British Columbia's Inland Rainforest

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Ecology, Conservation, and Management

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Abbreviations

BAFA	Boreal Altai Fescue Alpine biogeoclimatic zone
BEC	Biogeoclimatic Ecosystem Classification
BP	before present
BWBS	Boreal White and Black Spruce biogeoclimatic zone
CDF	Coastal Douglas-fir biogeoclimatic zone
CPOM	coarse particulate organic matter
CWD	coarse woody debris (generally used in reference to terrestrial systems)
CWH	Coastal Western Hemlock biogeoclimatic zone
dbh	diameter at breast height
dw	dry warm (in reference to a biogeoclimatic subzone)
ESSF	Engelmann Spruce–Subalpine Fir biogeoclimatic zone
FPOM	fine particulate organic matter
FRDA	Forest Resource Development Agreement
GIS	Geographic Information System
Gt	gigatonne (1 billion tonnes)
ICH	Interior Cedar-Hemlock biogeoclimatic zone
IDF	Interior Douglas-fir biogeoclimatic zone
Kt	kilotonne (1,000 tonnes)
LRMP	Land and Resource Management Plan
LUP	Land Use Plan
LWD	large woody debris (generally used in reference to aquatic systems)
mc	moist cold (in reference to a biogeoclimatic subzone)
mk	moist cool (in reference to a biogeoclimatic subzone)
MLA	Member of the Legislative Assembly (of British Columbia)
MS	Montane Spruce biogeoclimatic zone
Mt	megatonne (1 million tonnes)

mw	moist warm (in reference to a biogeoclimatic subzone)
NTFP	non-timber forest product
OGMA	Old Growth Management Area
ppm	parts per million
SBS	Sub-Boreal Spruce biogeoclimatic zone
sph	stems per hectare
SWB	Spruce-Willow-Birch biogeoclimatic zone
vk	very wet cool (in reference to a biogeoclimatic subzone)
vm	very wet maritime (in reference to a biogeoclimatic subzone)
wc	wet cold (in reference to a biogeoclimatic subzone)
wk	wet cool (in reference to a biogeoclimatic subzone)

Biogeoclimatic Variants of the Inland Rainforest

ICHvk1	Columbia Very Wet Cool Variant of the Interior Cedar-Hemlock Zone
ICHvk2	Slim Very Wet Cool Variant of the Interior Cedar-Hemlock Zone
ICHwk1	Shuswap Wet Cool Variant of the Interior Cedar-Hemlock Zone
ICHwk2	Quesnel Wet Cool Variant of the Interior Cedar-Hemlock Zone
ICHwk3	Goat Wet Cool Variant of the Interior Cedar-Hemlock Zone
ICHwk4	Cariboo Wet Cool Variant of the Interior Cedar-Hemlock Zone

Preface

This book originated as an extension report on the operational application of silvicultural systems in British Columbia's inland rainforest. The two of us responsible for this report, Michael Jull and Susan Stevenson, began where we believed a discussion of silvicultural systems should begin – with a look at the basic ecology of the forests. As we worked, we realized that the references we needed were scattered, often unpublished and unsynthesized. We also became increasingly aware of the special qualities of the ecosystem, and the fact that those special qualities were largely unappreciated both by the public and by the managers whose decisions were changing the face of the inland rainforest.

We expanded the scope of the project and drew in additional authors who had different areas of expertise and on-the-ground experience in different geographical parts of the inland rainforest. The report turned into a book, and became a collaborative effort among the six coauthors. We have met repeatedly, read the manuscript repeatedly as it developed, and commented on one another's work to the extent that we have often lost track of who wrote what. In general, the broad areas to which the individual coauthors have contributed are as follows:

- Harold Armleder – wildlife habitat ecology, silvicultural systems
- André Arsenault – lichen and bryophyte ecology, landscape-level management
- Darwyn Coxson – lichen ecology, conservation biology
- Craig Delong – landscape ecology, plant ecology, landscape-level management
- Michael Jull – silviculture, silvicultural systems, operational forestry
- Susan Stevenson – overall coordination, wildlife habitat ecology, lichen ecology

Despite the broad interests of the coauthors, we found that there were some areas in which none of us had the necessary expertise. The following sections were prepared wholly or in part by contributing authors:

- Paul Sanborn – Physiography, Glacial History, and Landforms; Soils
- Darwyn Coxson, André Arsenault, and Zoë Lindo – Canopy Organisms and Forest Floor Associations
- Brian Heise – Streams and Their Trophic Interactions with the Riparian Forest; Aquatic Environments
- John Shultis – Outdoor Recreation
- Patrick Laing and Bob Drinkwater – Invasive Species
- Art Fredeen – Carbon Dynamics

The views expressed in this book are those of the various coauthors and contributing authors and do not necessarily reflect those of the agencies employing them.

We are indebted to many other colleagues who have helped us in various ways. Susan Hall contributed information and ideas to the section on conservation trends. Greg Halseth, Gail Fondahl, and Kent Sedgewick contributed texts and references to the historical section. Nancy Turner contributed references to the sections on First Peoples, and Carla Burton reviewed those sections. Andreas Hamann prepared climate change maps specific to the wet and very wet subzones of the Interior Cedar-Hemlock zone; these were later updated by Tongli Wang. Marten Geertsema added new material on paleoenvironmental studies. Val Miller, Percy Folkard, Jeff Hallworth, Laura Kristiansen, and Linda Wilson contributed to the section on invasive species. Bruce McLellan reviewed the sections on wildlife habitat. The book has been much improved by the comments of Richard Hebda, Andy MacKinnon, Michael Nash, Ordell Steen, and Alan Vyse, and one anonymous reviewer who read earlier drafts of the entire manuscript.

Throughout the preparation of this book, several organizations provided vital in-kind contributions. The University of Northern British Columbia (UNBC) provided faculty members as primary and contributing authors, gave key administrative support, and supplied facilities for the many meetings of the authors. The British Columbia Ministry of Forests and Range aided the project extensively, by providing three coauthors, in-house scientific expertise, and access to provincial forest and ecological databases. The Aleza Lake Research Forest Society, a partnership of UNBC and the University of British Columbia Faculty of Forestry, likewise lent considerable staff time and logistical support to the project. Silvifauna Research, the consulting business operated by the coordinating author, dedicated a great deal of her time to the project.

We are grateful to the staff of UBC Press for their work on this book, especially Randy Schmidt, who patiently guided us through the entire publication process, and Holly Keller, who oversaw the book's production. The figures were produced by Indigo Graphic Design and by UBC Press staff, and the maps by Eric Leinberger. Nicole Wheele helped to format the references. We thank Virginia Karr for permission to use her poem "Lichens."

