census Profile. 18pp. Available at: www.bcstats.gov.bc.ca/data/cen01/profiles/59000000.pdf.
1009 Greater Vancouver Sewerage and Drainage District. 2002. Interim Report on Effectiveness of Stormwater Source Control. 44pp. Available at: www.gvrd.bc.ca/sewerage/stormwater_reports_1997_2002/sc_assessment_interim/report_interim_mar02(2).pdf.
1010 Guthrie, R. and J. Deniseger. 2001. Impervious Surfaces in French Creek. Ministry of Water, Land and Air Protection, Nanaimo, BC. 25pp. Available at: wlapwww.gov.bc.ca/vir/es/pdf/Impervious Surfaces technical document.pdf.
1011 Jeffrey, M. 2002. Identification of Eco-Industrial Networking Opportunities in Greater Vancouver: Demand Side Management Benefits. Greater Vancouver Regional District, Policy and Planning Division, Vancouver, BC. 48pp. Available at: www.drsociety.bc.ca/TEIP/documents/ein_opportunities_study.pdf.
1012 U.S. Environmental Protection Agency. No date. Puget Sound Georgia Basin Ecosystem Indicator Report: Executive Summary. 2pp. Available at: www.epa.gov/region10/psgb/indicators/urbaniz_forest_change/media/pdf/Urbanization and Forest Change Indicator Summary.pdf.
1013 Davis, C. No date. Synthesis of data and methods across scales to connect local policy decisions to regional environmental conditions: the case of the Cascadia Scorecard. 20pp. Available at: ma.caudillweb.com/documents/bridging/papers/davis.chris.pdf.
1014 Haskell, D.G. 2000. Effects of forest roads on macroinvertebrate soil fauna of the southern Appalachian Mountains. Conservation Biology 14: 57-63.
1015 Reed, R.A., J. Johnson-Barnard and W.L. Baker. 1996. Contribution of roads to forest fragmentation in the Rocky Mountains. Conservation Biology 10: 1098-1106.
1016 Ito, T.Y., N. Miura, B. Lhagvasuren, D. Enkhbileg, S. Takatsuki, A. Tsunekawa and Z. Jiang. 2005. Preliminary evidence of a barrier effect of a railroad on the migration of Mongolian gazelles. Conservation Biology 19: 945-948.
1017 Marsh, D.M., G.S. Milam, N.P. Gorham and N.G. Beckman. 2005. Forest roads as partial barriers to terrestrial salamander movement. Conservation Biology 19: 2004-2008.
1018 Epps, C.W., P.J. Palsbøll, J.D. Wehausen, G.K. Roderick, R.R. Ramey III and D.R. McCullough. 2005. Highways block gene flow and cause a rapid decline in genetic diversity of desert bighorn sheep. Ecology Letters 8: 1029-1038.
1019 See endnote 848.
1020 Trombulak, S.C. and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14: 18-30.
1021 Forman, R.T.T. 2000. Estimate of the area affected ecologically by the road system in the United States. Conservation Biology 14: 31-35.
1022 See endnote 159.
1023 See endnote 145.
1024 Westcoast Environmental Law. 2003. Pump it Out: The Environmental Costs of BC's Upstream Oil and Gas Industry. 109pp. Available at: www.wcel.org/wcelpub/2003/14028.pdf.
1025 See endnote 159.
1026 See endnote 805.
1027 See endnote 848.
1028 Hatfield, T., A. Lewis and D. Ohlson. 2002. British Columbia Instream Flow Standards for Fish Phase 1 – Initial Review and Consultation. B.C. Ministry of Water, Land and Air Protection, Victoria, BC.
1029 Hatfield, T., A. Lewis, D. Ohlson and M. Bradford. 2003. Development of instream flow thresholds as guidelines for reviewing proposed water uses. B.C. Ministry of Sustainable Resource Management and B.C. Ministry of Water, Land and Air Protection, Victoria, BC.
1030 See endnote 170.
1031 Ibid.
1032 See endnote 848.
1033 B.C. Hydro. 2008. Generation System. Available at: www.bchydro.com/info/system/system15240.html.
1034 See endnote 848.
1035 B.C. Hydro. 2008. Our Facilities. Available at: www.bchydro.com/info/system/system15274.html.
1036 See endnote 848.
1037 Northcote, T.G. 1998. Inland waters and aquatic habitats. *In* G.G.E. Scudder and I.M. Smith (eds.). Assessment of Species Diversity in the Montane Cordillera Ecozone. Ecological Monitoring and

