North Coast LRMP

Background Report

Natural Disturbance Dynamics on the North Coast

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for the North Coast LRMP

BRITISH COLUMBIA

This report was prepared by Brigitte Dorner (School of Resource and Environmental Management, Simon Fraser University) and Carmen Wong (independent consultant), as background information on natural disturbance dynamics in the North Coast LRMP area. The information in this report was collected from a wide range of sources and was reviewed by government staff for accuracy and completeness. The final product is presented as the professional judgement of the authors and does not necessarily reflect the view of the Province.

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Terms of Reference

The purpose of this project will be to synthesize various sources of information and research and provide LRMP participants with a concise overview of:

- Natural disturbances in the North Coast,
- A conceptual model describing relationships and interactions between natural disturbances, forest and vegetation structure, landscape pattern and biodiversity.
- Implications of natural disturbance dynamics to LRMP strategic planning and identify related strategic planning issues
- Gaps in knowledge on North Coast natural disturbances

For the North Coast of BC, there has been no synthesis of past natural disturbances. This project will synthesize existing research on natural disturbances on the North Coast. Research from other areas outside of the North Coast will be used if the study area is similar in forest type, climate and topography to sites in the North Coast. Local ecologists will be contacted to gather expert knowledge on local forest dynamics and planning concerns.

This project will:

1. Identify predominant natural disturbance agents associated with North Coast BEC variants and ecoregions,
2. Define and classify the North Coast into physical units with broadly similar disturbance dynamics, based on how natural disturbances act in North Coast forests and other similar ecosystems.

3. For each predominant agent, attempt to document the past frequency, severity, size and spatial distribution of events. To describe disturbance severity we will
   a. attempt to document the resulting effect on forest structure at a stand-level using measures such as:
      - mortality
      - resulting stand structure (age/size and species composition) after a disturbance event,
      - mortality
      - effect on regeneration, successional pathways and other forest processes such as nutrient cycling.
4. Describe effects of disturbance on landscape pattern by characterizing the spatio-temporal distribution of forest types and successional stages across the landscape.
5. Assess the quality of information available on natural disturbances in the plan area.
6. Discuss how habitat requirements of indicator species[i] are related to disturbance processes and landscape structure.
7. Discuss implications of natural disturbance dynamics and current forest practices for LRMP strategic planning and identify strategic planning issues.

[i] Indicator information will be acquired from other LRMP projects.

Executive Summary

Natural disturbances, along with the activities of First Nations peoples, have historically shaped the composition and structure of forests on the North Coast. Natural disturbances can impact timber production by damaging or killing trees, but they are also agents of diversity and renewal that ensure a steady supply of important habitat elements such as snags, fallen trees, and browsing opportunities for many species. A good understanding of natural disturbance dynamics is an important first step towards achieving forest management goals such as sustained timber supply and the maintenance of habitat characteristics to which native species have adapted. This report provides background information to the North Coast LRMP Table on natural disturbance regimes and identifies forest management issues arising from our understanding of natural forest dynamics in the plan area.

The moist, cool climate strongly influences forest dynamics on the North Coast. The landscape in the plan area is varied, consisting of lowlands, intricate coastlines, extensive floodplains, coastal mountains and steep sided fjords. These physiographic and topographic characteristics are also influential drivers of disturbance dynamics in the area. In the watersheds of the coastal mountain ranges, the forest mosaic typically consists of large, continuous tracts of all-aged, structurally diverse old-growth coastal western hemlock (CWH) forest, separated by cliffs, gullies, wetlands, and shrub-covered avalanche and landslide tracks. In the low-lying coastal sections, patches of productive forest occur within a matrix of non-forested bog lands and stunted bog woodland.

Over the majority of the North Coast landscape, small canopy gaps of ten trees or less, caused primarily by wind or pathogens are the primary mode of disturbance. Geomorphic disturbances can play an important role in susceptible parts of the landscape and are the main naturally occurring high-severity, stand-replacing events in the area, although wind and fire may also occasionally create larger canopy openings. Flooding is a key element of forest dynamics in floodplains and estuaries. Other agents that may occasionally injure or kill trees include frost and drought, insects, and mammals, most notably porcupines, beavers, and deer. The different types of disturbances do not occur homogeneously across the forest landscape. Rather, many of the agents are confined to, or occur predominantly in specific stand types and on specific site types or landscape positions.

Frequent cyclonic storms originating in the Gulf of Alaska make blowdown one of the key disturbance agents in the plan area. The severity of wind effects is determined by topographic exposure, species and growth form, stand structure, and site characteristics, as well as the amount of precipitation accompanying the storm. The vast majority of openings created by wind are small canopy gaps, but patches of partial or complete canopy blowdown up to several hundred hectares in size have been reported along the northwest coast of British Columbia and southeast Alaska. The primary mode of mortality during windstorms is stem snap. Fallen trees serve an important ecological role as large woody debris, which is a key feature of both terrestrial and hydro-riparian habitat. Uprooting of trees during windstorms, although comparatively rare, provides habitat for various species and helps to maintain soil productivity. Harvesting, by opening up the canopy, may create conditions favourable for blowdown. Under climate change predictions the incidence and severity of blowdown is likely to increase.

Geomorphic disturbances, such as avalanches, rockslides, and debris flows and torrents, are the primary natural agents of stand-replacing disturbance on the North Coast. Major slide events in natural terrain along the coast appear to be episodic and associated with unusually severe rainstorms. Geomorphic disturbances dislodge trees, soil, and rocks and deliver sediments and woody debris considerable distances to valley floors, often modifying stream channels and floodplains in the process. Jams of large woody debris, in particular, alter flow patterns and provide protection from flood scour so that vegetation can develop downstream. Thus, geomorphic disturbances can modify both landform and forest structure. Avalanche paths, landslides and debris flows fragment the lateral connectivity of upland forest and create early-seral corridors between high elevations and valley floors. Slides and debris flows generate more soil disturbance than avalanches and can contribute towards maintaining long-term forest productivity in those areas where mineral soil is deposited. Any disturbance that removes tree cover and changes local drainage patterns, including clearcut harvesting and road building, can increase the risk of mass wasting and avalanches.

Floods, triggered by rainstorms, rain on snow, or rapid snowmelt, can cause varying degrees of tree mortality. However, flooding rarely kills a substantial number of mature trees unless debris flows or torrents are triggered. Flooding and associated mass movements are confined to specific landscape positions, and typically influence only a small proportion of area in a watershed. Floodplains, fans and estuaries subject to flooding are highly productive and support forests of various composition and ages, depending on disturbance frequency and severity. Portions of fans that are frequently flooded or experience debris torrents support black cottonwood, red and slide alder, deciduous shrub, and berry and herb communities. Very large, widely spaced Sitka spruce and western hemlock are common in less active, well-drained areas of floodplains and fans. Portions that are not well-drained may support shrub and sedge wetlands. Climate change is expected to increase the frequency of extreme storms and thus mass wasting, flooding and erosion.

Lightning caused fires are rare on the North Coast, due to the cool, wet climate. There is no research specific to the North Coast on natural fires before 1950. The closest published study of fire in coastal western hemlock forests (CWHvm1) stems from Clayoquot Valley, Vancouver Island. There, average time since the most recent fire ranged between 750 and 4500 years ago. Certain portions of the landscape are likely more susceptible to fire than others, depending on topography and vegetation types. Intentional low-severity burning by aboriginals to enhance berry production has been documented for First Nation peoples in the area. Aboriginal burning of cedar to hollow out canoes is also a probable cause of origin for several fire-regenerated cedar stands observed on the mid- and north coast. Fire affects post-disturbance succession by reducing thick organic layers, improving nutrient availability, providing a good seed bed for western redcedar and removing advance regeneration of mistletoe infected western hemlock. We expect that climate change will influence fire regimes by affecting fuel moisture during the summer. However, the direction of change is uncertain as there is a fair amount of uncertainty in projections regarding summer precipitation levels for the North Coast.

Short-term climatic disturbances, such as frost and drought, can injure tree canopies and root systems. The degree of reduced growth or mortality from these agents depends on tree vigour, size, and microsite. Currently, the most significant impact of climatic disturbance in the North Coast may be yellow cedar decline, which is hypothesized to be due to climatic warming beginning at the turn of the century.

Decay fungi, including heart, root, and butt rots, are the most important biotic disturbance agents in the plan area. The parasitic hemlock dwarf mistletoe also plays an important role. Although pathogens rarely cause direct mortality, they can predispose infected trees to blowdown and other modes of disturbance. Thus, pathogens enhance structural complexity and accelerate succession to all-aged stands with old-growth characteristics. Heart rot, the predominant mode of fungal decay in the North Coast, spreads through air-born spores and enters trees primarily through wounds, which may be caused by falling trees during a windstorm, mammal damage, or activities related to forest management. Both fungi and mistletoe seem to grow slower at higher latitudes than further south, and, in the plan area, infection may show serious effects only after trees reach several hundred years of age. With global warming, the speed of rot development may increase and the relative importance of different pathogens may shift.

Other biotic disturbance agents play a less important role in coastal forests than in many other forest types, though they have had considerable impacts in some instances. Mature western hemlock can suffer growth reduction and some mortality after consecutive years of defoliation by several types of budworm and loopers. Stands of young Sitka spruce can be deformed by weevils and feeding by aphids has caused high mortality in some areas. Mammals may also affect stand development where conditions are favourable. Beavers use saplings and pole-sized trees for food and construction, and can substantially alter ecosystem structure and dynamics in hydroriparian zones. Porcupines may also kill or injure trees and thus contribute to gap dynamics, especially in second-growth stands. Deer populations, if concentrated on the landscape, can sometimes denude the understory and impede tree regeneration. Climate change and harvesting will likely increase the importance of insects and mammals as disturbance agents.

Based on the current scientific understanding of natural disturbance dynamics on the North Coast and similar ecosystems, we propose the following key issues for consideration by the LRMP table.

(1) Given our understanding of natural dynamics on the North Coast, what are appropriate spatial and temporal scales for forest management?

- Landscape dynamics on the North Coast are strongly influenced by the underlying mosaic of physiography and topography. The paradigm of a shifting mosaic of seral stages[ii] that underlies the management approach proposed in the Biodiversity Guidebook does not fit this type of landscape very well, since much of the early-seral vegetation is confined to a few areas subject to repeated disturbance, whereas most of

[ii] This paradigm applies to a landscape where forest dynamics are similar across the landscape and occurrence of natural disturbances is not restricted to particular topographic or other site characteristics. In such a landscape, the spatial distribution of young and old forest throughout the landscape is similarly independent of topography or other site characteristics, and the forest mosaic therefore 'shifts' at random across the landscape over time as disturbances create new openings and older openings gradually merge back into the matrix of old forest.

the operable, productive forests of interest to harvesting rarely experience severe, large-scale disturbance. A planning approach that fails to take this into consideration will make it difficult to incorporate knowledge about natural dynamics in a meaningful way. The disturbance units proposed in Section 3 of this report, or a similar type of landscape stratification, would be a logical subdivision of the landscape in terms of maintaining ecological processes and their outcomes. Such a stratification could also help identify planning areas where special management is required to avoid undesirable interactions with dominant disturbance agents.

- Climate also is a significant driver of forest dynamics on the North Coast. Future climate change along coastal BC is predicted to bring increases in average temperatures by 1.5 to 4°C, as well as increases in winter precipitation, severity of winter storms, glacial retreat, increased flooding especially in the spring, and also flooding of coastal areas. These changes will likely increase the incidence and/or severity of most disturbance agents and affect how forests respond to these agents and other processes. Consideration of intermediate and long-term climatic trends is therefore essential for anticipating and planning future forest development.
- Since most ecosystem processes on the North Coast often seem to progress on the scale of decades or centuries, undesired effects of management activities may take a long time to manifest and even longer to reverse. This suggests a need for careful long-term planning and continued monitoring if negative ecosystem impacts are to be minimized.
- While forests on the North Coast are primarily driven by gap dynamics, larger, more severe natural disturbance events do occur episodically in some parts of the landscape. Negative impacts of such rare events on sustained timber supply and biodiversity are to be avoided, proactive planning and forecasting over long time horizons will be required. This could include considering the potential of earthquakes or landslides on road networks and taking into account loss of timber to episodic severe natural disturbances in timber supply analyses.

(2) How can natural disturbance regimes serve as a guide for forest management on the North Coast?

- The forests in the North Coast are predominantly considered NDT (Natural Disturbance Type) 1 in the Biodiversity Guidebook, with intervals between stand replacing disturbances averaging 250 to 350 years. Although some small sections of the landscape may experience relatively frequent stand-replacing disturbances, there is no evidence to support the disturbance intervals for the North Coast postulated in the Guidebook on a broader landscape scale. The scientific evidence also indicates that in forests considered productive and operable, disturbance return intervals for large, stand-replacing events were generally much longer than commercial rotation periods.
- Because forests on the North Coast are primarily driven by gap dynamics, natural disturbance regimes provide no template for clearcutting systems, or traditional approaches to even-aged management in general. If the objective of forest

management is to emulate natural disturbance patterns, a variable retention silvicultural system such as the one proposed by the Clayoquot Sound Scientific Panel, which retains trees and forest patches similar to patterns and remnant structures left after natural disturbances, is the closest match. Whereas variable retention is considered more appropriate for maintaining the structural characteristics of old-growth forests, it may also result in reduced tree growth rates (as compared to clearcut harvesting) and may increase the incidence of some types of natural disturbance such as blowdown, mistletoe, and fungal infection. In cases where high retention levels are not a desirable option, the potential risk of negative ecological impacts from silvicultural practices that do not maintain natural dynamics may be reduced through extended rotations, and by constraining the proportion of the landbase over which harvesting may occur. However, if a reduction in harvesting landbase is to be offset by more intensive management zones, it will be important to carefully consider the allocation of such areas, since in many cases the most productive areas from a timber growth perspective also tend to be of primary importance for biodiversity.