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British Columbia's Inland Rainforest

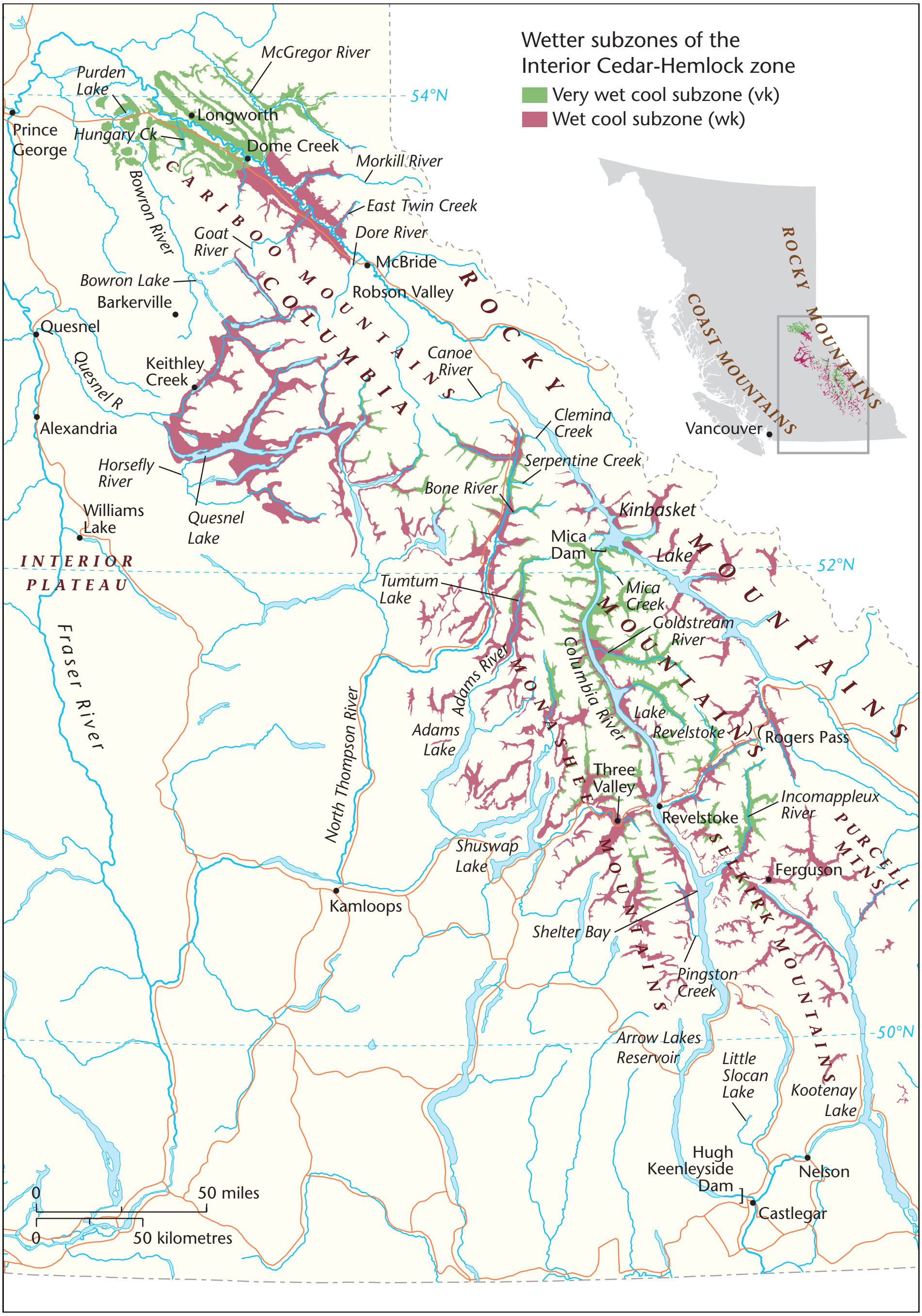

Figure 1.1 Location of British Columbia's inland rainforest

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Introduction

"Misty mountains clad in cedar, hemlock, and spruce, towering peaks and deep valleys, rushing salmon streams, grizzly and black bears, and rich old-growth ecosystems" – this description conjures up visions of the well-known and justifiably world-renowned temperate coniferous rainforests that hug Pacific Ocean shores and coastal inlets on the west coast of North America, from Alaska to California.

Much less known is that this description applies equally to a unique British Columbia inland rainforest ecosystem found more than 500 km from the nearest ocean. Confounding traditional notions of rainforest geography and climate, this ecosystem abuts the Rocky Mountains and, in places, the Continental Divide, and is subject to winter blasts of subalpine and arctic weather systems. It is the domain not only of grizzly bears (*Ursus arctos*), ancient forests, and plant species with moist maritime or oceanic affinity but also of the high-profile mountain caribou (*Rangifer tarandus caribou*), an animal more closely linked to a cold continental climate than to a warm maritime one.

Not only does the general public know little about British Columbia's inland rainforest but those who have made decisions about land use within it may have done so without adequate access to scientific information about the ecosystem. Much of the information relevant to its management has lain scattered in a variety of journal articles, extension notes, government reports, and unpublished documents. The purpose of this book is to synthesize the best available information about the ecology and management of the inland rainforest for the benefit of all those interested in this distinctive ecosystem and how it is managed.

The inland temperate rainforest of British Columbia has features that are globally unique and that present unusual challenges to managers. Because of its high latitude and its distance from the ocean, seasonal temperature differences are pronounced. At the same time, maritime air masses from the west deposit moisture as they are pushed up over the mountains. In no other region of the world has a similar integration of continentality and humidity been documented. Although the coastal rainforests have long been a focus of scientific investigation, environmental concern, and media attention, their inland counterparts – the rainforests of intermontane British Columbia – are still poorly known.

Although other scientists have used the term "inland rainforest" to refer to a broader geographic area, we use it here in a more restricted sense. Inland rainforests in British Columbia were first defined by Goward and Arsenault (1995), and described in more detail by Arsenault and Goward (2000), as the wettest biogeoclimatic subzones of the Interior Cedar-Hemlock (ICH) zone – the wet cool (ICHwk) and very wet cool (ICHvk) subzones (Meidinger and Pojar 1991). These forests are restricted to a region of anomalously humid climate, in which a plentiful snowmelt during late spring is followed by ample rainfall during the height of the growing season. The definition of inland rainforests provided by Alaback and colleagues (2000) is essentially equivalent to the Columbian forest described by Rowe (1972) and to the Interior Cedar-Hemlock zone described by Ketcheson and colleagues (1991), except that Alaback's inland rainforest extends into the United States. Here we adopt the definition of Arsenault and Goward (2000), because it allows us to focus our attention on the most pronounced expression of the phenomenon – the rainforest found in the central interior of British Columbia, between about latitude 50°30′ N and latitude 54° N along the western slopes of the Columbia and Rocky Mountains (Goward and Spribille 2005) (Figure 1.1). We refer to the broad geographic area of elevated moisture in which the inland rainforest is located as the "interior wetbelt," including the very wet subzone of the Sub-Boreal Spruce (SBS) zone, the moist, wet, and very wet subzones of the ICH zone, adjacent higher-elevation ecosystems, and corresponding ecosystems in the United States.

Some of the other biogeoclimatic units in British Columbia that experience boreal or coastal influences include the Boreal White and Black

Temperate rainforests: a global perspective

Globally, the inland rainforest is a rare ecosystem. Whereas tropical rainforests are thought to have covered approximately 16 million km^2 (1,600 million ha) (Mabberley 1992), or 11% of the land area of the earth, a few hundred years ago, the original extent of temperate rainforests was probably only about 42 million ha, or less than 0.3% of the earth's land area (Table 1.1). The vast majority of the temperate rainforest area of the world – over 98% – was coastal.

Today, less than half of the earth's temperate rainforest remains in a naturally forested condition. The largest area by far is found in western North America. Substantial blocks of temperate rainforest also remain in South America (mostly in Chile), the South Island of New Zealand, and Tasmania. The temperate rainforest of mainland Australia, always fragmented by geography, is even more fragmented today. Temperate rainforests are believed to have been historically present in southern Iceland, southwestern Norway, the western Highlands of Scotland, western Ireland, and the eastern coast of the Black Sea. According to Kellogg (1992), however, the natural vegetation of those areas has been so transformed by human activities that inhabitants today have little "cultural sense" of the presence of temperate rainforests.