Assessment Network, Burlington, ON. Available at: www.naturewatch.ca/eman/reports/publications/99_montane/intro.html.
1038 Fearnside, P.M. 2004. Greenhouse gas emissions from hydroelectric dams: controversies provide a springboard for rethinking a supposedly 'clean energy source' – an editorial comment. Climatic Change 66: 1-8.
1039 See endnote 1035.
1040 Ibid.
1041 The Energy and Biodiversity Initiative. 2003. Integrating Biodiversity Conservation into Oil and Gas Development. 58pp. Available at: www.celb.org/ImageCache/CELB/content/energy_2dmining/ebi_2epdf/v1/ebi.pdf.
1042 See endnote 805.
1043 M. Winfield, B.C. Ministry of Environment, personal communication.
1044 See endnote 805.
1045 Lions Gate Consulting Inc. 2003. Tourism Opportunity Strategy: Bonnington Sustainable Resource Management Zone. Report for the Ministry of Sustainable Resource Management. 195pp. Available at: www.taskbc.bc.ca/documents/Bonnington_TOS_000.pdf.
1046 Marlyn Chisholm and Associates. 2002. Shuswap Tourism Opportunity Study. Prepared for the Salmon Arm Economic Development Corporation and the Columbia Shuswap Regional District. 183pp. Available at: ilmbwww.gov.bc.ca/cis/initiatives/tourism/tos/Shuswap/finalreport.pdf.
1047 UBC Interactive Digital Environmental Assessment Laboratory (IDEAL). 2006. Motorized Recreation Perspectives for TFL 38. 13pp. Available at: www.ideal.forestry.ubc.ca/cons481/Labs/MRG..pdf.
1048 Bleich, V.C., R.T. Bowyer, A.M. Pauli, M.C. Nicholson and R.W. Anthes. 1994. Mountain sheep *Ovis canadensis* and helicopter surveys: ramifications for the conservation of large mammals. Biological Conservation 70: 1-7.
1049 Simpson, K. and E. Terry. 2000. Impacts of Backcountry Recreation Activities on Mountain Caribou – Management Concerns, Interim Management Guidelines and Research Needs. B.C. Ministry of Environment, Lands and Parks, Wildlife Branch, Victoria, BC. Wildlife Working Report No. WR-99. 11pp.
1050 Harper, W.L. and D. Eastman. 2000. Wildlife and Commercial Backcountry Recreation in British Columbia: Assessment of Impacts and Interim Guidelines for Mitigation. B.C. Ministry of Environment, Victoria, BC.
1051 Bergerud, A.T. 1996. Evolving perspectives on caribou population dynamics: have we got it right yet? Rangifer Special Issue No. 9: 95-116.
1052 Goldstein, M.I., A.J. Poe, E. Cooper, D. Youkey, B.A. Brown and T.L. McDonald. 2005. Mountain goat response to helicopter overflights in Alaska. Wildlife Society Bulletin 33: 688–699.
1053 Stokowski, P.A., and C.B. LaPointe. 2000. Environmental and Social Effects of ATVs and ORVs: An Annotated Bibliography and Research Assessment. University of Vermont, School of Natural Resources. Available at: bluewaternetwork.org/reports/rep_atv_socialeffects.pdf.
1054 Acoustic Ecology Institute. 2001. Motorized Vehicle Management. Available at: www.acousticecology.org/wildlandvehicles.html.
1055 See endnote 1047.
1056 Orchard, S.A. 1991. Provincial status report for the tiger salamander, *Ambystoma tigrinum*. B.C. Ministry of Environment, Wildlife Branch, Victoria, BC. Unpublished report. 31pp.
1057 Sarell, M.J. 1996. Status of the tiger salamander (*Ambystoma tigrinum*) in British Columbia. B.C. Ministry of Environment, Wildlife Branch, Victoria, BC. 18pp.
1058 Knapp, R.A., K.R. Matthews and O. Sarnelle. 2000. Resistance and resilience of alpine lake fauna to fish introductions. Ecological Monographs 71(3): 401-421.
1059 Pilliod, D.S. and C.R. Peterson. 2001. Local and landscape effects of introduced trout on amphibians in historically fishless watersheds. Ecosystems 4: 322-333.
1060 Pierce, C.L. and B.D. Hinrichs. 1997. Response of littoral invertebrates to reduction of fish density: simultaneous experiments in ponds with different fish assemblages. Freshwater Biology 37: 397-408.
1061 Bechara, J.A., G. Moreau and D. Planas. 1992. Top-down effects of brook trout (*Salvelinus fontinalis*) in a boreal forest stream. Canadian Journal of Fisheries and Aquatic Sciences 49: 2093-2103.
1062 See endnote 244.
1063 Grasslands Conservation Council of B.C. 2004. BC Grasslands Mapping Project – A Conservation Risk Assessment: Final Report. Available at: www.bcgrasslands.org/projects/conservation/mapping.htm.
1064 R. Doucette, Grasslands Conservation Council of B.C., personal communication.
1065 See endnote 804.
1066 See endnote 848.
1067 See endnote 1063.
1068 See endnote 804.
1069 See endnote 848.
1070 See endnote 159.
1071 See endnote 804.
1072 See endnote 848.
1073 Ibid.
1074 B.C. Ministry of Agriculture and Lands. No date. Fisheries and Aquaculture - Frequently Asked Questions: Non-salmon Species. Available at: www.env.gov.bc.ca/omfd/fishstats/aqua/species.html.
1075 See endnote 804.

Index

Page numbers in **boldface** type refer to figures, maps or tables.

Species Index

Page numbers in **boldface** type refer to figures, maps or tables.

"British Columbia's biodiversity is globally significant because of its variety and integrity, but without immediate action, it is vulnerable to rapid deterioration, especially in light of climate change."

Printed on 100% post-consumer recycled paper, processed chlorine free
Design: Alaris Design

BioDiversity BC
CONSERVING THE VARIETY OF LIFE

www.biodiversitybc.org