- Most of the interactions between harvesting and natural disturbance on the North Coast are synergistic, i.e., harvesting is likely to increase occurrence of natural disturbances. Moreover, incidence or severity of most natural disturbances is likely to increase as a response to climate change, and use of fire or mechanical site preparation as a management tool to improve soil productivity may further increase the overall incidence of disturbance across the landscape. In summary, disturbance rates are likely to increase in the future even without harvesting, and harvesting will almost certainly lead to disturbance rates substantially higher than the landscape has historically experienced. This emphasizes the need to monitor landscape conditions to recognize and avert potential negative impacts on ecosystem function and biodiversity.
- Uprooting by wind and other forms of soil disturbance are important for maintaining soil productivity, particularly in hypermaritime forests (CWHvh). Uprooting of large trees has a more thorough, long-lasting effect than uprooting of small trees. Thus the loss of large trees from the stand through logging may have negative impacts on soil productivity. Note however, that the contribution of uprooting to maintaining soil productivity was likely limited on the North Coast since the primary mode of mortality in old growth forests is stem snap. Soil disturbance as a silvicultural treatment, if appropriately applied, may offset the reduction in soil disturbance associated with the loss of large trees, and counteract the negative impacts on soil productivity associated with harvesting.
- Although natural disturbances are a key aspect of forest dynamics, forests are shaped and maintained by a variety of factors that are partially or completely outside the scope of this report. Even if harvesting is designed to emulate natural disturbances very closely, consideration of other factors influencing forest development over the long and short term is essential for maintaining ecosystem integrity and productivity. These factors include drainage patterns, nutrient cycling, soil development, availability of seed sources, as well as genetic health of tree populations. The impact of harvesting on some of these factors is being studied in operational trials on the North Coast as part of the Hyp^3 Ministry of Forest Research Project.

(3) One of the key principles of ecosystem management is that species are adapted to, and therefore most likely to persist under the environment and processes they have experienced historically. What are the key habitat characteristics historically maintained by natural dynamics, and how is forestry affecting these characteristics?

- The majority of the forested landscape on the North Coast was historically in all-aged stands dominated by gap-phase replacement. Reducing the supply of this type of habitat may negatively impact old-growth-dependent species.
- Because historically stand replacing disturbances were largely constrained to susceptible locations within the landscape, late seral forest was persistent throughout the remainder of the forested area. Current areas of persistent late seral forest can act as habitat refugia for species dependent on them. Continued existence of such refugia can be ensured by setting aside old growth areas or by managing some parts of the landscape at rotation rates that allow development of old growth characteristics.
- The long stem-exclusion[iii] stage ensuing after clearcut harvesting means that understory plants and species dependent on these plants may drop out of the stand. Requirements for persistence and recolonization of such species may therefore need to be considered if these species are to be maintained in the landscape.
- The historical landscape mosaic provided connected routes for movement and dispersal of species dependent on particular habitat characteristics. Where harvesting or other forms of development interrupt connectivity, the ability of species to move and disperse throughout the landscape may be impacted.
- Several of the species listed in the indicator section rely on the juxtaposition of early-seral herb and shrub communities and forest cover for protection and denning. Where forest management creates larger openings and reduces the amount of small canopy gaps characteristic of old-growth forests, the result may be a lack of suitable cover for some species.
- Productive valley bottom areas and estuaries often have high economic timber value as well as high habitat value and may thus be especially vulnerable. Since narrow riparian buffers are susceptible to blowdown, effective protection of hydro-riparian ecosystems may require additional measures to ensure that these buffers will be able to fulfil their intended role.
- Standing dead and downed wood are important habitat elements in both terrestrial and aquatic ecosystems. Natural disturbances generally ensure an ample supply of snags, root wads, and downed wood. Reduced recruitment of snags and large woody debris in managed stands may have long-term effects on nutrient cycling, tree regeneration, and habitat quality. Since the large root mounds and downed logs of old-growth forests persist for a long time, the impacts of reduced input of dead wood into the system may only become fully apparent after one or two rotations of second growth.

[iii] Stage of forest development where a dense layer of young to mature trees prevents others from establishing. The intense competition for resources in this stage results in the death of many of trees and thus reduced stem density.

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1 Introduction

1.1 Background and Rationale

Natural disturbances, along with the activities of First Nations peoples, have historically maintained the composition and structure of forest stands and landscapes. Natural disturbances will almost certainly continue to play a significant role in future landscapes in British Columbia. Thus, a good understanding of natural disturbance dynamics is an important first step towards achieving forest management goals such as sustained timber supply and maintenance of habitat characteristics to which native species have adapted.

This report provides background information to the North Coast LRMP Table on natural disturbance regimes and forest management issues arising from our understanding of natural forest dynamics in the plan area. For each disturbance agent, we document the currently available knowledge on historical occurrence, effects on forest and landscape structure and habitat characteristics considered important for maintaining biodiversity, as well as interactions with other disturbance agents, forest management and climate change. We further present a conceptual framework for understanding natural disturbance dynamics, vegetation structure, and implications for biodiversity in a landscape context. A list of strategic planning issues arising out of current scientific understanding of natural disturbance dynamics in coastal ecosystems is included for consideration by the LRMP Table. The report also outlines the most important gaps in knowledge about natural disturbances on the North Coast.

In preparing this report, we relied on published scientific literature, augmented by unpublished material and information provided by specialists. Where available, studies from the North Coast were given the highest priority. However, we also drew heavily from the published literature from other coastal regions, particularly southeast Alaska, the Queen Charlotte Islands/Haida Gwaii, the central and south coast of BC, the west coast of Vancouver Island, and the US Pacific Northwest. Since it is generally understood that forests on the North Coast differ in some important aspects from those on the south coast and south and central Vancouver Island (e.g., Veblen and Alaback 1996, Chourmouzis and Kayahara 1998, Banner 1999, Pojar et al. 1999), we relied most heavily on studies from coastal regions adjacent to the North Coast, where available. We discuss potential limitations and caveats in cases where we believe that the applicability of results and conclusions to the LRMP plan area might be limited.

1.2 Study Area

The North Coast LRMP area roughly coincides with the North Coast Forest District, excluding Princess Royal Island, The Nisga’a Lands, and some of the islands in the Skeena

River. The area comprises the northernmost coastal section in British Columbia and is bounded by the Pacific Ocean to the west and the Coast Mountains to the east (Tamblyn and Horn 2001). The North Coast is part of the North American perhumid temperate rainforest zone, which extends along the northwest coast of North America from the northern tip of Vancouver Island through the Alaskan panhandle, delimited in its eastern extent by the Coast Mountain range (Veblen and Alaback 1996). The climate is characterized by cool, moist summers and mild, wet winters. Temperatures average 15.5° C in July and –2.2 ° C in January (Tamblyn and Horn 2001). Prince Rupert receives more than 2500mm of annual rainfall (Taylor and Taylor 1997). Snowfall is common throughout the area in winter, but rarely accumulates in the coastal lowland areas (Tamblyn and Horn 2001).

The area is characterized by an east-west climatic gradient. Hyper-maritime influence in the westernmost section gradually shifts to more continental influence with warmer, drier summers and colder winters in the eastern parts. The North Coast is primarily subdivided into two ecosections expressing this gradient, the Hecate Lowland Ecosection and the Kitimat Ranges Ecosection. The Southern Boundary Ranges and Meziadin Mountains Ecosections comprise the northernmost section of the planning area.

The wind and leeward side of the Kitimat ranges are part of the Kitimat Ranges Ecosection. This area features deeply incised fjords and extensive floodplains. It receives most of its precipitation from coastal frontal systems, although the relatively low mountain barrier and long fjords allow some of the moisture to escape eastwards towards the interior. Forests types characteristic of the area are temperate rainforests dominated by western hemlock, western redcedar, amabilis fir, and Sitka spruce (Coastal Western Hemlock biogeoclimatic zone, CWH); floodplain forests dominated by Sitka spruce, black cottonwood, red alder and willows; and subalpine forests dominated by mountain hemlock, amabilis fir, and yellow-cedar (Mountain Hemlock biogeoclimatic zone, MH). Predominant biogeoclimatic variants of the Kitimat Ranges Ecosection occurring in the plan area are CWHvm, vh2, MHmm1 and AT (Alpine-Tundra. CWHws1, ws2, vh, MHmm2, wh1 variants also occur in substantial proportions, and CWHwm is represented in small amounts (Banner et. a. 1993, Prince Rupert Protected Areas Team, 2001b).

The coastal lowlands in the westernmost land-based part of the planning area are part of the Hecate Lowland Ecosection. This ecosection comprises a narrow band of islands and coastal lowlands. The climate is dominated by frontal systems moving in from the Pacific Ocean. The area has been heavily glaciated and exposed, glacially abraded bedrock is a common feature. Although elevations are below 650 m, topography is rough, with intricate coastlines and deep fjords. Forest cover is often stunted, and scrubby bog forests and hypermaritime peatlands are a characteristic feature of the landscape. Most of the area is classified as CWHvh2. Other biogeoclimatic variants within this Ecosection include MHwh1, and a small component each of CWHvm and AT (Prince Rupert Protected Areas Team, 2001a).

The Southern Boundary Ranges and Meziadin Mountains Ecosections cover the northernmost section of the plan area. The area is mountainous, but due to the presence of long inlets the climate is moderated by coastal influences. The mountain ranges are wet and snowy, with extensive ice fields. Coastal peatlands are common along the outer coast. CWHwm, AT and MHmm1 are the most common biogeoclimatic variants, followed by MHmm2, CWHvh, CWHws2, and small amounts of CWHws1 and MHwh. In the coastal temperate rainforests of the CWHvh, CWHwm, and CWHws western hemlock and Sitka spruce predominate. Western redcedar, and amabilis fir are less common, except in the Kitsault valley. Riparian forests are typically composed of Sitka spruce and western hemlock; as well as extensive cottonwood, alder, and willow on wetter sites. Mountain hemlock - yellow-cedar forests are predominant at higher elevations.

1.3 Climate Trends and Climate Change Predictions

Climate is an important driver for various aspects of natural disturbances – temperature and precipitation patterns influence insect populations, distribution of diseases (Williams et al. 2000), mass wasting (Septer and Schwab 1995), windthrow (Jacobs 2000), fire frequency and severity (Gavin 2000), as well as soil development, tree growth, and ecosystem composition (deGroot et. al. 2002). It is now well accepted that greenhouse gas emissions are having significant impacts on global climate and will likely continue to do so in the future (Albritton and Filho 2001). If our knowledge of historical disturbance dynamics is to be used to inform and guide future forest management, it is essential to understand how climate change may affect disturbance dynamics. In the following, we give a brief overview of recent climatic trends and scientific predictions for the next century. Specific implications regarding expected trends in frequency and severity for different disturbance agents are discussed in the sections pertaining to these agents.

In the past century, average temperature in coastal British Columbia has increased by 0.4°C (Taylor and Taylor 1997). Predictions of the Canada Country Study (CCS, Taylor and Taylor 1997) for coastal BC to the year 2050 include:

- A temperature increase of 1 to 4.5°C in winter and 1.5 to 4°C in summer.
- Up to 40% increase in winter precipitation. Predictions for summer precipitation are less consistent and range from a 30% decrease to a 30% increase.
- It is not clear, whether the combination of milder temperatures and increased precipitation in winter will increase or decrease snow accumulation. Potentially there might be more snow at high elevations, but less snow at low elevations.
- Increased intensity of the Aleutian Low, resulting in more severe winter storms; the Canadian Climate Centre (CCC) model predicts 4% decrease in overall frequency of cyclones in the northern hemisphere, but increases in the frequency of intense cyclones.
- A 30 cm rise in sea levels on the North Coast. This is less than in other areas because of continuing crustal rebound and tectonic uplift.
- Increased spring flooding.
- Increased sedimentation and coastal flooding in low gradient intertidal areas.

- Increased summer drought.
- Glacial retreat and accompanying flow reductions in glacier-fed rivers.

2 Natural Disturbance Agents

The following section provides an overview of abiotic and biotic disturbance agents of relevance in coastal forests. Gap dynamics, driven by wind and pathogens, are the primary mode of disturbance over the majority of the North Coast landscape. Geomorphic disturbances can play an important role in susceptible parts of the landscape and are the main naturally occurring high-severity, stand-replacing events in the area, although wind and fire may also occasionally create larger canopy openings. Flooding is a key element of forest dynamics in floodplains and estuaries. Other agents that may occasionally injure or kill trees include frost and drought, insects, and mammals, most notably porcupines, beavers, and deer. In this section we review the available scientific information for each of these agents. As far as possible, we describe size, spatial distribution, and frequency, as well as disturbance effects and post-disturbance succession, briefly outline the role of each agent in maintaining ecosystem function and biodiversity, and discuss interactions with other disturbance agents, forest management, and climate change. A synthesis of disturbance dynamics for different sections of landscape within the plan area can be found in section 4. Appendix 1 summarizes in table format estimates for disturbance return intervals and opening sizes for the most important stand-replacing disturbance agents as provided in the scientific literature.

2.1 Wind

2.1.1 Disturbance dynamics

Wind is a major disturbance agent on the North Coast (Chourmouzis and Kayahara 1998). The northwest coast of America is prone to cyclonic storms originating from the Gulf of Alaska primarily during the fall and winter months (Salmon 1997). These storm systems tend to weaken as they move further inland. In the mainland valleys and inlets, strong katabatic (outflow) winds may be more important as agents of disturbance (Harris 1989, Mitchell 1998, Pojar et al. 1999). The effects of windstorms range from loss of foliage and branches, to small gap formation to complete overstory blowdown (Harris 1989, Foster and Boose 1992, Everham and Brokaw 1996, Parminter 1998, Pearson 2000, Ulanova 2000). The heavy precipitation that tends to accompany storm systems saturates soils, reduces root adhesion and increases the weight of tree crowns and thus makes trees more susceptible to damage (Everham and Brokaw 1996).