Table 1.1

Estimated area (ha) worldwide of original temperate rainforest and currently unmodified temperate rainforest

Geographic area	Area of original* temperate rainforest (ha)	Area of currently unmodified temperate rainforest (ha)	Source
North America			
Coastal	25,000,000	14,000,000	Schoonmaker et al. (1997)
Inland	1,095,795†	867,557‡	BC Ministry of Forests and Range (2006c)
Chile and Argentina	7,612,000	2,925,000	Kellogg (1992)
Mainland Australia	Unknown	363,120	Adam (1992)
Tasmania	760,000	646,000	Kellogg (1992)
New Zealand	5,360,000	1,500,000	Kellogg (1992)
Europe	2,181,400	Unknown (<1%)	Kellogg (1992)
Total	42,009,195	20,301,677	

* Generally refers to inferred postglacial, pre-colonization rainforest distribution.
† ICHvk and ICHwk subzones, excluding non-forested areas.
‡ ICHvk and ICHwk subzones, excluding non-forested areas and harvested areas.

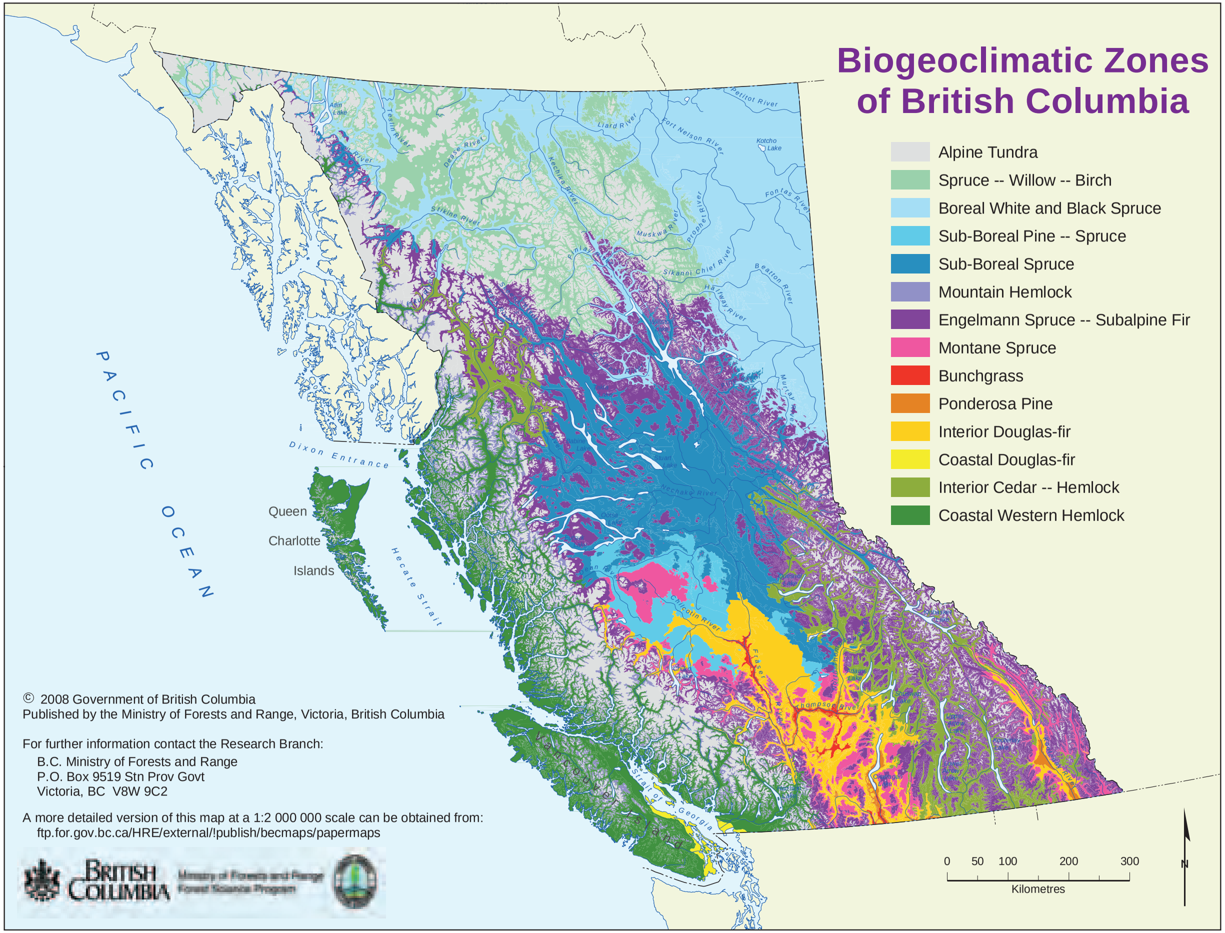

Figure 1.2 Biogeoclimatic zones of British Columbia. The Boreal Altai Fescue Alpine, Coastal Mountain-heather Alpine, and Interior Mountain-heather Alpine zones are shown as Alpine Tundra. (British Columbia Ministry of Forests and Range, Forest Science Program, 2008. Adapted from *Biogeoclimatic Zones of British Columbia*.)

Figure 1.3 Along the coast of British Columbia, the Coastal Western Hemlock zone occupies low elevations. At higher elevations, it gives way to the Mountain Hemlock zone. (Photo: Will MacKenzie)

Spruce (BWBS) zone, the Sub-Boreal Spruce zone, the Engelmann Spruce–Subalpine Fir (ESSF) zone, the Coastal Western Hemlock (CWH) zone, and the Mountain Hemlock (MH) zone (Figure 1.2), as well as the other subzones of the ICH zone (Meidinger and Pojar 1991). The CWH and MH zones (Figure 1.3) are subject to the effects of Pacific air masses, but lack the continental influence experienced by the inland rainforest. The ICH subzones in the Nass Basin and portions of the Hazelton and Skeena Mountains of northwestern British Columbia are transitional between coastal and interior systems. The ICH subzones to the south and east of the inland rainforest are warmer and drier, although discontinuous expressions of the inland rainforest can be found as far south as Idaho and Montana in cool, moist habitats, such as the spray zones of watercourses and waterfalls. The SBS and BWBS zones are the British Columbia expressions of the boreal forest that stretches across Canada; they share the continentality of the inland rainforest but are generally

Figure 1.4 Mixed forests of broad-leaved trees and conifers are common in the Boreal White and Black Spruce zone (shown here) and in the Sub-Boreal Spruce zone. (Ministry of Forests and Range file photo)

confined to plateaus and drier valleys, where there is little orographic influence from the interior mountains (Figure 1.4). The ESSF zone is immediately adjacent to the ICH zone, but at higher elevations (Figure 1.5); the expression of oceanic and continental influences in the ESSF zone differs from that in the ICH zone because of its overall colder climate.

The ecology of the inland rainforest is shaped by its distinctive climate and its location along the mid to lower slopes of mountains (Plate 1). It experiences wet summers and cool to cold winters, with moderate to high snowfall. It lacks the growing season frosts that may occur in valley bottoms. The combination of prolonged snowmelt, frequent summer rains, warm summer temperatures, and summer morning fog is instrumental in producing rainforest conditions and in keeping the forest environment productive throughout the growing season.

The natural disturbance regime – the type, extent, and frequency of natural events that kill or damage trees – is one of the important determinants of the character of a forest. Fire and outbreaks of western hemlock looper (*Lambdina fiscellaria lugubrosa*), a defoliating insect, are the dominant large-scale stand replacement disturbances in the inland rainforest, but both occur infrequently. The average fire return interval

Figure 1.5 The Engelmann Spruce–Subalpine Fir (ESSF) zone is the high-elevation forested zone in the interior wetbelt. In the upper ESSF zone (foreground), subalpine fir grows in clumps, separated by heath or meadow. Below the parkland is continuous forest (background) of subalpine fir and Engelmann spruce. (Photo: Will MacKenzie)

varies among sites and has been estimated to range from 130 years (Wong et al. 2003) to as long as 800-1,200 years (Sanborn et al. 2006). Some stands on lower slopes and toe positions show no evidence of catastrophic fires, and may have gone through several generations of dominant trees since the last stand-destroying disturbance. Infrequent episodic outbreaks of the western hemlock looper affect large tracts of forest, resulting in various levels of tree mortality and subsequent complex stand structures (Plate 7).

Because stand replacement disturbances occur infrequently, the inland rainforest is naturally dominated by older stands. Estimating the amount of old forest that would have existed within the inland rainforest in the absence of human intervention is difficult. In Table 1.2, however, we present estimates of the amount of old forest (older than 140 years) by adding what exists now to that which has been harvested, based on the Vegetation Resources Inventory database maintained by

Table 1.2

Area (ha) of the British Columbia inland rainforest at the biogeoclimatic variant level, derived from the British Columbia Ministry of Forests and Range Vegetation Resources Inventory database

Attribute	ICHvk1	ICHvk2	ICHwk1	ICHwk2	ICHwk3	ICHwk4	Total
A Total land area	295,740	132,020	592,680	203,838	94,348	142,492	1,461,118
B Total non-forest	120,538	8,557	159,344	47,497	5,177	24,211	365,324
C Total forest	175,201	123,463	433,337	156,341	89,172	118,281	1,095,795
D Total harvested	33,592	21,674	92,299	39,234	15,021	26,418	228,238
E Total not harvested >140 yrs	115,043	84,422	213,113	68,686	61,914	63,083	606,261
F >140 yr old forest (D + E)*	148,635	106,095	305,412	107,921	76,935	89,501	834,499
G 80-140 yr old forest (not including D)†	11,411	14,772	80,672	29,018	10,054	28,898	174,825
H 40-79 yr old forest (not including D)†	12,759	2,598	39,411	18,412	1,677	8,099	82,956
I <40-yr old forest (not including D)†	2,422	423	7,840	991	505	260	12,441
Percentage of forest harvested (D/C)	23%	20%	30%	36%	20%	30%	27%
Estimated original percentage of forest >140 yrs (F/C)	85%	86%	70%	69%	86%	76%	76%
Percentage of forest 80-140 yrs (G/C)	7%	12%	19%	19%	11%	24%	16%
Percentage of forest 40-79 yrs (H/C)	7%	2%	9%	12%	2%	7%	8%
Percentage of forest <40 yrs (I/C)	1%	0%	2%	1%	1%	0%	1%

* Assumes that all forest that was harvested was >140 years old when harvested.

† Does not include anything with a harvesting history according to the inventory.

Source: British Columbia Ministry of Forests and Range (2006c).

the British Columbia Ministry of Forests and Range (2006c). Our estimates are based on the assumption that harvested forest was greater than 140 years old prior to harvesting. Accordingly, 76% of the inland rainforest would be old in the absence of human intervention, with a low of 69% for the Quesnel variant of the ICHwk subzone (Steen and Coupe 1997) and a high of 86% in one variant each of the ICHwk and ICHvk subzones (Lloyd et al. 1990).

In these near-continuous older forests, other disturbance agents operate on a finer scale. Damage agents such as root diseases, bark beetles, heart rots, and storms create canopy gaps by killing one or a few trees, but in the inland rainforest they rarely destroy entire stands. Instead, forest regeneration is dominated by gap dynamics, a process of plant succession within small openings (Plate 6). Over time, these stands develop special structural attributes associated with old forests, such as large-diameter standing trees and logs, hollow trees, and very old woody substrates. A complex forest canopy (vertical structural diversity) and fine-grained pattern of open- and closed-canopy forest (horizontal structural diversity) offer a variety of niches for plants, animals, fungi, lichens, and microbes.

During much of the 20th century, these old western redcedar (*Thuja plicata*)–western hemlock (*Tsuga heterophylla*) forests were considered to have little commercial value. The provincial government actively encouraged the forest industry to derive whatever economic benefit it could from the old stands, and replace them with rapidly growing young trees. Although some elements of this attitude persist to the present day, recent scientific work has highlighted the significance of these forests from a conservation perspective (Arsenault and Goward 2000; Arsenault 2003; Goward and Spribille 2005; Serrouya et al. 2007; Spribille et al. 2009), and the inland rainforest has attracted the interest of local, provincial, and international environmental groups (e.g., Craighead and Cross 2004; Sherrod 2005; ForestEthics 2009). As the stewardship of forest resources evolves toward ecosystem management, more knowledge of old-growth forests and of the species closely associated with them is required. This knowledge is important to enable informed decisions on the retention of old-growth forests and specific habitats in managed landscapes, thereby reducing impacts to environmental values.

It is often difficult to determine the true age of inland rainforest stands. Western redcedar is the longest-lived species in most of the inland rainforest and individuals have been aged at as much as 700 years

(A. Arsenault, unpublished data), but the prevalence of internal decay usually makes it impossible to age the largest trees (DeLong et al. 2004a). Attempts to extrapolate western redcedar tree ages from partial cores in Idaho (Parker and Johnson 1993) have yielded tree ages of about 3,000 years, which seem questionable, as they are much higher than previously documented western redcedar ages in coastal Pacific Northwest forests (Earle 2007). Although stands with structural attributes associated with very old forests can be mapped using aerial photointerpretation, forests that have existed continuously longer than any of the individual trees in the stand – sometimes for over 1,000 years – cannot be detected consistently either on the ground or through remote sensing (DeLong et al. 2004a). Like Goward (1994), we use the term "antique" for such forests to distinguish them from other forests that may also be very old but in which the oldest trees date back to a stand replacement event.

Antique forests represent areas of long environmental continuity. In a number of temperate ecosystems, long environmental continuity has been found to be associated with many rare species (Esseen et al. 1992; Rose 1992; Goward 1994; Gauslaa 1995). In the inland rainforest, very old and antique forests are most likely to occur on lower slope and toe-slope positions on the valley floor, and to be associated with riparian ecosystems. Forests in these topographic positions tend to be wetter than forests on steep mid-slopes, and are thus more likely to survive fire and to retain old-growth legacies in the landscape. Some inland rainforests on toe slopes and lower slopes resemble coastal rainforests in the complexity of their architecture, the lushness of their respective under storeys, and the presence of species with oceanic affinities.

In many groups of organisms, such as lichens and other fungi, bryophytes (mosses, liverworts, and hornworts), and invertebrates, there are a number of species that are intimately dependent on old-growth forest features (Esseen et al. 1992). Although relatively few species of birds and mammals are strictly dependent on old-growth forests, many require certain structures that are more common in old forests. Some key old-growth forest structures for wildlife include large logs on the forest floor, especially hollow ones; living western hemlock and western redcedar trees with large internal cavities and other senescent features; large standing dead trees in a wide range of decay classes; and patchy, multilayered vegetation. These features are generally more abundant in old-growth forests, but can also be found in multi-aged forests or young forests that have retained old-growth legacies.

The inland rainforest contains species and ecological communities that are globally significant. The distribution of mountain caribou is so closely associated with the interior wetbelt that they have been considered a "flagship species" for this area, and an indicator of the health of the ecosystem (Mountain Caribou Technical Advisory Committee 2002). Mountain caribou have been designated as threatened by the Committee on the Status of Endangered Wildlife in Canada, and of the fewer than 1,900 remaining animals, over 98% are found in British Columbia. Arboreal lichen communities within the inland rainforest, especially the epiphytic cyanolichen assemblages on conifers, are among the richest in the world (Goward and Arsenault 2000a). Species such as these that depend on forests with old-growth attributes can disappear if the amount of habitat available to them falls below a critical threshold. This has been demonstrated in Europe, where silvicultural practices have nearly eliminated these forest features, and with them a high number of old growth–dependent species (Berg et al. 1994).