Temporal dynamics

Although events causing mild to moderate damage to trees occur frequently enough to be considered endemic, large-scale blowdown resulting in substantial canopy openings is primarily an episodic phenomenon. Relatively rare, severe events are typically responsible for the majority of area blown down in larger openings (Harris 1989, Sinton 1996, Mitchell 1998, Nowacki and Kramer 1998). Whereas studies from southeast Alaska concur that catastrophic wind disturbance is frequent enough in wind-exposed forests to control development and structure of forests over a large part of the land base (Harris 1989, Nowacki and Kramer 1998, Kramer et al. 2001, Kramer in prep.), evidence from Vancouver Island and the Central Coast suggests that the role of severe blowdown may be much more limited in other coastal areas (Lertzman et al. 1996, Pearson 2000, Pearson in prep., Pearson pers. comm.). Studies from southeast Alaska indicate that for those locations most prone to severe blowdown, intervals between partial or complete canopy replacement are short enough to prevent development of all-aged stand structure, which likely translates into estimated recurrence times of 300 years or less (Nowacki and Kramer 1998, Kramer et al. 2001).

Mitchell (1998) analyses the effect of blowdown on timber supply in the North Coast Forest District. Our re-analysis of his data indicates that between 1960 and 1996 a total of approximately 1,500 ha were blown down in small, scattered patches throughout the operable land base, most of it in two large storm events in 1979 and 1990. This translates into an annual proportion of approximately 0.03% of operable area disturbed by wind for the 37-year period covered by the analysis, or a corresponding return interval of approximately 3000 years[iv]. Mitchell asserts that the distribution of blowdown patches did not follow a clear pattern. However, even if we assume that all blowdown in fact occurred in a small susceptible proportion, say 10% of the operable land base, this would still result in a relatively long return interval of 300 years for this susceptible proportion.

In interpreting the data in Mitchell (1998) it should be noted that the period covered may be too short to capture the full range of historical wind dynamics. The author indicates that several major windstorms have occurred in Douglas Channel earlier in the 20th century and that a large area in the south of the TSA was “flattened by catastrophic windfall approximately 150 years ago”. Since widespread catastrophic blowdown has been reported not only for southeast Alaska, but also for some parts of Vancouver Island, Washington and Oregon (Keenan 1993, Sinton 1996, Veblen and Alaback 1996, Pojar et al. 1999), it is possible that more extensive blowdown has historically occurred on the North Coast than indicated by the data. However, it seems unlikely that such events were frequent and widespread enough to prevent development of all-aged stands dominated by gap dynamics over much of the area.

[iv] Meaning a stand would go on average 3000 years between consecutive blowdown events. This analysis does not account for area disturbed repeatedly during the period of analysis. However, given the low incidence of blowdown, accounting for repeat disturbance would have a very minor impact on estimates of overall disturbance frequency.

Spatial pattern

Size distribution of openings created by wind is typically 'reverse-J' shaped: the vast majority of openings consist of small canopy gaps (< 10 trees, Lertzman et al. 1996, Veblen and Alaback 1996, Nowacki and Kramer 1998), but maximum opening sizes observed for southeast Alaska, Vancouver Island, and other parts of the west coast of North America range to hundreds of hectares (Schoonmaker and Powell, Harris 1989, Sinton 1996, Veblen and Alaback 1996, Nowacki and Kramer 1998, Parminter 1998, Pojar et al. 1999). Total area in gaps in coastal productive forests is often around 10%, though values as low as 4% and as high as 34% have been observed (Lertzman et al. 1996, Veblen and Alaback 1996, Ott 1997, Nowacki and Kramer 1998).[v] Where large openings are part of the wind regime, the resulting landscape mosaic can be complex, made up of single cohort stands, stands with multiple even-aged cohorts, and all-aged stands maintained primarily through gap dynamics (Harris 1989, Everham and Brokaw 1996, Nowacki and Kramer 1998, Ulanova 2000, Kramer et al. 2001).

The distribution of opening sizes for the North Coast, as reconstructed from the data compiled by Mitchell (1998), follows the reverse-J pattern generally observed for blowdown (Figure 1). Patch sizes in the database range from 0.8 to 112 ha, with a mean of 10.8 ha and a median of 6.2 ha. One major windfall area at Alice Arm, which was later salvage logged, covered a total of 807.6 ha. This area was not included in the patch size distribution since it is not clear whether the area blown down was comprised of single or multiple patches. Thus, openings larger than 112 ha may have occurred since 1960 in the Alice Arm blowdown, and it is possible that a longer observation period would reveal a size distribution with a longer tail of substantially larger openings. Note also, that the relatively small number of patches less than 5 ha is likely due to the limited resolution of the forest cover data and does not necessarily reflect ecological reality. Mitchell explicitly notes that gap-size openings are not captured in the study.

The proportion of trees blown down within individual openings ranged from 30%, which was the cut-off for defining a patch as 'blown down', to 100%. Since disturbance years for individual blowdown patches are not available, it was not possible to associate mortality with individual storm events. However, the data show no clear trends towards higher or lower mortality for particular regions. There is also no clear relationship between the size of blowdown patch and proportion of trees blown over, but the low (50%) overall mortality for the salvage-logged Alice Arm windfall area and the similarly low (40%) mortality for the largest contiguous blowdown patch seems to contradict the hypothesis that large events lead to more mortality.

[v] Note that in studies of gap dynamics a clear distinction between wind and other causes of tree fall is not always possible. Thus, not all of the gaps observed in the cited studies may be attributable to wind.

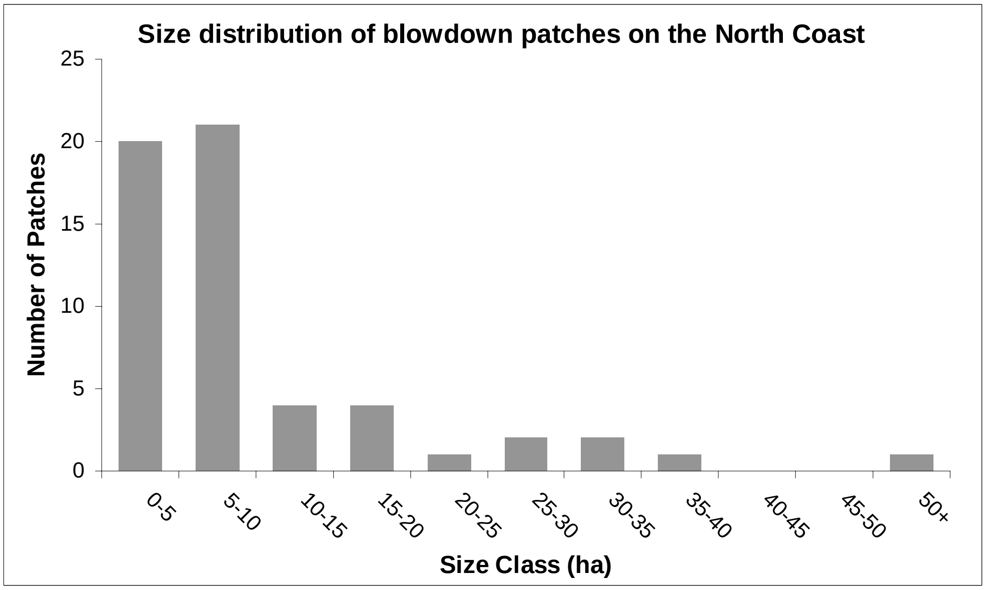

Figure 1: Size of blowdown patches in the North Coast forest district, as derived from forest cover maps and air photos. The data span the period 1960-1996 and cover the operable landbase only. (data from Mitchell 1998).

2.1.2 Disturbance effects and post-disturbance succession

Tree fall during wind events may be through stem snap or uprooting, and trees may be blown down directly or brought down by other falling trees (Everham and Brokaw 1996). In the coastal forests of British Columbia and southeast Alaska, the primary mode of mortality is stem snap, whereas only approximately 10% of trees are uprooted (Lertzman et al. 1996, Veblen and Alaback 1996, Pearson 2000). Blowdown primarily affects canopy trees and sub-canopy trees, although mechanical damage through falling trees and branches and litter accumulation tend to cause some understory mortality (Everham and Brokaw 1996, Veblen and Alaback 1996). Presence of large, decaying logs further favours establishment of advance regeneration (e.g., Harmon and Franklin 1989, Ott 1997).

Because the understory is mostly left intact, regeneration after wind disturbance tends to follow different pathways than regeneration after mass wasting or fire. Gaps created by windfall are primarily filled through lateral growth of adjacent canopy trees or through the release of seedlings and saplings present in the understory (Deal et al. 1991, Ott 1997). Whereas western hemlock, western redcedar, and amabilis fir can maintain themselves in a gap replacement regime, the somewhat less shade-tolerant Sitka spruce may need larger openings to regenerate successfully (Ott 1997). Depending on the size of the opening, the proportion of canopy trees blown down, and the return time of wind events, post-disturbance stands may develop even-aged, multi-cohort, or all-aged characteristics (Kramer et al. 2001). However, even in single-cohort stands establishing after severe wind disturbance structural and species diversity is significantly higher than in even-aged stands established after clearcutting (Nowacki and Kramer 1998, Price et al. 1998).

Root mounds created by uprooting play a key role in the dynamics of forests prone to windthrow. The pit and mound topography results in a diverse range of microhabitats on the forest floor (Deal et al. 1991, Ott 1997). Uprooting also leads to mixing of soil strata. Sitka spruce in particular might benefit from exposed mineral soil and the absence of the otherwise abundant hemlock advance regeneration (Deal et al. 1991, Ott 1997). On the North Coast, soil mixing is also of special concern since it can maintain soil productivity by reversing the built-up of a thick layer of dense organic soil, which eventually leads to waterlogging and bog development (paludification) (Ugolini and Mann 1979, Banner et al. 1983, Bormann and Kramer 1998, de Groot et. al. 2002). However, soil disturbance is only one of several factors influencing build-up of organic soil and bog formation. Climate and topo-edaphic (site) factors also play a large, ultimately perhaps more significant role (e.g., Ugolini and Mann 1979, Banner et al. 1983, Alaback 1991, Emili et al. 1998, de Groot et. al. 2002). Bormann and Kramer (1998) estimate that soil mixing would have to occur at intervals of 200 years or less to maintain soil fertility. Given the low incidence of uprooting as a mode of mortality it thus seems unlikely that windthrow has historically played a key role in maintaining soil productivity over large portions of the landscape.

2.1.3 Factors influencing susceptibility, severity of effects, and post-disturbance succession

Exposure to prevailing winds is largely controlled by local and regional topography. Valley bottoms in valleys open to the south and east to west facing slopes near ridge tops are most exposed to prevailing winds, receive the greatest amounts of precipitation (Jakob 2000), and also tend to experience the highest rates of blowdown (Harris 1989, Nowacki and Kramer 1998, Kramer et al. 2001). Local patterns such as channelling of winds, turbulence on leeward slopes near ridge tops, and increases in wind velocity in constricted areas also have considerable influence on blowdown patterns (Foster 1988, Harris 1989, Nowacki and Kramer 1998, Kramer et al. 2001).

Site conditions that affect susceptibility to storm damage other than exposure to predominant winds include growing conditions and soil properties. Rooting depth is restricted in shallow soils over bedrock or in riparian areas, which makes the trees on these sites more susceptible to blowdown (e.g., Harris 1989, Pearson 2000). Stands established after blowdown may be more susceptible to further blowdown because trees established on upturned soil and roots tend to be stilt-rooted and hence weaker (Harris 1989).

Biotic factors that affect susceptibility to wind disturbance and its severity include tree species, diameter and height, strength and elasticity of the bole, rooting strength, and crown shape, all of which influence the amount of force wind exerts on a tree and the ability of the tree to withstand this force (e.g., Everham and Brokaw 1996). Conifers are generally less windfirm than hardwoods (Everham and Brokaw 1996). Among the conifer species of the North Coast, cedar is the most windfirm (Harris 1989, Keenan 1993). Compared to other species, mortality in cedar is more often by uprooting, rather than stem snap (Harris 1989, Pearson 2000). Tall trees with top-heavy canopies provide most leverage to wind (Stathers et al. 1994), and trees that extend above the canopy experience more wind drag and turbulence (Pearson 2000). However, trees exposed to wind can adapt their growth pattern to increase windfirmness against winds from common directions (Harris 1989). Thus, a fringe of trees along exposed sea and lakeshores may withstand a southeasterly gale while trees further inland are blown down (Foster 1988, Harris 1989).

Stand characteristics and landscape context also affect susceptibility to wind. Bog woodlands and low productivity cedar stands are little affected by wind because of their openness and small, tapered tree canopies (Harris 1989, Kramer 1997). Productive stands in valley bottom areas are among the most affected by wind disturbance, likely because of their large, top-heavy canopies and because the high water table in riparian forests restricts rooting depth (Harris 1989). Openings and unevenness in the forest canopy create turbulence and allow for deeper wind penetration. Thus, dense, even-aged stands tend to be relatively windfirm, but become susceptible to blowdown once their canopy has opened up (Gardiner et al. 1997), particularly in the first following five years (Mitchell et al. 2001).

2.1.4 Direct and indirect effects on habitat

Wind disturbance fulfills an important role in creating and maintaining habitat for a variety of species. Foliage and lichens blown down during storms provide an important winter food source for deer (Harris 1989). Increased production of shrubs and herbs in canopy openings also increases browsing opportunities for a range of mammals, although fallen stems and branches may impede movement in some cases (Harris 1989, Alaback 1991). The combination of frequent landslides and blowdown results in input of both sediments and large woody debris into streams, two factors that, supplied in moderate amounts, are critical for maintaining stream productivity and salmon habitat (Bryant and Everest 1998, Lofroth 1998, Price and McLennan 2001). Woody debris also provides food and shelter for many terrestrial species (Lofroth 1998). Root wads are used as denning sites by bears and other mammals (Bormann and Kramer 1998).

2.1.5 Interactions with other disturbance agents, forest management, and climate change

The interaction between wind and diseases and pathogens is a key factor driving gap dynamics in coastal forests. Pathogens such as heart and butt rots and hemlock dwarf mistletoe gradually reduce the structural integrity of infected trees and make them more susceptible to wind damage (Hennon 1995). Pathogens and mistletoe are also responsible for the predominance of stem snap as the primary mode of mortality. Consequently, the predominance of stem snap over uprooting increases with stand age and varies by species (cedar vs. hemlock) (Nowacki and Kramer 1998, Pearson 2000). Wind damage in turn facilitates the spread of heart rots since wounds created by falling trees during a windstorm provide entry points for fungal infection (Hennon 1995, Hennon and DeMars 1997).