Management of the inland rainforest is challenging and sometimes contentious. The same ecosystem that supports rich old-growth forests with high conservation values also includes some of the most productive sites for tree growth in interior British Columbia. Despite the high level of decay in many mature inland rainforest trees, wood from the inland rainforest supports local communities and contributes to the wood supply for mills in larger centres. Products range from pulp to sawlogs to specialty western redcedar items. Those whose livelihoods depend on wood products from the inland rainforest are understandably wary of the growing interest in inland rainforest conservation.

In response to changes in scientific knowledge and in public expectations, many forest managers in British Columbia have been trying to understand and implement a new management paradigm, known as ecosystem management. This paradigm recognizes the forest as a complex and dynamic ecosystem, and focuses on maintaining ecosystem functions while gaining social and economic benefits from the forest (Grumbine 1994). An important component of ecosystem management is attempting to maintain the range of variability of the past patterns resulting from natural disturbances, from small treefall gaps to large wildfires. This is done both by approximating natural patterns with our forest management disturbances and by preserving unmanaged forests in which disturbances occur naturally. The intent is that, by maintaining natural patterns, we can maintain the natural processes that are associated with them. The ecosystem management paradigm has gained some acceptance, and is increasingly used in parts of British Columbia where stand-destroying fires occur frequently. The implications of ecosystem management in the inland rainforest, where old forests dominate the natural landscape, are more challenging to integrate with the demand for social and economic benefits, because significant alteration of intact old forests is required for many of these benefits – such as timber products and mineral resources – to be realized. The problem of identifying an appropriate ecosystem management approach is made more complex by the prospect of climate change, which is expected to affect both the vegetation community and the natural disturbance regime of the inland rainforest.

Decision makers face other difficulties as well. Resource management objectives – such as sustaining employment, producing fibre, maintaining scenic quality, providing recreational opportunities, protecting watershed values, and safeguarding biodiversity – often conflict with one another. The ability of the forest industry to adapt to changing public expectations is constrained by operational and economic challenges, such as difficult terrain, high levels of internal tree decay in many older stands, vegetation management problems on rich sites, and poor or fluctuating log markets. Although these challenges are not limited to the inland rainforest, they add to the difficulties that managers experience in trying to integrate ecosystem management concepts with economic realities.

The prospect of increased forest harvesting in the inland rainforest makes the need to understand and apply ecosystem management especially urgent. From 2000 to 2010, forest harvesting in the interior of British Columbia has been largely focused on stands attacked by the mountain pine beetle (*Dendroctonus ponderosae*), and the level of harvest activity in much of the inland rainforest has been relatively low. Once the mountain pine beetle has run its course, a renewal of harvesting pressure on regional non-pine forest types, including the inland rainforest, is likely. Decisions that are made in the wake of the mountain pine beetle outbreak, when the forest industry and forestry-dependent communities examine their timber supply options, will shape the future of the inland rainforest.

Given the challenges and the urgency, it is especially important that decision makers have access to scientific information. It is our goal to inform decision makers so they can best conserve and manage British Columbia's inland rainforest while addressing the requirements of regional land-use plans, the expectations of many publics and international markets, and demands for the economically and environmentally sound harvest of timber. We also seek to increase public awareness of the importance of the inland rainforest, and to better equip those interested in helping to shape how it is managed.

We begin in Chapter 2 by describing the physical setting of the inland rainforest. The physical setting dictates ecological drivers, such as climate and topography, and ecological processes, such as hydrological cycles, geomorphic processes, soil development, and disturbance regime. Viewed separately, features of the physical setting of the inland rainforest are not unique; it is the combination of features that creates a globally unique physical setting. Besides supporting a distinctive ecosystem, the physical setting and linear configuration of the inland rainforest tend to concentrate human disturbances, such as transportation corridors, clearing for agriculture, and forest harvesting, on the easily accessible valley bottoms and lower slopes.

The climate and even the geomorphology of the inland rainforest have changed over time and will continue to change. As the earth is currently in an era of accelerated climate change, we look at the potential future climate of the inland rainforest, as projected by recent climate models.

In Chapter 3, we describe the ecology and productivity of the inland rainforest. Much of what is unusual about this ecosystem stems from the environmental continuity afforded its extensive and extremely old forests. Antique forests and the organisms that depend on them are explored in this chapter, as they exemplify the importance of the inland rainforest ecology to global biodiversity. Even so, we may just be scratching the surface. Some of the reservoirs of biodiversity in the inland rainforest – canopy arthropod communities, the flora and fauna of decaying wood, mycorrhizal diversity, and the biota of the forest floor – are largely unexplored.

A productive climate and old forests means very large trees, many exceeding 2 m in diameter. We examine what this means for the development of habitat features, such as dens, that are found in abundance in the different stages – live, dead standing, and fallen – of these large trees. Another manifestation of the physical setting is the high timber productivity. The inland rainforest supports more species of commercially valuable trees than most British Columbia ecosystems, and some of the most productive timber-producing sites in the interior of the province. In this context, we examine the growth potential of the common tree species. This sets the stage for the remaining chapters, which explore the history of human values placed on the inland rainforest, the human management goals and related impacts, and a vision for a sustainable future.

In Chapter 4, we consider how shifts in the interests and technological skills of the rainforest's human inhabitants, from the First Peoples to contemporary communities, have brought about changes in how the forest was valued. Exploring how different inhabitants of the rainforest viewed the forest and what they extracted from it provides human context for the ecology and productivity of this ecosystem. The complexity of views on devil's club (*Oplopanax horridus*) highlights the importance of human context. Disparaged by settlers and woodsmen for the discomfort it caused them, devil's club was revered by First Peoples for its medicinal and spiritual values. Today, it is harvested for herbal and nutraceutical markets, but its commercialization raises important questions about the ethical use of traditional ecological knowledge. In the past, the inland rainforest fulfilled the needs of its local inhabitants, but now its globally rare species and awe-inspiring forests fulfill the conservation and recreational interests of the planet. Our hope is that this chapter will expand the horizons of readers so that they can view and appreciate the inland rainforest through the lens of its diverse human interests.

In Chapter 5, we focus in on human use of the timber resources of the inland rainforest, examining historical attitudes toward the inland rainforest as a "decadent" forest. Since annual growth has decreased in many of the large old trees, and some of the wood has rotted away, many people have felt that the true timber productivity of the sites was underutilized. Past government policy and industry goals called for the "liquidation" of old growth and its replacement by thrifty young stands. Historical data on harvesting and planting reflect these policies and goals, and also help to explain the patterns of stand age and species composition that we see on the landscape today.

The practice of silviculture in the inland rainforest has changed substantially since those early days, when the goal of replacing old cedar-hemlock stands with rapidly growing plantations of hybrid white spruce (*Picea engelmannii* × *glauca*) or lodgepole pine (*Pinus contorta*) was often unrealized because of the high incidence of regeneration failures. Today, because of better-quality planting stock and improved understanding of silvicultural methods, regeneration is more successful. The goalposts have changed, however. In the interests of promoting stand-level biodiversity, forest health, and ecological resilience, there is increased demand for a more ecologically appropriate mix of tree species, including western redcedar and western hemlock, in managed stands. Other emerging strategies include the acceptance of natural regeneration and broad-leaved trees in the mix.

Today there are competing social goals for these forests, centring on the recognition that they will produce the greatest timber volume through periodic harvest and reforestation but that they have their greatest value for maintaining rare species if left unharvested. Chapter 5 goes on to examine alternatives to clearcutting that leave patterns on the landscape more closely resembling those left by small-scale natural disturbances, and that have the potential to maintain some of the habitats and species associated with old-growth inland rainforests. In Chapter 6, we explore the potential impacts of human activities on the ecology of the inland rainforest. Different parts of the landscape respond differently to human activities, depending on the steepness of the slopes, the texture of the soil, the amount of rainfall, the hydrological pattern, and other attributes of the physical setting. Here we draw on published and unpublished research to review what is known about the sensitivity of various components of the inland rainforest ecosystem to human interventions. By examining wide-ranging species, such as the grizzly bear and mountain caribou, which respond to changes at the landscape scale, and the tiny stubble lichens (lichens in the order Caliciales) and other sedentary species that respond to changes in microclimate at the level of a single tree, we identify the need for a multi-scale approach to management of the inland rainforest.

Chapter 7 examines how the choices that humans have made up to now will affect the inland rainforest for a very long time, and the further potential of the choices that humans make now to determine the future of this ecosystem. The inland rainforest both affects climate change and is affected by climate change. Because of its high productivity and high levels of standing biomass, it has a role in global carbon dynamics that is disproportionate to its area. We review what is known about carbon dynamics in the inland rainforest, and what is known about the impacts of anticipated climate change on the rainforest ecosystem. There are many uncertainties regarding the influence of climate change on the inland rainforest, but it is important to explore possible outcomes in order to establish the need for flexible and adaptable management systems.

In Chapters 8 and 9, we examine differing management approaches at the landscape and stand scale, and begin to establish some possible alternate futures for the inland rainforest. One possible approach is to manage small areas intensively, leaving substantial areas with little human disturbance. Another is to manage much larger areas with lower-impact management strategies that leave much of the natural forest structure intact. We explore the myriad of future forest conditions that might be possible using a combination of landscape- and stand-level management strategies, and examine current and emerging risks to the inland rainforest. Finally, we offer our collective vision of what is needed to fully implement ecosystem management in the inland rainforest, based on our current scientific understanding of the ecology of the system, our interpretation of societal needs, and our understanding of what is possible in the realm of alternate landscape- and stand-level management practices. Through this book, we hope to draw attention to this unique British Columbia forest ecosystem and initiate discussion about its future.

2

The Physical Setting

> The east side of the [Rocky] Mountains is formed of long slopes, very few in this defile that are steep; but the west side is more abrupt, and has many places that require steady sure footed Horses, to descend it's [sic] banks in the open season: one is tempted to enquire what may be the volume of water contained in the immense quantities of snow brought to, and lodged on, the Mountains, from the Pacific Ocean, and how from an Ocean of salt water the immense evaporation constantly going on is pure fresh water; these are mysterious operations on a scale so vast that the human mind is lost in the contemplation.
>
> – *David Thompson's narrative of his explorations in western America, 1784-1812* (Tyrell 1916, 450)

Many of the distinctive attributes of the inland rainforest derive from its physical setting. Its location in relation to physiographic features and the characteristic movements of Pacific and Arctic air masses determine its unique climate. The climate, in turn, plays an important role in differentiating the soils of the inland rainforest from those of other British Columbia ecosystems.

Geographic Distribution and Climate

The Interior Cedar-Hemlock (ICH) biogeoclimatic zone, excluding the coastal transition subzones of northwestern British Columbia, covers approximately 4.1 million ha of land. Of this area, 18% is classified into dry subzones and 49% into moist subzones. The remaining 1.5 million ha (33%), which fall into the wet or very wet subzones (Table 1.2), comprise the area that we consider the inland rainforest.

The inland rainforest stretches from valley bottom to midslopes in river valleys of east central British Columbia. It generally occurs at elevations ranging from 400 to 1,500 m, eventually giving way to high-elevation snow forests of the Engelmann Spruce–Subalpine Fir (ESSF) biogeoclimatic zone (Figure 1.2). These rainforests are distributed in 21 large watersheds between Kootenay Lake in the south and the McGregor River in the north, and more specifically on the lower slopes of the Columbia Mountains, the windward side of the Continental Divide along the Rocky Mountains, and the Quesnel and Shuswap Highlands.

Climate station data for 1971-2000 (data from Reynolds 1997, updated to 2000 by British Columbia Ministry of Forests and Range staff) show that the climate of the inland rainforest shares some features with the wet and very wet subzones of the Coastal Western Hemlock (CWH) biogeoclimatic zone (here referred to as the coastal rainforest) and some features with the wet and very wet subzones of adjacent interior zones (Figure 2.1). The mean annual temperature in the inland rainforest ranges from 2.7 to 4.5°C, which is at the lower end of the range of the coastal rainforest but clearly warmer than its interior neighbours. Summer temperatures of the inland and coastal rainforests are similar, but the mean temperature of the coldest month ranges from –8.0 to –9.5°C in the inland rainforest, and +4.1 to –6.4°C in the coastal rainforest. As a result, most of the winter precipitation in the inland rainforest falls as snow, whereas much of the winter precipitation on the coast falls as rain.

The mean annual precipitation in the inland rainforest is 788 to 1,240 mm, similar to that of the wet and very wet subzones of the Sub-Boreal Spruce (SBS) biogeoclimatic zone but well below that of the coastal rainforest. This level of precipitation is lower than the threshold levels of 1,200 mm (Schimper 1903, cited in Adam 1992) to 1,300 mm (Alaback et al. 2000) that have been used to identify other temperate rainforests. Why, then, should the inland rainforest be considered a rainforest at all? Why do we see an assemblage of species and structures associated with coastal ecosystems reappearing in the inland rainforest? There are two answers to this question. First, although total precipitation is lower than that of coastal ecosystems, the May to September

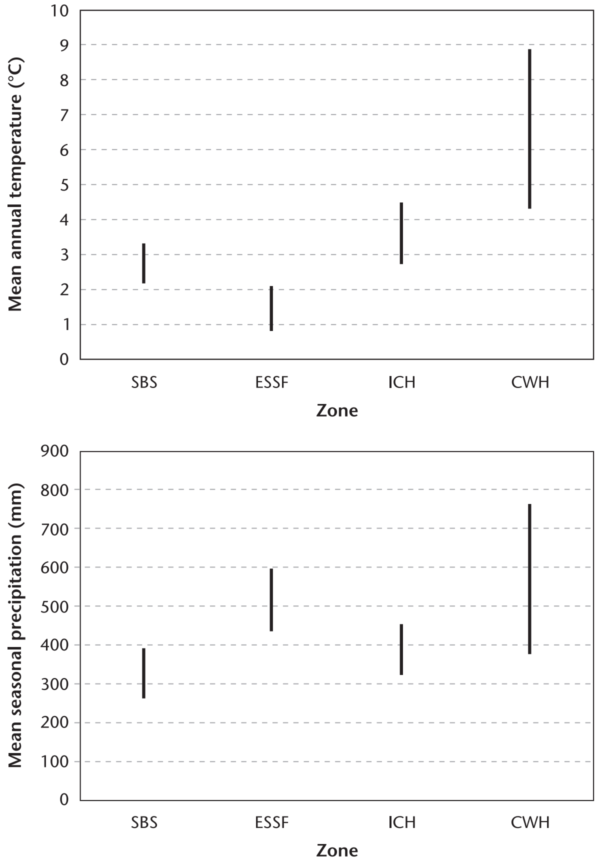

Figure 2.1 Range of mean annual temperature (°C) and mean seasonal (May to September) precipitation (mm) at the variant level for the wet and very wet subzones of the ICH zone (excluding the northwestern portion) and the wet and wet subzones of three other biogeoclimatic zones. (Data of Reynolds 1997, updated to 2000 by British Columbia Ministry of Forests and Range staff)

precipitation of 320-452 mm falls within the range of the coastal rainforest (Figure 2.1). Second, snowpacks in the inland rainforest are moderate to deep, with up to 2 m of settled snow in mid to late winter in the wettest portions, and far deeper in the ESSF zone, which lies upslope of the inland rainforest. Prolonged melt of this deep snowpack over summer months, and the subsequent groundwater flow it initiates, minimize soil moisture deficit (Ketcheson et al. 1991). Orographic rainfall at higher elevations and morning mists that often blanket valley bottoms may also help to maintain humid conditions during summer.