Synergetic effects between rainstorms, windthrow, and debris slides and avalanches are also well documented (Harris 1989, Schwab 1995, Jakob 2000). Windthrow and the swaying of trees in the wind create soil disturbance that may trigger soil movements. Conversely soil movements reduce anchoring strength and thus may trigger windthrow. Wind-exposed cutblock edges on or near slide-prone terrain are particularly at risk from the combined effect of windthrow and soil mass movements (Swanston 1967).

Forest management can both increase and decrease the severity of wind disturbance. Since small trees are less susceptible to blowdown than large trees, clearcut harvesting with short rotation periods could be considered to 'suppress' wind disturbance to some degree. However, openings in the canopy typically lead to increased blowdown at the edges of the remaining stands (e.g., Harris 1989, Mitchell 1998, Mitchell et al. 2001). Thus, Mitchell (1998) predicts that increased cut rates and the implementation of the relatively small cutblocks mandated under the Forest Practices Code would lead to and increase in exposed edges, resulting in increased losses to blowdown. Blowdown along cutting boundaries is especially a problem in narrow riparian buffers, since buffers that experience a large degree of blowdown may not be able to fulfil their ecological function (Price and McLennan 2001). Moreover, blowdown in buffers may result in excessive input of woody debris into streams, which in turn may jam creeks and increase the risk of debris torrents (Grizzel and Wolff 1998).

Although there are no detailed studies on the effect of future climate change on ecosystem dynamics in coastal forests, some predictions can be made based on our understanding of past and current dynamics and the predictions of climate change models. Some of these models predict increases in the frequency and intensity of storms (Everham and Brokaw 1996, Taylor, 1997). Predicted increases in precipitation during the fall and winter storm season may also increase the severity of wind damage and possibly lead to relatively more uprooting, soil mixing and increased site productivity (Taylor and Taylor 1997, A. Banner pers. comm.). Higher average temperature and milder winters may result in increased growth rates for butt and heart rots and dwarf mistletoe and thus potentially results in more and earlier stem snap. In summary, global climate change will likely lead to increases in the frequency and severity of blowdown.

2.2 Geomorphic Disturbances

Geomorphic disturbances, by modifying slopes, disturbing soils and delivering sediment and woody debris considerable distances to valley floors where they alter stream channels and floodplains, are significant disturbances in coastal watersheds (Naiman et al. 2000). Below we describe the dynamics and effects of different geomorphic disturbances.

2.2.1 Earthquakes

The fault systems off the Queen Charlotte Islands stretching through southeastern Alaska are relatively active – three of the ten largest earthquakes in the world originated in Alaska in this century (Hansen and Combellick 1998). Experts propose that earthquakes of at least 8.25 on the Richter scale be considered for emergency planning in southeast Alaska (Hansen and Combellick 1998). Combellick and Motyka (1995) estimate that earthquakes measuring 7.9 on the Richter scale can reoccur every 120 years, whereas earthquakes of magnitude 6 would be expected every five years. Earthquakes can trigger tsunamis, avalanches, landslides, and submarine landslides, which affect forest structure and productivity, and precipitate channel change and large inputs of sediment and woody debris into streams (Allen et al. 1999, Pearson 2000). In areas such as Clayoquot Sound, which experience sufficient seismic activity, landslides triggered by earthquakes may be a significant geomorphic process on the landscape (Pearson 2000).

2.2.2 Tsunamis

Tsunamis may result from earthquakes or landslides and could have widespread impact in the Hectate Lowland Ecosection as much is below 30 m in elevation (J. Pojar, pers. comm.). Also, because the North Coast is composed of deep inlets surrounded by steep slopes, tsunamis can oscillate in a large wave impacting the shore several times within minutes before dissipating. In 1958, a landslide in Lituya Bay, Alaska generated a wave that stripped trees to an elevation of 500 m on the opposite shore. A similar wave occurred in Troitsa Lake, BC triggered by an underwater landslide off a steep slope of a fan delta. It carried a mat of uprooted trees 150 m inland (Schwab 1999). Similar fan deltas, where deposited sediment is perched on steep slopes underwater, are found along the side walls of coastal fjords and steep-sided fjord-like lakes in the Meziadin Mountains, Southern Boundary Ranges and Kitimat Ranges Ecosections. These fan deltas are very productive but highly unstable, with past landslide evidence often concealed under water.

2.2.3 Volcanic eruptions

The Aleutian and Wrangell volcanic centers are several hundred kilometers away to the north and west, but eruptions may cause ash fallout in the plan area (Combellick and Motyka 1995). An eruption 1,500 years ago in the Wrangell-St. Elias Mountain deposited ash over 300,000 km^2 in eastern Alaska and southern Yukon. Ash fallout on leaves can inhibit tree growth by blocking photosynthesis and affect soil productivity depending on the chemical composition and thickness of the ash layer (Veblen and Alaback 1996, Cook et al. 1981).

2.2.4 Avalanches

Avalanches which affect forests are high-severity disturbances that occur in mountainous terrain with sufficient snowfall, such as that found in the Meziadin Mountains, Southern Boundary Ranges and Kitimat Ecosections. Avalanches are triggered by weaknesses in the snowpack –in the North Coast these can be caused by rain on snow events, windloading or rapid warming of the surface layer in a deep snowpack as might occur on south aspects (Septer and Schwab 1995). The frequency and severity of avalanches within one path depends on the regional climate (likelihood of heavy snowfall, wind, temperature, etc.), and the terrain (e.g., slope of the path, and starting zone and runout elevation). Avalanches in a certain path may occur repeatedly in a single winter, once every few years, or may be rare events. The importance of avalanche disturbance depends on the watershed – between 4 and 67% of the area of watersheds in the Outer Coast Mountains are at risk of avalanches (Pearson in prep.) Avalanche paths break up the lateral connectivity of upland forest and create early-seral corridors between alpine and valley-bottom areas. The size of avalanche paths in the Invermere Forest District ranged from 2 ha to 885 ha (Ferguson and Pope 2001), in Clayoquot Sound from 2.4 to 34 ha (Pearson 2000).[vi]

Avalanches that occur frequently maintain a mosaic of upland and wetland herb communities, deciduous/shrub, coniferous/shrub and subalpine meadow communities (Walsh et al. 1994, Ferguson and Pope 2001). The herb and shrub communities in the runout zone are key foraging habitat for bears in the spring and early summer (Ferguson and Pope 2001).

2.2.5 Mass wasting

Mass wasting includes a wide range of geomorphic disturbances which occur at different rates and intensities, depending upon the surface material, slope shape and inclination, vegetation and soil saturation (Chatwin et al. 1994). Heavy rainstorms or rapid snowmelt and earthquakes can trigger mass wasting events[vii]. Schwab (1995) estimates that rainstorms heavy enough to trigger earth movements on the North Coast and the Queen Charlotte Islands can occur every 2 to 10 years. Mass wasting events are likely very important disturbances in the Meziadin Mountains, Southern Boundary Ranges and Kitimat Ecosections where there are steep and potentially unstable slopes, shallow soils and high rainfall. In the Queen Charlotte Islands approximately a third of the area is estimated to be susceptible to mass wasting (Schwab 1995).

Creeps, slumps and earthflows

Creeps are the slow downslope movement of surficial material at rates of centimeters per year to millimeters per year (Chatwin et al. 1994). Slumps and earthflows involve the movement of a block of material either slowly or rapidly (meters per second). Bedrock slumps typically occur below the surface of the earth as a relatively slow displacement of bedrock. They are common on steep slopes underlain by fractured bedrock. Creeps often precede slumps and earthflows. Excess rainfall can cause weaknesses particularly in clay material, resulting in creeps, slumps or earthflows on slopes as gentle as 2-3 degrees.

Rock slides, debris slides, flows and torrents

Rock and debris slides are relatively rapid, shallow landslides, typically originating on steep (35º - 60º) slopes (Combellick and Long 1983, Chatwin et al. 1994, Howes and Kenk 1997). If there is water present, debris slides can become debris flows moving at rates of metres per minute to metres per second. Debris torrents occur when a mixture of water, earth and vegetation debris rapidly moves through a steep, well-defined stream channel. Damming of this channel by woody debris may occur. During major storms these dams may fail moving large volumes of water, wood, soil and rock extremely rapidly. When channels drop below eight degrees, such as when meeting tributaries, significant amounts of sediment, organic

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[vi] We examined the size distribution of avalanche paths in the North Coast using Baseline Thematic Mapping data (range: 0.9 – 39,850 ha, median: 87 ha). We did not report this here because some patches delineated as avalanches were questionable – e.g., the maximum of 39, 850 ha is more likely to be an interpretation error. Seven out of the 963 patches were > 10,000 ha likely causing an overestimation of the actual average size of a path.

[vii] Schwab (1995) suggests it is primarily rainstorms which trigger debris flows and earthquakes that trigger rock landslides.

material and coarse woody debris are deposited (Chatwin et al. 1994). Sediment deposition from debris flows and torrents is thought to move as a gradual wave through a drainage network (Naiman et al. 2000). Sediment and debris supply from these geomorphic disturbances in combination with floods modify channel and floodplain characteristics (Naiman et al. 2000).

The type of geomorphic disturbance that dominates a watershed has significant implications for the delivery of sediment and woody debris to the valley floor. The type of dominating geomorphic disturbance appears to vary in watersheds along BC's coast. Avalanches and debris flows are the predominant stand-replacing events in the watersheds of the Outer Coast Mountains along the Mid Coast (Pearson 2000, Pearson in prep.). In Clayoquot Valley, rockslides thought to be triggered by earthquakes, are the primary geomorphic disturbance (Pearson 2000). Where debris flows are rare, the input of woody debris and sediment originates locally from floods.

Major slide events in natural terrain appear to be episodic (Schwab 1995, Septer and Schwab 1995, Pearson 2000) and associated with unusually severe rainstorms, which are approximately as frequent as severe windstorms that have caused major blowdown events. Landslide frequency in unlogged terrain in Clayoquot Valley is between 0.0037 - 0.0055 slides per km^2/year. Similar to blowdown patches, the size distribution of landslides is reverse J-shaped, i.e., most slides are small (< 1ha, Jakob 2000). The majority of slides are on east to south facing slopes, which receive the most precipitation. The North Coast District Erosion Event Summary estimates that landslides have impacted on average 100 ha every year in the Forest District between 1995-1999 (BC Ministry of Forests 1999). It is unknown how much of this is associated with roads and cutblocks.

Similar to succession after avalanches, succession after landslides is dominated by early-seral communities of deciduous shrubs, red alder, and Sitka spruce, western hemlock and redcedar (Smith et al. 1984). Slides and debris flows also fragment the lateral connectivity of upland forest and create early-seral corridors between high elevations and valley floors - the terrain or type of slide material may inhibit use by wildlife. Slides and debris flows generate more soil disturbance than avalanches with the top two-thirds of the slide typically scoured to bedrock and the soil deposited in the lower third (Smith et al. 1984). Mineral soil and bedrock exposure decreases as slides age – the lower portions of slides are vegetated more quickly than the upper portions (Veblen and Alaback 1996, Smith et al. 1984). As discussed in section 2.1.2, exposure and/or deposition of mineral soil can counteract the built-up of organic soil that has been associated with reduced forest productivity (Ugolini and Mann 1979, Banner et al. 1983, de Groot et. al. 2002). Thus, geomorphic disturbances can contribute towards maintaining long-term forest productivity in those areas where mineral soil is deposited. Succession on landslides differs from logged areas of the same age – in slides red alder dominates early stand composition and the height growth of Sitka spruce and western hemlock is much less (Smith et al. 1984). Over time, conifers become dominant on inactive slides and some slides even regenerate to conifers immediately (A. Banner pers. comm.).

Debris from debris flows can be key for triggering forest succession in riparian areas (Naiman et al. 2000). Jams of large woody debris in particular, can alter local flow patterns and provide refugia against flood scour which allow vegetation to develop downstream (Naiman et al. 2000). These jams may be stable for centuries, permitting floodplains to extend and mature riparian forest to develop. Woody debris is important for salmon habitat and riparian function, however, at extreme levels debris can also greatly modify riparian channels and destroy habitat (e.g., Bryant and Everest 1998).

2.2.6 Interactions with other disturbance agents, forest management, and climate change

Geomorphic disturbances in concert with flooding modify valley floor landforms –the relative timing and size of both disturbance types affects the degree to which channel and floodplains are modified (Naiman et al. 2000). Geomorphic disturbances and flooding are the only disturbance agents which influence both landform and forest structure in the plan area.

Any disturbance that removes tree cover can increase the risk of mass wasting and avalanches. Trees anchor soil and decrease the point at which soils become saturated. They also intercept snow and rain in their canopies and moderate temperature fluctuations of the snow surface reducing the likelihood of weak layers in the snowpack (McClung 2001). Jakob (2000) estimates that it takes approximately 20 years after trees establish for soils to stabilize. Avalanches and mass wasting can increase susceptibility to blowdown by opening up the forest canopy (Mitchell 1995) and increase susceptibility to pathogens by wounding trees. If avalanches have been particularly erosive, they can increase the likelihood of debris flows. If the runout of either avalanches or mass wasting events dam streams or lakes, it can lead to flooding. Flooding in turn can undercut slopes and reduce slope stability (Chatwin et al. 1994).

Logging and road building increase the frequency of geomorphic disturbances. Although clearcuts appear to be responsible for the majority of harvesting-related mass wasting in coastal areas, roads affect drainage patterns and thus also increase the risk of landslides (Jakob 2000). Landslides originating from clearcuts can occur on flatter slopes, tend to be smaller in volume, and travel less distance than those originating in natural terrain (Swanston et al. 1996, Jakob 2000). In Clayoquot Valley the frequency of landslides in logged terrain was approximately nine times higher than the natural rate (Jakob 2000). Similar or higher increases in landslide frequency in response to clearcut harvesting and road building have been recorded for other areas of Vancouver Island, the Queen Charlotte Islands, and parts of the North Coast Forest District (Banner et al. 1989, Schwab 1995, Jordan 2001). According to Schwab (1995), logged terrain in the North Coast has yet to experience rainstorms severe enough to trigger the serious natural debris slides that have occurred in the past (see also Septer and Schwab 1995). The potential effects of such severe rain events on harvested areas are unknown at this point.

The frequency of landslides and debris flows will likely increase as a result of climate change as winter precipitation rises, rainstorms become more frequent (Evans and Clague 1997), and retreating glaciers expose unstable slopes of glacial till.

2.3 Flooding

2.3.1 Disturbance dynamics

Flooding events of varying magnitude, frequency and triggers have occurred in the North Coast (Septer and Schwab 1995). Flooding events between 1891 and 1991 for many rivers and creeks in the plan area are detailed in Septer (1995). Four types of events occur:

1. *Rainstorm triggered floods.* Rainstorms severe enough to cause flooding may occur throughout the year, although the most intense storms occur during the fall (Harris 1989). Melting of shallow snowpacks due to continuous fall rains or rapid melting of snow in late spring may also cause substantial flooding. Floods triggered by rainstorms have caused extensive debris flow and torrent activity throughout the plan area.

2. *Icejam floods* occur from November to April during the freeze-up or break-up of ice. These have occurred on the Skeena River.

3. *Glacial outbursts* occur when there is a sudden release of water stored behind a glacial ice dam, particularly in the summer (Combellick and Long 1983). These are relatively rare flooding events (at least 27 in northwestern BC since 1852) but are usually of high-severity because the amount of water discharged is often much more than the expected runoff after rainstorms for most watersheds (Septer and Schwab 1995).

4. *Tidal flooding of estuaries*.

Because flooding is so strongly associated with climatic events, flooding can occur region-wide –e.g., a rainstorm in 1978 caused synchronous events observed in the Queen Charlotte Islands across to Terrace (Septer and Schwab 1995). Flooding is also influenced by topography and soil characteristics –the steep slopes with thin soils in the Kitimat Ranges, Meziadin Mountains and Southern Boundary Ranges Ecosections can transport water rapidly to streams, increasing the likelihood of flooding.

Flooding, through erosion and deposition of sediment and coarse organic material downstream, support the development of floodplains in wide valleys and fans where steep streams meet the valley floor. Extensive floodplain-fan complexes occur in many watersheds in the Outer Coast Mountains (Price and McLennan 2001). Floods can cause varying degrees of tree mortality, but most events are stand-maintaining unless debris flows or torrents are triggered. Floodplains and fans subject to flooding are highly productive and support forests of various composition and ages, depending on disturbance frequency and severity (Price and McLennan 2001). Portions of fans that are frequently flooded or experience debris torrents support red and slide alder, deciduous shrub and herb communities (Price and McLennan 2001). Very large, widely spaced Sitka spruce and western hemlock are common in less active, well-drained areas of floodplains and fans. Portions that are not well-drained may support shrub and sedge wetlands.

Tidal flooding of estuaries mixes marine water and sediment with freshwater and river sediment to create a productive mosaic of unique forest wetlands, shrub thickets, sedge and grassland ecosystems, salt, brackish, and freshwater marshes, and mudflats (Price and McLennan 2001).

2.3.2 Interactions with other disturbance agents, forest management, and climate change

Debris from avalanches and mass wasting can dam streams and cause flooding (see geomorphic disturbances for a description of how flooding interacts with geomorphic disturbances to modify channels and floodplains). Roads without proper drainage and young clearcuts, which reduce canopy interception of rain and snow, can increase the incidence of flooding relative to unlogged landscapes. Climate change in BC is expected to increase spring flooding and increase the frequency of extreme storms and events (Beckmann et al. 1997). It is uncertain whether the increase in precipitation predicted for the North Coast can offset the effects of glacial retreat due to warmer temperatures on flow to glacial fed streams. The expected rise in sea level and increase in precipitation is expected to increase coastal flooding and erosion of estuaries (Beckmann et al. 1997).

2.4 Fire

2.4.1 Disturbance dynamics

Large fires are rare in the North Coast (Banner et al. 1993, British Columbia Ministry of Forests 1995) as indicated by few seral stands of fire origin on the current landscape (BC Ministry of Forests 1999) and in similar forests in Clayoquot Sound (Pearson 2000) and the Central Coast (Pearson in prep.). There is no research specific to the North Coast on past fires. In coastal western hemlock forests (CWHvm1) in Clayoquot Valley the median time since last fire ranged from 750 to 4500 years ago . Fires rarely exceeded 250 m in diameter in this study, although sampling may have been too limited to lower elevations to detect fires that spread to higher elevations. Evidence from other sites in coastal BC and Washington support the conclusion that fires are infrequent in coastal western hemlock forests (Huff 1995, Green et al. 1999). Fire regimes in these forests are thought to be of mixed severity: a combination of infrequent, high-severity crown and low-severity surface fires causing partial or complete stand-replacement (Parminter 1990). Fires also occur rarely in the subalpine Mountain Hemlock zone – intervals between stand-replacing events can be centuries to millenniums (Lertzman 1992, Hallet et al. in prep.). A 11,000-year fire history, reconstructed from charcoal in soil and subalpine lake sediment found mean fire intervals were 555 ±100 years (±1 std. error) for a subalpine site in the Coastal Mountains (D. Hallett, pers. comm.).

2.4.2 Traditional burning by First Nations

Intentional low-severity burning by aboriginals has been documented for the Haisla, Nisga'a, Tsimshian and the Haida peoples on the Queen Charlottes before concentrated European settlement (John Corsiglia pers. comm., Turner 1991, McDonald in prep). The Haisla enhanced berry production of various *Vaccinium* species (e.g., Alaskan blueberry, red huckleberry) and the Haida also burned to stimulate salal (*Gautheria shallon*) (Turner 1991, Johnson Gottesfeld 1994). The interior Gitksan and Wet'suwet'en peoples in the Skeena and Bulkley Valleys near Hazelton burned lowbush blueberry in valley bottoms and black huckleberry patches "half way up the mountain" every four years in the fall (Johnson Gottesfeld 1994). Some place names in Tsimshian territory such as "burnt mountain top" suggest similar burning practices (McDonald in prep.). The Nisga'a are also thought to have burned every four years for berry production as recorded in the Oolichan Petition (John Corsiglia pers. com). Further evidence of aboriginal burning is suggested by 100-200 year old western redcedar stands, some as large as 30-40 ha, observed along the mid and north coast. These stands contain culturally modified trees and burned out cedar stumps and are hypothesized to have originated after fires escaped from attempts to burn out cedars for canoes or from clearing for village sites (A. Banner pers. com, B. Fuhr pers. comm.).[viii] As First Nations have lived throughout the plan area for tens of thousands of years (Tamblyn and Horn 2001), aboriginal burning was likely a key disturbance in certain areas. Aboriginal burning in the North Coast, similar to other regions in British Columbia, probably decreased as populations declined with the small pox epidemic in 1862 and ceased with Forest Service policies in the 1930s (Turner 1991, Johnson Gottesfeld 1994). A study is under way to document First Nation resource management practices in the North Coast (contact: Charles Menzies, UBC).

2.4.3 Disturbance effects and post-disturbance succession

Stand-replacing fires tend to eliminate advanced western hemlock regeneration, making it easier for spruce, amabilis fir, and western redcedar to regenerate (Veblen and Alaback 1996). Very successful regeneration of western redcedar has been observed in stands established after fire on the North Coast (A. Banner pers. comm.). These stands are thought to have regenerated after aboriginal burning and while uncommon, they illustrate the role that fire can play in regeneration in coastal forests. Fire affects post-disturbance succession by reducing thick organic layers, improving nutrient availability, providing a good seed bed for western redcedar and removing advance regeneration of mistletoe infected western hemlock (A. Banner pers. comm.). Fire also influences habitat by creating snags, large coarse woody debris, and *Vaccinium* communities, which provide nutritious early seral forage for wildlife species such as bears and deer (Gray and MacKenzie 2001). In particular, subalpine forests that burn are generally transformed into *Vaccinium* meadows and tree regeneration appears to be largely unpredictable and only partially correlated with time-since-disturbance or climate as it is also affected by browsing, snow creep[ix] and the duration of the snowpack (Agee and Smith 1984).

2.4.4 Factors influencing susceptibility, severity of effects, and post-disturbance succession

Fuel moisture and fire spread are influenced by climatic factors, as well as forest structure and topography (Agee 1993). Dryer southerly aspects are typically more susceptible than

[viii] As these stands are smaller than the resolution of forest cover maps, more detailed surveys are required to document the distribution of such stands.
[ix] Slow movement of snow downslope.

northerly aspects (Agee 1993). Median time-since-fire values were six times shorter on slopes than terraces in Clayoquot Valley, and shorter in cedar-salal forests than in other forest types (Gavin 2000). Gavin (2000) suggests that fires might be involved in a feedback mechanism for maintaining salal and stunted cedar forests by causing nitrogen volatization and poorer productivity leading to a forest structure favouring drier fuels. In contrast, A. Banner (pers. comm.) indicates that on the North Coast fire in cedar hemlock stands of low productivity may actually improve productivity by reducing the organic layer and improving nutrient availability. Fire occurrence is also strongly tied to regional climatic trends. Area return intervals of fires occurring around Clayoquot Lake increased from 50 years to 350 years between 900 and 1100 AD, coincident with the onset of the Little Ice Age (Gavin 2000).

2.4.5 Interactions with other disturbance agents, forest management, and climate change

Fires can increase the incidence of other disturbance agents by stressing trees and increasing susceptibility to insects (Bradley and Tueller 2001) and fungal infection (Geiszler et al. 1980). Other disturbance agents such as blowdown can increase fuel loadings (Turner et al. 1999). In the subalpine, fallen snags from fires can prevent snowcreep and inhibit browsing (Agee and Smith 1984).

Because of different land management practices and fire suppression, the present-day fire patterns likely differ from those that occurred before European settlement. The provincial fire database indicates that 83% of ignitions in the North Coast between 1950 and 1998 were by humans. These recent fires were likely ignited by humans in different locations and seasons from natural or traditional aboriginal ignitions. Although escaped campfires are responsible for the most ignitions, fires ignited by logging activities have burned the most area. The lack of access and high amounts of slash associated with logging sites are likely responsible for the larger fires. Fires since 1950 have typically been small– median size was 0.1 ha and the maximum was 390 ha. Since 1950, efforts to suppress these fires total approximately $912,000. Relative to many forest districts in interior BC, the total area burned (760 ha) between 1950 and 1998 is extremely small.

We expect that climate change will influence fire regimes by affecting fuel moisture during the summer. However, the direction of change is unknown as there is a fair amount of uncertainty in projections regarding summer precipitation levels for the North Coast.

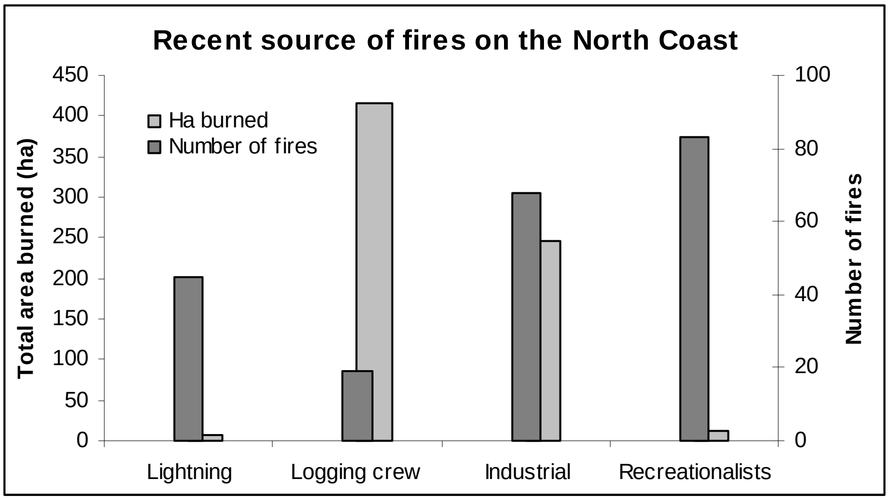

Figure 2. Recent source of fires in the North Coast forests as recorded in the MOF Protection Branch Database between 1950 and 1998. 'Industrial' includes ignitions associated with railroads and BC Hydro right-of-ways. The category of general public, although found in the database, was not included as most of these fires were associated with urban areas.

2.5 Short-term Climatic Disturbances

Fluctuating climatic factors such as frosts and periods of severe cold or drought can injure tree canopies and roots systems. Frost injury results after a sudden drop in temperature before tissues have hardened in the fall. Resulting lesions provide access for decay fungi (Allen et al. 1996). Frost can also kill seedlings, particularly in low-lying depressions, and soil freezing may cause root injury. During periods of drought, dieback of the leader, or top-kill, can occur, particularly in microsites such as gravel bars which poorly retain water. Drought mortality may also occur in winter, when trees lose water through transpiration during unseasonable warm, drying winds and are unable to replace that water because the ground is frozen (Allen et al. 1996). "Red belts" of injury across mountain slopes often indicate the elevational zone of the drying winds. Drought caused injury is rare on the North Coast (J. Pojar, pers. comm.).

Climatic events occur across large regions but resulting effects on growth or tree mortality can be patchy depending on tree species and microsite conditions. If adverse climatic conditions persist, trees may gradually deteriorate, often resulting in death (Williams et al. 2000). The decline of yellow cedar in southeast Alaska is thought due to climatic warming beginning in 1880 (Williams et al. 2000). Yellow cedar decline is also occurring on the North Coast but not to the same extent as in southeast Alaska (A. Woods, pers. comm.). The decline in southeast Alaska is thought to result from a combination of reduced snowpack and extreme freeze-thaw events, resulting in root injury from soil freezing – these events are not as likely at sea level in the North Coast. Climatic warming is also hypothesized to affect western hemlock. If global warming continues as predicted under a doubling of CO_2, one model predicts that CWH forests may undergo catastrophic collapse, as trees become highly susceptible to frost events because of an inadequate chilling period to induce winter cold hardiness (Burton and Cumming 1995).