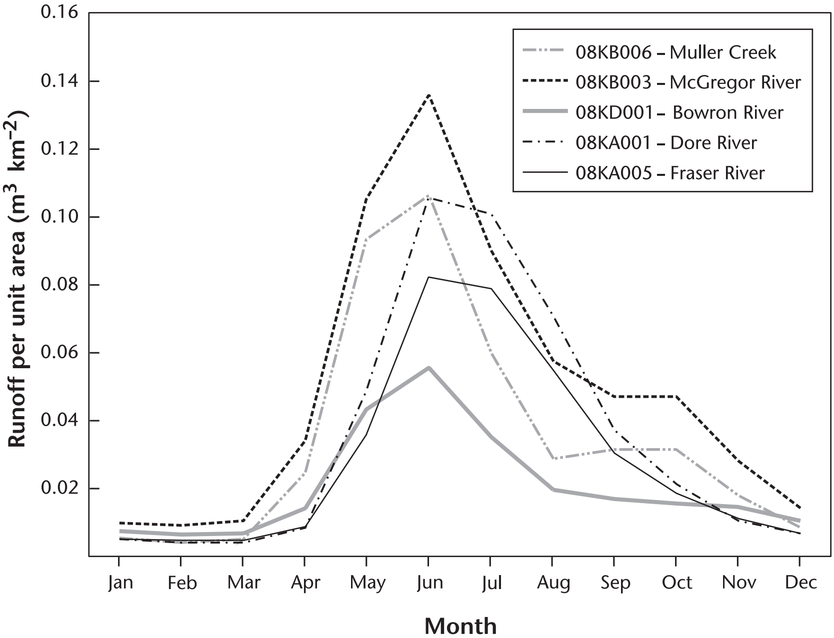

Figure 2.2 Runoff per unit area by month in several representative watersheds of the northern interior wetbelt. Identification numbers refer to Water Survey of Canada hydrometric stations.

At a finer geographic scale, topography can have a marked effect on local climate. In the northern portion of the inland rainforest, for example, cold air drainage in valley bottoms apparently lowers temperatures enough that forests dominated by spruce (*Picea* spp.) and subalpine fir (*Abies lasiocarpa*) commonly replace cedar-hemlock forests.

Peakflow in northern interior watersheds is usually generated by spring snowmelt. Typical hydrographs, such as those for the Bowron, Dore, or McGregor Rivers, show streamflow peaks in the late spring or early summer (Figure 2.2). Sometimes there is a much smaller peak in the fall due to increased rainfall.

Until about 4,000-5,000 years ago, the climate of the inland rainforest was quite different from the present climate. Walker and Pellatt (2008) reviewed paleoclimatological data covering the northern Columbia basin, an area that includes the southern half of the inland rainforest. Drawing on data from a variety of sources (glacial history, lake deposits, pollen and plant macrofossils, lake salinity indicators, chironomid midges, dendrochronology, and historical records), they described four major climatic phases since the last glaciation. The maximum extent of the Wisconsin glaciation, which covered nearly all of British Columbia, was followed by a cold, dry late-glacial phase (over 11,500 calendar years before present [BP]). The early Holocene (about 10,500 to 7,800 calendar years BP) was a dry period, warmer than today by about 2-4°C (Hebda 1995; Rosenberg et al. 2004; Chase et al. 2008). This was followed by a gradually cooling phase through the mid-Holocene (about 7,800 to 4,500 calendar years BP). During the late Holocene (since about 4,500 calendar years BP), the climate in the Columbia Mountains and Southern Rockies has been similar to that of the present (Hebda 1995; Chase et al. 2008). Air temperatures, however, have warmed by about 1°C over the last century (Walker and Pellatt 2008).

Global climate change over the next century is expected to significantly affect the climate of the inland rainforest. Figure 2.3 shows changes in mean annual temperature and mean annual precipitation in the inland rainforest predicted by three climate change models (CGCM2_B2x, CGCM1_gax, and HADCM3_A2), selected according to procedures of the Canadian Institute for Climate Studies (2007) to represent a range of results. We used the program ClimateBC v. 2.3 (Hamann and Wang 2005; Wang et al. 2006a, 2006b) to generate annual climate variables for the reference period 1961-90, observed values for the years 1998-2002, and projected climate variables for the periods 2010-39, 2040-69, and 2070-99. The data are the means of values for eight locations each across the geographic range of the ICHvk and the ICHwk subzones, respectively (Table 2.1).

These three models predict an increase in mean annual temperature by 2070-99 from the baseline value of 2.9°C to projected values of 5.7-6.9°C in the ICHvk subzone, and from the baseline value of 3.9°C to projected values of 5.8-8.0°C in the ICHwk subzone (Figure 2.3). A temperature change of the magnitude predicted by the most conservative model, 2-3°C, would restore the thermal environment of the inland rainforest to that of the early Holocene over a 100-year period. These models predict a slight increase in precipitation from 1,030 mm to 1,073-1,170 mm in the ICHvk subzone, and from 933 mm to 970-1,018 mm in the ICHwk subzone. Predictive models of future climates are based on available data and modelling approaches, and should be treated as working scientific hypotheses that will be refined over time as more information becomes available.