2.6 Pathogens

Pathogens are key components of ecosystem function in coastal forests (Hennon 1995). In southeast Alaska, heart rots are ecologically most important, although root rots and the parasitic hemlock dwarf mistletoe also play a role (Hennon 1995, Trummer et al. 1998). Further south, the relative importance of root rots and mistletoe increases (Haak and Byler 1993, Hennon and DeMars 1997, Garbutt 1998). Generally, the behaviour and relative importance of fungi is very region-specific, even if the fungal species themselves are widespread (Hennon and DeMars 1997). Thus, applicability of results from southeast Alaska and the central and southern BC coast may be limited in some respects, as regional inter- and extrapolations may not always reflect North Coast dynamics very accurately.

2.6.1 Rots

The coastal climate is very conducive to the development and spread of fungal infections. The literature generally distinguishes between three types of rots, based on the effect the fungal infection has on the tree. *Heart rots* affect the bole, *root rots* infect the root system, and *butt rots* affect the butt and lower bole of the tree (e.g., BC Ministry of Forests 1995c). The latter are generally caused by root rot fungi that spread upwards into the butt or by fungi that enter through wounds in the butt. Effects of root rots may range from weakening of the root system and reduced tree vigour to eventual death of the affected tree. Since heart rot fungi colonize primarily heartwood, their main damage to the tree is a gradual undermining of structural integrity, which makes the tree more susceptible to breakage during windstorms and under heavy snow loads (Hennon 1995).

Decay fungi differ in their modes of spread and infection.Root rots propagate through root contact with infected roots, though some species can also spread by air-borne spores. Heart rots are typically spread by windborn spores. . Heart rot infection is primarily through wounds exposing heartwood or dead sapwood, although some heart rot species can infect trees through small twigs and branch stubs (Hennon 1995, Hennon and DeMars 1997). The relatively thin bark of coastal tree species facilitates injury and subsequent infection (Hennon 1995). Infection rate of wounds is very high—Hennon and DeMars (1997) report nearly 100% for their study area in southeast Alaska. All coastal conifer species are susceptible to heart rot, although some fungal species show distinct preferences for certain tree species (Hennon 1995). While cedars have protective compounds in the heartwood that inhibit fungal growth, this protection is often eventually overcome by a succession of fungi, and heart rot is very common in older western redcedars (van der Kamp 1975).

Hennon and DeMars (1997) indicate that the spread of fungal infections and development of decay is slower in the North Coast than on the south coast of BC or in the coastal forests of Oregon and Washington. In southeast Alaska, trees show little evidence of decay at 100 years of age. At 200 yrs, 65% of western redcedar, 50% of western hemlock, and 20% of Sitka spruce contained some decay (Kimmey 1956). Hennon (1995) estimates that for most forests in coastal Alaska annual loss to decay is at or near equilibrium with volume of wood produced annually. Bole failure may take a century or more after initial infection (Hennon 1995). Because of the long time it takes for heart rot to develop after wounding, the bole breakage – wounding cycle is not likely to result in expanding canopy gaps, but rather in a pattern of scattered gaps across landscape.

2.6.2 Hemlock dwarf mistletoe

Hemlock dwarf mistletoe is primarily a parasite of hemlock, although it may occasionally infect Sitka spruce, lodgepole pine, and amabilis fir (BC Ministry of Forests 1995b, Trummer et al. 1998). Infected trees develop swellings and abnormal growth on boles and branches commonly known as 'brooms'. Severe infection slows down tree growth and weakens the bole of the tree around infection points (Wallis et al. 1980, Thomson et al. 1984, BC Ministry of Forests 2001). Hemlock dwarf mistletoe affects stands of all age classes (Garbutt 1998), but is more prevalent in older and all-aged stands (Nevill et al. 1996, Trummer et al. 1998). On Kuiu and Chicagoff Islands in southeast Alaska all hemlocks older than 300 years were infected (Trummer et al. 1998). The parasite propagates by ejecting seeds up to 15m away. It can spread horizontally from crown to crown and vertically from infected canopy trees to surrounding sub-canopy trees (BC Ministry of Forests 1995b). As a result, the distribution of mistletoe-infected trees tends to be patchy (Smith 1977).

Like fungal infections, mistletoe spreads and develops more slowly at higher latitudes. In southeast Alaska, researchers do not expect infection levels to be damaging for rotation lengths of 90 –120 years (Trummer et al. 1998, Shaw III 1982). In contrast, on southern Vancouver Island loss of volume is estimated to be 25% in severely infected trees, and 15% in moderately infected trees by age 80 (Thomson et al. 1984). Reasons for slower development at higher latitudes are likely climatic; e.g., freezing can rupture fruit capsules and reduce seed dispersal by up to 95% (Trummer et al. 1998).

2.6.3 The role of pathogens in the forest ecosystem

Pathogens and parasites impair the vigour or the structural integrity of affected trees, but they also play an important role as agents of diversity and structural complexity (van der Kamp 1991). Van der Kamp (1991) suggests that pathogens may induce genetic diversity in host populations. Hemlock dwarf mistletoe, by reducing the competitive ability of western hemlock, may contribute to the persistence of other tree species in hemlock-dominated forests (Trummer et al. 1998, van der Kamp, 1991). Dwarf mistletoe has also been shown to enhance wildlife habitat, including nesting for marbled murrelets (Smith 1982, Bennetts et al. 1996). Decayed wood provides food and shelter for many organisms (Lofroth 1998, McKinnon 1998). Rots create access to the inner tree bole, which is critical for cavity-nesting birds, especially if rot develops before a tree dies (Alaback 1991, McKinnon 1998). Finally, decay fungi and mistletoe are often the principal cause of gap formation and thus promote structural complexity and accelerate the succession to gap-phase dynamics after large-scale high-severity disturbances (Hennon 1995).

2.6.4 Interactions with other disturbance agents, forest management, and climate change

Injuries by falling trees in a windstorm provide an entry point for fungal infection. Wounds may also be caused by porcupines, bears, and beavers, as well as forest management activities such as harvesting, road building, and thinning (BC Ministry of Forests 1995c, Hennon 1995, Hennon and DeMars 1997, Zeglen 1997). Whereas clearcutting reduces infection sources and thus reduces incidence of mistletoe, partial harvesting may promote infection by maintaining infected overstory trees (BC Ministry of Forests 1995b, Trummer et al. 1998). Both deliberate wounding and management to maintain a certain level of mistletoe-infection have been proposed as a strategy to manage for wildlife habitat and structural diversity in second-growth stands (Hennon and DeMars 1997, Trummer et al. 1998).

Because of the close link between pathogen spread and climatic conditions, climate change may lead to changes in pathogen dynamics. The milder temperatures predicted by global climate models will likely accelerate the development of infections and make trees succumb faster to pathogens (Taylor and Taylor 1997, Williams et al. 2000). This could accelerate development of structural diversity in second-growth stands, but increased rates of decay could also mean that the lifespan of woody debris, snags and other structural elements is reduced. In addition, in the North Coast we may expect an increased role of root rots and fungal species currently more important on BC’s south coast.

2.7 Insects

2.7.1 Disturbance dynamics

Insects do not typically have a major influence across the forested landscape in the North Coast (BC Ministry of Forests 1999) but can be influential within some stands. Defoliators, weevils and aphids can cause varying degrees of tree mortality and growth reduction in host species and responses in non-host species at endemic and outbreak levels. Standing dead trees as the result of insect attacks offer habitat opportunities (Lofroth 1998).

Defoliators such as the green-striped forest looper (*Melanolophia imitata*), western blackheaded budworm (*Acleris gloverana*), and western hemlock looper (*Lambdina fiscellaria lugubrosa*), feed primarily on the foliage of western hemlock and may cause mortality if trees are defoliated several years in a row. While individual trees are killed on a regular basis, a few large outbreaks have been recorded in the Central Coast (Pojar et al. 1999) and the Queen Charlotte Islands (Turnquist et al. 2000). Mortality during outbreaks can be high in severely defoliated areas– e.g., green-striped forest looper may cause up to 25% mortality in stands (K. White pers. comm.). Growth increments may also be reduced by 50% for approximately four years after budworm outbreaks (BC Ministry of Forests 1995a). Historically these defoliators have preferred old and mature stands of western hemlock, primarily in valley bottoms (Koot 1993, BC Ministry of Forests 1995a, Hoggett 2000). However, recent outbreaks of blackheaded budworm on the Queen Charlotte Islands have caused severe defoliation of youngwestern hemlock stands and nearby mature Sitka spruce

(Turnquist et al. 2000). Severe defoliation can significantly alter the nitrogen cycle – in sites of high precipitation or gravely soils, the nitrogen from needles is lost from the forest floor into streams; in other sites, the nitrogen can be redistributed into insect frass and biomass and retained in the forest floor (Lovett et al. 2002).

Plantations of Sitka spruce in the Central Coast are often attacked by the spruce leader weevil (*Pissodes strobi*), the woolly adelgid (Pineus spp.), and the green spruce aphid (*Elatobium abietinum*) (Pojar et al. 1999). Weevils feed on the terminal leader of young trees (0.5 – 12 m high) and do not directly cause mortality but decrease growth and deform stems (Alfaro 1989). Attacks in Sitka spruce plantations begin five years after planting, increase rapidly until stands are 30 years old and then decrease to affect approximately 5% of trees, which is considered an endemic level for coastal stands (BC Ministry of Forests 1996). High-severity attacks of this weevil can cause a shift in species from planted Sitka spruce to western hemlock or amabilis fir. Aphids feed on the needles of all ages of trees. Infestations lasting one to three years have been reported along most of the coast on the Queen Charlotte Islands since 1960 (Koot 1991, Garbutt and Vallentgoad 1992). Tree mortality in stands along the east coast of the islands has reached up to 67%.

2.7.2 Interactions with other agents of change

Insect attacks often weaken trees and predispose them to other disturbance agents (Shepherd 1994). It is hypothesized that weevils can introduce decay fungi, which further weaken trees. The western blackheaded budworm is coincident with outbreaks of hemlock sawfly (*Neodiprion tsugae*). Forest management can also influence insect populations. For example, planting stands of pure Sitka spruce increases the susceptibility of landscapes to attacks first by spruce weevils and later by spruce aphids (Garbutt 1998). Since most defoliators of western hemlock prefer mature and old stands, harvesting may decrease the susceptibility of landscapes to outbreaks in the short term (Garbutt 1998). However, the recent widespread defoliation of juvenile stands on the Queen Charlotte Islands calls this hypothesis into question.

Temperature and precipitation patterns greatly influence the population dynamics of insects (Williams et al. 2000). For example, heavy rains during the flight period can reduce egg laying and survival of western hemlock looper (Koot 1994) and outbreaks of spruce aphids typically follow mild winters and are inhibited by prolonged cool and overcast periods (Koot 1991). Thus, milder winters may increase the probability of multiple generations of spruce aphids in a year, and increases or decreases in summer precipitation may reduce or increase western hemlock looper populations. Because the climatic triggers of outbreaks are unknown for the green striped looper, it is unclear how climate change may impact this looper (K. White, pers. comm.).

2.8 Browsing by Mammals

Porcupines (*Erethizon dorsatum*), beavers (*Castor canadensis*), and black-tailed deer (*Odocoileus hemionus*) can substantially affect forest dynamics and sometimes kill trees or substantially affect growth of trees or seedlings in coastal BC and Alaska. Cyclic increases of vole (*Microtus* spp.) populations also occasionally result in clipping, scarring and sometimes mortality of seedlings (Garbutt and Vallentgoad 1992).

2.8.1 Porcupines

Porcupines feed on a diet of grasses, herbs and forbs in summer, but turn to the vascular tissue and foliage of pole-sized or mature trees in winter (Sullivan and Cheng 1989). Most of the winter feeding occurs in close proximity to dens, creating a patchy pattern of impact hotspots (Sullivan and Cheng 1989). In the Shames Valley near Terrace, porcupines forage for trees in an area of approximately one to two hectares around denning sites, attacking on average one new tree per day (Zimmerling and Croft 2001). Porcupines predominantly feed on vigorous western hemlock trees in larger diameter classes (Sullivan et al. 1986, Garbutt and Vallentgoad 1992, Zimmerling and Croft 2001). They can partially or completely girdle trees, which may result in stunted growth, crown dieback, or death of the affected tree (Sullivan et al. 1986). The incisor marks also provide an entry point for heart rot (Hennon and DeMars 1997). Thus, porcupine feeding promotes development of canopy gaps and structural complexity and may also counteract the dominance of western hemlock (Alaback 1991).

While the importance of porcupines as a disturbance agent in coastal old-growth is not well documented, porcupine feeding seems to be more prevalent in young, even-aged forest or pole-size second-growth (Sullivan et al. 1986, Alaback 1991, D. Steventon pers. comm.). In the Kalum TSA, porcupine feeding was apparent on 490 out of a total of 720 mapped hectares (Garbutt and Vallentgoad 1992). Feeding was concentrated on lower west- or south-facing slopes and in valley bottom areas. Tree mortality was < 1% in younger stands, though most trees were scarred. A study in 30-year old second-growth stands in Khutzeymateen inlet found that approximately 5% of previously unaffected trees were attacked every year, and about half of the trees showed signs of porcupine feeding (Sullivan et al. 1986). The authors estimate that if losses continue at this rate there will be few commercially viable trees available for harvest at the completion of the rotation. Preliminary results from PSP (permanent sample plots) in the Scotia River drainage also show some substantial porcupine impacts (BC Ministry of Forests 1999). However, such high impacts may be localized, and it is not clear to what degree these observations are representative of the situation of the North Coast in general. Currently ongoing studies may help to shed some more light on the question of regional importance of porcupine feeding.

2.8.2 Beavers

Beaver activity is generally restricted to the vicinity of streams and wetlands. Where beavers occur, their influence on the aquatic and surrounding terrestrial ecosystem can be substantial. Beavers primarily affect their habitat by falling small trees and damming streams, flooding forest, and to some degree by feeding on saplings and the bark of small trees. Their activity modifies stream channels, increases sediment retention, alters the hydrologic regime of the area, modifies species composition and stand structure in the riparian zone, and affects nutrient cycling in and around the stream (Naiman et. al. 1986). While there are, to our knowledge, no studies of beaver activity specific to the coast of British Columbia, studies from other areas have identified beavers both as a significant forest disturbance and as a keystone species maintaining aquatic ecosystems (e.g., Naiman et. al. 1986, Gibson 2001, Donkor and Fryxell 1999)

2.8.3 Deer

Deer browsing has especially large impacts on the islands of the outer coastal environment, where mild winters and, on some islands, absence of wolves, allow deer populations to persist only limited by food supply (Klein 1965, Alaback 1991). Deer generally favour cedar seedlings over hemlock and spruce and may thus shift the competitive balance away from cedar (Pojar and Banner 1984, Veblen and Alaback 1996, S. Liepins, pers. comm.). Intensive browsing by deer reduces shrub and tree seedling populations and may virtually denude the forest floor, with tree seedlings and dense understory vegetation primarily confined to areas out of reach of deer (Klein 1965, Pojar and Banner 1984). Once the understory is decimated, the habitat supports only a limited number of deer.

2.8.4 Interactions with other agents of change

Forest management and global climate change could substantially influence the role of browsing animals. The association between porcupine feeding and second-growth was already noted above. Deer populations are also favoured by increased supply of early-seral habitat. However, harvesting, by removing cover and forcing animals to concentrate in narrow riparian buffer strips, may also make deer more susceptible to predation (S. Liepins, pers. comm.) If global warming will result in milder winters with reduced snow cover, this may lead to increases in deer and other ungulate populations presently limited by access to food during winter (Taylor and Taylor 1997). Conversely, in inland areas and at higher elevations, where winter temperatures tend to be more severe, higher snowpacks due to increased winter precipitation may decrease ungulate populations. Another significant factor influencing deer populations is the increased human presence and improved access for hunters and poachers in actively managed forests, which has been shown to extirpate large predators (e.g., Person et al. 1996). In summary, we expect that animal feeding will become a more significant agent of forest disturbance in the future in many low lying areas.

3 Natural Disturbance Regimes Throughout the North Coast Landscape

From the preceding review of natural disturbance agents pertinent to the North Coast it should be clear that natural disturbances do not occur homogeneously across the forest landscape. Rather, several of the agents are confined to, or occur predominantly in specific stand types and on specific terrain types. Using information on natural disturbance regimes efficiently therefore requires a clear understanding of the particular disturbance regime each part of the landscape is subject to. In this section, we present such a description of disturbance regimes.

Landform and substrate play an important role in shaping ecosystem dynamics and regulating disturbance regimes in mountainous landscapes (Swanston et al. 1988, Swanson et al. 1993, Montgommery 1999). The subdivision into biogeoclimatic subzones and variants and the coarse stratification into natural disturbance types used in the Biodiversity Guidebook are of limited use for describing disturbance dynamics on the North Coast, since they do not capture landform or substrate differences. As an alternative, we propose a stratification based primarily on terrain characteristics. For the current purpose, we define disturbance units based on similarity in disturbance regimes and vegetation dynamics. Units are described based on their relative position in the landscape with respect to watershed topography, as well as topo-edaphic characteristics and, in some instances, predominant vegetation type. Below, we present two tables that summarize disturbance characteristics on the north coast. The first table is stratified by disturbance unit and covers wind, geomorphic disturbances and flooding. The most important disturbance agents for each unit are highlighted in red and italics. The second table summarizes characteristics of other disturbance agents, which are either of relatively minor importance on the North Coast or, in the case of pathogens, relatively unaffected by landscape position and dominant vegetation type. Although the proposed stratification into disturbance units is conceptual at this point, it should be relatively easy to develop a GIS model to derive a map of disturbance units for the North Coast from existing data layers.

3.1.1 Summary of disturbance characteristics

Table A Disturbance agents that vary substantially with site characteristics. The first line in each cell describes the frequency of the disturbance agent in the disturbance unit, the second line describes size distribution of opening, and the third describe disturbance severity. Disturbance agents in red and italics are the most prevalent on the disturbance unit, disturbances characteristics in bold are the most likely for each agent.

Disturbance Unit		Wind	Geomorphic	Flooding
Floodplains and fans		***endemic*** *rJ,* ***gap*** ***sl-fT,*** *soil, part.*	freq. to infreq. rJ soil, part.- compl	*endemic, freq. to infreq.* *rJ, gap* *soil, part.*
Productive upland forest, (Hem/Spruce leading or Amabilis fir/Cedar-leading)	steep, exposed	***endemic****, infreq.? to rare* *rJ,* ***gap*** ***sl-fT,*** *soil, part.- compl.?*	*freq.* *rJ* *soil, part.-* ***compl****.*	N/A
	steep, sheltered	endemic gap **sl-fT,** soil	*freq.* *rJ* *soil, part.-* ***compl****.*	N/A
	gentle, exposed	***endemic****, infreq.? to rare* *rJ,* ***gap*** ***sl-fT,*** *soil, part.- compl.?*	rare rJ soil, part.- compl	N/A
	gentle, sheltered	endemic gap **sl-fT,** soil	rare rJ soil, part., compl	N/A
Upland forest, (Cedar/Hem leading)	steep	endemic gap **sl-fT,** soil	*freq.* *rJ* *soil, part.,* ***compl***	N/A
	gentle	rare gap **sl-fT,** soil	rare rJ soil, part.- compl	N/A
Bog woodland blanket bogs		rare gap sl-fT**,** soil	rare(??) rJ soil, part.- compl	endemic gap soil, part.
Avalanche tracks		N/A	*freq.* *rJ* *soil, part.-* ***compl***	N/A
Subalpine forest and alpine		endemic gap sl-fT [c)], soil	freq.? to rare rJ soil, part.- compl	N/A
Gullies		**endemic**, rare? rJ, **gap** **sl-fT,** soil, part.- compl.?	*freq.* *rJ* *soil, part.-* ***compl***	N/A
Estuaries		***endemic*** *rJ,* ***gap*** ***sl-fT,*** *soil, part.- compl.?*	rare rJ soil, part.- compl	*endemic* *gap* *soil, part.*
Salt spray zone		***endemic*** *rJ,* ***gap*** ***sl-fT,*** *soil, part.- compl.?*	rare rJ soil, part., compl	endemic gap soil, part.

Table B Disturbance agents that vary little with site characteristics or are generally of minor significance on the North Coast.

Characteristics	Fire	Short-term climatic	Pathogens	Insects	Browsing
Frequency	rare	rare	end.-indirect	endemic, end.-indirect	endemic
Size distribution of openings	rJ	gap	gap	gap rJ	
Severity	part.- compl.	sl	sl-fT	sl, fT, part.	sl–fT

Key for description of the tables:
steep: steep slope (>30%)
gentle: slope < 30%
exposed: Areas regularly subject to strong winds capable of causing severe damage to trees, including windward slopes in topographically exposed locations (to southeasterly winter storms or katabatic winds); valleys and ridges parallel to the prevailing storm direction; constrictions and saddles; mountain flanks where winds may 'wrap around' from exposed slopes.
sheltered: Areas not subject to prevailing winds or areas where winds are rarely strong enough to cause blowdown.

Key for disturbance attributes:
(In cases where multiple attributes apply, predominant ones are marked in boldface. Question marks indicate uncertainty about the prevalence or effects of a disturbance agent.)

Disturbance rates/intervals, refer to stand replacement intervals:

endemic: an agent that occurs continually or in frequent outbreaks. Impact is persistent and results in mortality but not catastrophic, affects individual trees or small groups of trees.
end. - indirect: an agent that is endemic, but mainly weakens trees, making them susceptible to other forms of disturbance.
freq.: severe disturbance occurs frequently (interval < 100yrs, often much shorter). These forests rarely reach maturity/rotation age.
infreq.: disturbance occurs frequently enough to prevent succession to all-aged forest. Stand structure in these forests is single-cohort or multi-cohort. (intervals between 100 and 300 yrs).
rare: agent rarely affects stands. Not significant on the landscape level, but may occur in specific stands.

Size distribution of openings:
(For 'freq.', 'infreq.', and 'rare' types we give size range and shape of the distribution of opening sizes where possible)
gap: small canopy gaps, typically less than 10 trees.
rJ ('reverse J'-shaped): is used to represent a size distribution where most openings are small and frequency of openings rapidly decreases with increasing size.

Disturbance severity: proportion of overstory mortality, mode of death, and severity of understory disturbance
sl .sublethal effects such as reduced radial and height growth
fT: falling canopy trees cause mechanical damage to adjacent canopy and sub-canopy trees (wounding or breakage; implies some damage to understory).
soil: soil disturbance/exposure of mineral soil (implies damage to understory).
part.: partial canopy replacement.
compl.: complete canopy replacement; survival of canopy trees constrained to single veterans or small patches.

Table C. Compiled estimates of patch size, frequency and spatial distribution of disturbance agents. Tables in Appendix 1 summarize the existing information used to inform our estimates presented below.

Disturbance Type	Mean patch size (ha)	Frequency	Spatial distribution	Comments
Blowdown	5-15	Return interval Exposed sites: 50 – 350 years Sheltered sites: 700 years - never	More susceptible sites: • in valley bottoms directly exposed to southerly storms • on SW to SE slopes especially near the ridge • recent edges • closer to coast • Hw or Ss leading stands	• Frequency estimates are uncertain since the literature does not provide formal analyses for blowdown frequency. • Blowdown statistics include events where up to 90% of trees are left standing and should therefore be considered only partially stand-replacing. • The occurrence of stand-replacing blowdown is dependent on exposure to strong winds. The actual proportion and distribution of susceptible(i.e., 'exposed') sites on the North Coast is unknown and cannot be estimated without a field based study.
Debris flow	1-5	Unlogged: 0.003-0.001 debris flows/yr/km^2 Logged: 0.009-1 debris flows/yr/km^2	Unlogged: on concave, > 40 degrees slopes, more frequent on slopes closer to coast Logged: On 30-40degree slopes, more frequent on slopes closer to coast E, SE, S slopes	Frequency estimates depend on assumptions made about how long debris flows are evident in air photos. Frequency estimates for logged areas include roads and most were based on pre-Forest Practices code data.
Avalanche	10-50	< 20 years in non treed zone of path < 130 years in treed zone	More frequent on open slopes or gullies > 30-50^o and on those likely to experience snowpack warming or snow loading from winds. More frequent in the start zone than the run out zone.	Return interval is the average time between events within an established path.
Fire	< 1	750 years – never	More likely on south facing slopes or well drained Cw/Hw slopes	Estimates are very imprecise and based on very little historical data specific to the North Coast

4 Natural Disturbances and Biodiversity Indicators

Natural disturbances, by affecting the development of vegetation patterns across the landscape, influence the population dynamics of many animal and plant species (Oliver et al. 1998). Animal and plant species are thought to be adapted to certain natural disturbance regimes. For example, the proportion of species which breed in late-successional forests or use downed wood to breed in, tend to increase with longer disturbance return intervals in British Columbia (Bunnell 1995). Several indicator species and communities have been selected in the LRMP process to evaluate environmental risk in the North Coast. We summarize below how natural disturbances in the North Coast influence habitat considered important for these species and communities. Positive signs in the table indicate that disturbance dynamics of certain agents in the North Coast enhance habitat – double positive signs indicating relatively strong influence, negative signs indicate that disturbances have a negative influence on habitat, and blanks indicate no or minimal effect. Short-term climatic disturbances were not included here because of their limited influence in North Coast habitat.

Some key points:

- Certain indicators require structural attributes– e.g., uprooted trees for denning, mistletoe platforms for murrelet nesting. In the North Coast wind and pathogens are primarily responsible for creating these structures.

- Most indicators have seasonal requirements for mature and old-growth forest, e.g., for marbled murrelets when breeding and for mountain goats and black-tailed deer in the winter – due to the absence of frequent stand-replacing events, the North Coast has historically provided an ample supply of these late-successional habitats.

- Certain indicators such as those for moose and grizzly bears require early seral habitat for forage and browse – disturbances in the North Coast provide this primarily as a persistent landscape feature in specific locations – e.g., avalanche tracks, floodplains, mass wasting, riparian areas.

- Certain indicators require a specific spatial pattern between different habitat types required for foraging, bedding and cover from predators and between different habitat required in different seasons – e.g., grizzly bears feed in estuaries or avalanche chutes but tend to bed in mature to old-growth forest (MacHutchon et al. 1993) and mountain goats in the winter feed and take shelter in mature forests within 400 m of steep escape terrain. Because the landscape is naturally partitioned into landform units with distinct dynamics, the required juxtaposition of patches with different habitat characteristics has historically been a persistent landscape feature.