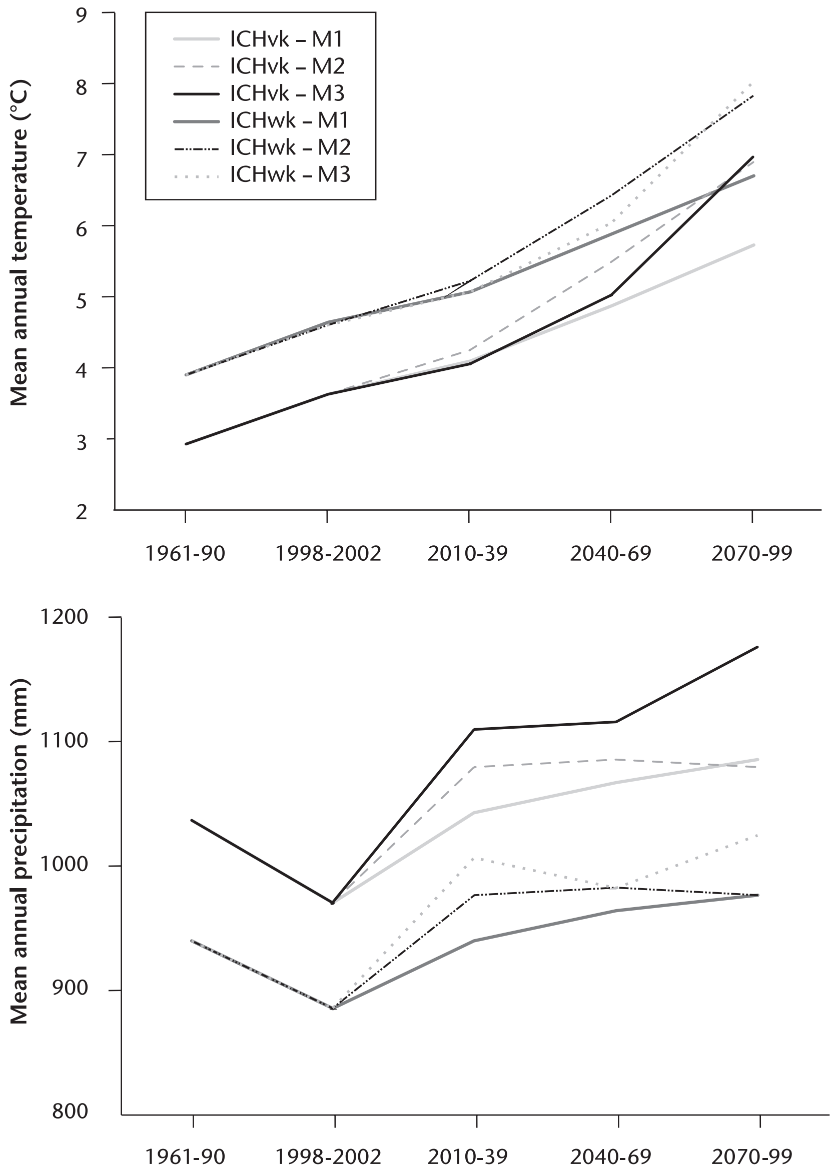

Figure 2.3 Projected changes in mean annual temperature (°C) and mean annual precipitation (mm) in the ICHvk and ICHwk subzones from reference values (1961-90) and observed values (1998-2002), according to three climate change models: CGCM2_B2x (M1), CGCM_gax (M2), and HADCM3_A2 (M3). Data are means of eight sample locations in each subzone. Generated with ClimateBC ver. 2.3 (Wang et al. 2006a).

Table 2.1

Projected changes in climate variables from 1961-90 ("1975") to 2070-99 ("2085") at selected locations in the ICHvk and ICHwk subzones

			Elev.	MAT		MWMT		MCMT		NFFD		MAP		MSP		PAS	
Subzone/site	Latitude	Longitude	(m)	1975	2085	1975	2085	1975	2085	1975	2085	1975	2085	1975	2085	1975	2085
ICHvk																	
Longworth	53.916	121.471	659	3.2	7.3	14.7	18.5	−9.7	−4.5	160	219	883	921	344	358	353	235
Purden	53.91	121.894	835	3.0	7.0	14.2	18.0	−9.3	−4.2	157	217	873	910	377	393	332	218
Hungary Creek	53.831	121.479	1,050	2.5	6.5	13.6	17.4	−9.5	−4.3	150	210	941	982	406	423	374	246
Dome Creek	53.732	121.137	810	2.9	6.9	14.1	17.9	−9.7	−4.5	152	213	822	858	364	380	312	209
Adams River	52.034	119.096	929	2.4	6.4	13.9	17.7	−9.7	−5.3	148	206	1,307	1,361	489	510	581	392
Mica Creek	52.006	118.566	626	3.5	7.5	15.5	19.3	−9.4	−4.8	164	221	1,161	1,209	296	308	582	382
Upper Goldstream	51.623	118.178	780	2.2	6.1	13.8	17.6	−10.2	−5.7	145	202	1,060	1,103	333	347	529	362
Incomappleux River	50.91	117.566	821	3.2	7.2	15.1	19.0	−9.3	−4.9	158	215	1,195	1,243	375	390	557	361
Mean change				4.0		3.8		4.8		58.6		43.1		15.6		−152	
ICHwk																	
Goat River	53.53	120.595	714	3.6	7.6	14.9	18.7	−9.3	−4.2	163	224	753	786	334	348	265	172
East Twin Creek	53.466	120.351	1,100	2.6	6.6	13.8	17.5	−9.6	−4.4	155	215	1,117	1,166	499	520	411	260
Keithley Creek	52.75	121.424	860	2.7	6.6	13.5	17.3	−8.9	−4.5	145	206	652	678	302	315	244	159
Quesnel Lake	52.646	120.907	1,100	2.5	6.4	13.6	17.3	−9.3	−4.9	145	208	905	942	396	412	356	227
Tumtum Lake	51.851	119.124	693	4.1	8.0	15.7	19.5	−8.3	−3.9	172	230	1,270	1,321	449	468	489	295
Lower Goldstream	51.667	118.599	619	4.0	7.9	15.6	19.5	−8.2	−3.8	173	232	884	919	291	303	368	223
Three Valley	50.926	118.476	515	5.1	9.0	16.7	20.5	−7.4	−3.3	181	239	1,082	1,124	417	434	356	203
Shelter Bay	50.632	117.931	521	6.3	10.3	17.9	21.8	−6.0	−1.9	202	261	797	828	286	298	237	124
Mean change				3.9		3.8		4.5		59.9		38.0		15.5		−133	

Notes: These values were generated with ClimateBC v. 2.3 (Wang et al. 2006a) using the climate model CGCM1_gax. MAT = mean annual temperature (°C); MWMT = mean warmest month temperature (°C); MCMT = mean coldest month temperature (°C); NFFD = number of frost-free days; MAP = mean annual precipitation (mm); MSP = mean annual summer precipitation (mm); PAS = precipitation as snow (mm).

Additional climate variables projected by the CGCM1_gax model for the 16 ICH sites (Table 2.1) show that the increase in winter temperatures is somewhat more pronounced than the increase in summer temperatures. Associated with the warmer winters is a drop in the amount of precipitation falling as snow. Although there is a growing consensus that we are experiencing significant anthropogenic climate change, uncertainty remains about how variable and how intense this change will be. Projected outcomes depend not only on the models but also on the assumptions that are made about future production of greenhouse gases by humans. As well as changes in mean values, increases in extreme weather events, such as droughts, heat waves, floods, and storms, are predicted (IPCC 2001; Lemmen and Warren 2004). The potential impacts of climate change on the vegetation of the inland rainforest are discussed in Chapter 7, under "Climate Change: Impacts and Mitigation."

Physiography, Glacial History, and Landforms

From east to west, the inland rainforest spans three major physiographic subdivisions of British Columbia, each with characteristic bedrock assemblages (Holland 1976) (Figure 2.4). The Rocky Mountains are composed of limestones, quartzites, schists, and slates, and are bounded on the west by the Rocky Mountain Trench. West of the trench, the Columbia Mountains consist of four major ranges. From northwest to southeast, these are the Cariboo Mountains (sedimentary and metamorphic rocks, particularly quartzite), the Monashee Mountains (gneissic metamorphic rocks, sedimentary and volcanic rocks, and intrusive igneous rocks), the Selkirk Mountains (a complex variety of sedimentary, metamorphic, and both volcanic and intrusive igneous rocks), and the Purcell Mountains (sedimentary and metamorphic rocks, including quartzite, argillite, and limestone, with intrusions of granitic rocks). The Quesnel and Shuswap Highlands mark the transition to the eastern edge of the Interior Plateau, composed of primarily sedimentary, metamorphic, and volcanic rocks.

Three major rivers drain the inland rainforest: the Fraser, the Thompson, and the Columbia. The latter has been heavily modified by major impoundments behind the Mica and Revelstoke dams that flooded significant areas of the inland rainforest. The largest natural lakes (Quesnel, Shuswap, and Adams) occupy glacially deepened basins in the Quesnel and Shuswap Highlands.

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Frontispiece photograph: An old inland rainforest stand in the upper Fraser River valley. The trunks of the large western redcedars are yellow from gold dust lichen (*Chrysothrix candelaris*). (Photo: Darwyn Coxson)

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