Table D. Effect of natural disturbance agents on the habitat requirements for certain indicator species on the North Coast

Indicator	Habitat requirements	Wind	Avalanches	Mass wasting	Flooding	Fire	Insects	Pathogens	Mammals	Logging
Marbled Murrelet[x] CWHvh, vm	Spring breeding: - Nest on platforms on large branches high in tall trees in mature and old-growth forests within 70 km of ocean							+		-
Grizzly Bear and Black Bear[xi] CWHvm,wm,ws	All seasons: - lower slopes and valley bottoms - Select floodplain young and old forests but also found in wetlands, estuaries - bed in sidehill, moist sites Spring and early summer: - Herb communities in avalanche run-out zones Denning : - Root wads - Large, hollow trees	+ dens, gaps for berry growth	++ early seral stage	+ early seral stage	+ early seral stage	+ rare, but does promote *Vaccinium*		+ dens, gaps for berry growth	+ dens, gaps for berry growth	+ early seral stage
Moose[xii] Inland CWHvm, wm,ws	Winter range: - Low elevation, <40% slope - Perpetual shrub particular willow communities (e.g., dynamic floodplains, fens but not estuaries) - Crown closure of at least 65% for snow interception - Wind protected exposures (e.g., sheltered slopes, gullies) - Accessible winter migration routes.	+ early seral stage	+ early seral stage	+	++ early seral stage					+ early seral stage
Mountain Goat[xiii] MH	Summer: - Alpine and subalpine meadows Winter: - Old-growth stands (for snow interception, thermal cover and forage) near steep terrain for escape - grasses, shrubs, lichens, fir - South and west facing slopes	+ shelter under root wads	+ forage near esc cover							- winter range canopy closure

[x] (Tamblyn and Horn 2001)
[xi] (Ferguson and Pope 2001), (MacHutchon et al. 1993)
[xii] (Pollard 2001),
[xiii] (Tamblyn and Horn 2001)

Indicator	Habitat requirements	Wind	Avalanches	Mass wasting	Flooding	Fire	Insects	Pathogens	Mammals	Logging
Deer[xiv] CWH vh, vm, wm, ws	<u>Winter range:</u> - Move to areas with less snow – areas near ocean, valley bottoms, floodplains - Browse on *Vaccinium* sp., deer fern in shrubby habitat and open canopy, mature forests on ridgetops and benches (20-45 degree slopes perhaps to avoid wolves) - In heavy snowfall years, require canopy closure for snow interception near good foraging areas.	+ creates gaps for understory			+	+ increase *Vaccinium*	+ creates gaps for understory	+ creates gaps for understory	+ creates gaps for understory	+ early seral stages - winter range canopy closure
Salmon CWHvh, vm, wm, ws	<u>Spawning:</u> - gravel beds - coarse woody debris for nutrients	+		+/-	+/-	+/-				-
Blue and Red listed Floodplain and alluvial forests and spray zone forests[xv] CWHvh, vm, wm, ws	See Ronalds and McLennan 2001 for specific community descriptions	+ increases soil productivity		+	+					-

[xiv] (Blood et al. 2002)
[xv] (Ronalds and McLennan 2001)

5 Management Practices

5.1.1 Forestry

Harvesting in the North Coast has concentrated in old growth coastal western hemlock forests that are accessible from the shore or valley bottoms (Tamblyn and Horn 2001). Only 7% of the forested landbase in the North Coast TSA is considered operable due to the rugged terrain or the poorly drained and low productive cedar-hemlock forests in the outer coast. In spite of low productivity, the high market value of western redcedar and yellow-cedar makes these stands of economical interest. The HyP^3 research program has been established to examine the sustainability of harvesting in these ecosystems and to develop ecologically based management guidelines for these stands (Banner 1999, Chourmouzis and Kayahara 1998, www.for.gov.bc.ca/prupert/research/index.htm).

The concept of emulating patterns of natural disturbances is part of official forest policy in BC (British Columbia Ministry of Forests 1995). The Biodiversity Guidebook groups the biogeoclimatic variants in the province into five Natural Disturbance Types (NDTs) and provides guidelines for seral distributions, patch size, and landscape connectivity within each NDT. The forests in the North Coast are classified as NDT1, with disturbance intervals between 250 years and 350 for stand replacing disturbances. The NDT classification scheme emphasizes stand-replacing disturbances. This may be misleading because while small sections of the landscape may experience relatively frequent stand-replacing disturbances, there is no evidence to support the disturbance intervals for the North Coast postulated in the Guidebook on a broader landscape scale. Although clearcutting has been the dominating harvesting regime on the North Coast, the use of variable retention systems is increasing (Tamblyn and Horn 2001). Of the timber harvesting landbase, approximately 13% is in management zones such as visual quality areas and community watersheds which require some form of partial harvesting (from North Coast LRMP area analysis of indicator/zones, H. Horn pers. comm.).

5.1.2 Mining

The northern portion of the plan area around Kitsault has had a long history of mining since the 1900s (Tamblyn and Horn 2001). Although mining companies now must obtain Free Use Permits from the Ministry of Forests before trees are cut, it is unclear what guidelines these companies must follow. Amendments to Energy and Mines Statutes currently proposed could allow mining companies to obtain Licenses to Cut without volume restrictions and Free Use Permits not subjective to resource management zones. Certainly mining has affected forests in some parts of the plan area – perhaps the most dramatic impact to date is fume kill[xvi] of several thousands of hectares of coniferous forest caused by the copper smelter

[xvi] Fume kill is tree mortality from chemical gases – western hemlock is one of the most susceptible species to sulphur dioxide gases (US Silvics Handbook).

operating in the Anyox area between 1910s to the 1930s, which is still evident as a distinct patch of young forest (S. Liepins, B. Pollard pers. comm.).

6 Management Issues for the LRMP

Based on the current scientific understanding of natural disturbance dynamics on the North Coast and similar ecosystems, we propose the following key issues for consideration by the LRMP table.

(1) Given our understanding of natural dynamics on the North Coast, what are appropriate spatial and temporal scales for forest management?

- Landscape dynamics on the North Coast are strongly influenced by the underlying mosaic of physiography and topography. The paradigm of a shifting mosaic of seral stages[xvii] that underlies the management approach proposed in the Biodiversity Guidebook does not fit this type of landscape very well, since much of the early-seral vegetation is confined to a few areas subject to repeated disturbance, whereas most of the operable, productive forests of interest to harvesting rarely experience severe, large-scale disturbance. A planning approach that fails to take this into consideration will make it difficult to incorporate knowledge about natural dynamics in a meaningful way. The disturbance units proposed in Section 3 of this report, or a similar type of landscape stratification, would be a logical subdivision of the landscape in terms of maintaining ecological processes and their outcomes. Such a stratification could also help identify planning areas where special management is required to avoid undesirable interactions with dominant disturbance agents.
- Climate also is a significant driver of forest dynamics on the North Coast. Future climate change along coastal BC is predicted to bring increases in average temperatures by 1.5 to 4°C, as well as increases in winter precipitation, severity of winter storms, glacial retreat, increased flooding especially in the spring, and also flooding of coastal areas. These changes will likely increase the incidence and/or severity of most disturbance agents and affect how forests respond to these agents and other processes. Consideration of intermediate and long-term climatic trends is therefore essential for anticipating and planning future forest development.
- Since most ecosystem processes on the North Coast often seem to progress on the scale of decades or centuries, undesired effects of management activities may take a long time to manifest and even longer to reverse. This suggests a need for careful

[xvii] This paradigm applies to a landscape where forest dynamics are similar across the landscape and occurrence of natural disturbances is not restricted to particular topographic or other site characteristics. In such a landscape, the spatial distribution of young and old forest throughout the landscape is similarly independent of topography or other site characteristics, and the forest mosaic therefore 'shifts' at random across the landscape over time as disturbances create new openings and older openings gradually merge back into the matrix of old forest.

long-term planning and continued monitoring if negative ecosystem impacts are to be minimized.

- While forests on the North Coast are primarily driven by gap dynamics, larger, more severe natural disturbance events do occur episodically in some parts of the landscape. Negative impacts of such rare events on sustained timber supply and biodiversity are to be avoided, proactive planning and forecasting over long time horizons will be required. This could include considering the potential of earthquakes or landslides on road networks and taking into account loss of timber to episodic severe natural disturbances in timber supply analyses.

(2) How can natural disturbance regimes serve as a guide for forest management on the North Coast?

- The forests in the North Coast are predominantly considered NDT (Natural Disturbance Type) 1 in the Biodiversity Guidebook, with intervals between stand replacing disturbances averaging 250 to 350 years. Although some small sections of the landscape may experience relatively frequent stand-replacing disturbances, there is no evidence to support the disturbance intervals for the North Coast postulated in the Guidebook on a broader landscape scale. The scientific evidence also indicates that in forests considered productive and operable, disturbance return intervals for large, stand-replacing events were generally much longer than commercial rotation periods.
- Because forests on the North Coast are primarily driven by gap dynamics, natural disturbance regimes provide no template for clearcutting systems, or traditional approaches to even-aged management in general. If the objective of forest management is to emulate natural disturbance patterns, a variable retention silvicultural system such as the one proposed by the Clayoquot Sound Scientific Panel (1995), which aims to retain trees and forest patches similar to patterns and remnant structures left after natural disturbances, is the closest match. Whereas variable retention is considered more appropriate for maintaining the structural characteristics of old-growth forests, it may also result in reduced tree growth rates (as compared to clearcut harvesting) and may increase the incidence of some types of natural disturbance such as blowdown, mistletoe, and fungal infection. In cases where high retention levels are not a desirable option, the potential risk of negative ecological impacts from silvicultural practices that do not maintain natural dynamics may be reduced through extended rotations, and by constraining the proportion of the landbase over which harvesting may occur. However, if a reduction in harvesting landbase is to be offset by more intensive management zones, it will be important to carefully consider the allocation of such areas, since in many cases the most productive areas from a timber growth perspective also tend to be of primary importance for biodiversity.
- Most of the interactions between harvesting and natural disturbance on the North Coast are synergistic, i.e., harvesting is likely to increase occurrence of natural disturbances. Moreover, incidence or severity of most natural disturbances is likely to increase as a response to climate change, and use of fire or mechanical site

preparation as a management tool to improve soil productivity may further increase the overall incidence of disturbance across the landscape. In summary, disturbance rates are likely to increase in the future even without harvesting, and harvesting will almost certainly lead to disturbance rates substantially higher than the landscape has historically experienced. This emphasizes the need to monitor landscape conditions to recognize and avert potential negative impacts on ecosystem function and biodiversity.

- Uprooting by wind and other forms of soil disturbance are important for maintaining soil productivity, particularly in hypermaritime forests (CWHvh). Uprooting of large trees has a more thorough, long-lasting effect than uprooting of small trees. Thus the loss of large trees from the stand through logging may have negative impacts on soil productivity. Note however, that the contribution of uprooting to maintaining soil productivity was likely limited on the North Coast since the primary mode of mortality in old growth forests is stem snap. Soil disturbance as a silvicultural treatment, if appropriately applied, may offset the reduction in soil disturbance associated with the loss of large trees, and counteract the negative impacts on soil productivity associated with harvesting.
- Although natural disturbances are a key aspect of forest dynamics, forests are shaped and maintained by a variety of factors that are partially or completely outside the scope of this report. Even if harvesting is designed to emulate natural disturbances very closely, consideration of other factors influencing forest development over the long and short term is essential for maintaining ecosystem integrity and productivity. These factors include drainage patterns, nutrient cycling, soil development, availability of seed sources, as well as genetic health of tree populations. The impact of harvesting on some of these factors is being studied in operational trials on the North Coast as part of the Hyp^3 Ministry of Forest Research Project.

(3) One of the key principles of ecosystem management is that species are adapted to, and therefore most likely to persist under the environment and processes they have experienced historically. What are the key habitat characteristics historically maintained by natural dynamics, and how is forestry affecting these characteristics?

- The majority of the forested landscape on the North Coast was historically in all-aged stands dominated by gap-phase replacement. Reducing the supply of this type of habitat may negatively impact old-growth-dependent species.
- Because historically stand replacing disturbances were largely constrained to susceptible locations within the landscape, late seral forest was persistent throughout the remainder of the forested area. Current areas of persistent late seral forest can act as habitat refugia for species dependent on them. Continued existence of such refugia can be ensured by setting aside old growth areas or by managing some parts of the landscape at rotation rates that allow development of old growth characteristics.

- The long stem-exclusion[xviii] stage ensuing after clearcut harvesting means that understory plants and species dependent on these plants may drop out of the stand. Requirements for persistence and recolonization of such species may therefore need to be considered if these species are to be maintained in the landscape.
- The historical landscape mosaic provided connected routes for movement and dispersal of species dependent on particular habitat characteristics. Where harvesting or other forms of development interrupt connectivity, the ability of species to move and disperse throughout the landscape may be impacted.
- Several of the species listed in the indicator section rely on the juxtaposition of early-seral herb and shrub communities and forest cover for protection and denning. Where forest management creates larger openings and reduces the amount of small canopy gaps characteristic of old-growth forests, the result may be a lack of suitable cover for some species.
- Productive valley bottom areas and estuaries often have high economic timber value as well as high habitat value and may thus be especially vulnerable. Since narrow riparian buffers are susceptible to blowdown, effective protection of hydro-riparian ecosystems may require additional measures to ensure that these buffers will be able to fulfil their intended role.
- Standing dead and downed wood are important habitat elements in both terrestrial and aquatic ecosystems. Natural disturbances generally ensure an ample supply of snags, root wads, and downed wood. Reduced recruitment of snags and large woody debris in managed stands may have long-term effects on nutrient cycling, tree regeneration, and habitat quality. Since the large root mounds and downed logs of old-growth forests persist for a long time, the impacts of reduced input of dead wood into the system may only become fully apparent after one or two rotations of second growth.

7 Knowledge Gaps

There are gaps in our ability to estimate the relative and absolute significance of different disturbance agents for the North Coast and quantify historical temporal and spatial variability in disturbance attributes. This affects our ability to use natural disturbance regimes to guide management practices, as well as our ability to accurately predict the impacts of natural disturbance on timber and habitat supply.

1. Research specific to the North Coast is scarce for wind, avalanches, pathogens, insects, fire, mammal browsing and short-term climatic disturbances. Some disturbance agents have been well described for similar and proximate ecosystems in southeast Alaska, the Queen Charlotte Islands, mid and south coast BC.

[xviii] Stage of forest development where a dense layer of young to mature trees prevents others from establishing. The intense competition for resources in this stage results in the death of many of trees and thus reduced stem density.

However, only wind, pathogens and deer have been extensively studied in both the mid/south coast BC and southeast Alaska, permitting probable interpolations to the North Coast.

2. In spite of the fairly extensive body of research on wind, discrepancies between results for adjacent areas only allowed us to draw tentative conclusions about the historical role of severe, stand-replacing blowdown on the North Coast.

3. Interactions between different disturbance agents, except between wind and pathogens and between forest management and landslides, are generally poorly understood.

4. While it is clear that disturbance regimes on the North Coast are strongly influenced by landform and vegetation characteristics, studies generally do not provide enough detail to compile a reliable description of disturbance characteristics for each disturbance unit.

5. The influence of climate change on disturbance agents is also uncertain in many cases.

Harvesting has been occurring on the North Coast for close to 100 years. However, the implications of past harvesting on biodiversity are unknown. Stands which have been harvested with different types of systems should be sampled to determine resulting forest and understory structure and composition. These data could be added to existing data sets on second growth productivity (e.g., Hyp3 operational trials; Banner 1999) so that the costs and benefits to timber production versus biodiversity indicators can be evaluated for different harvesting systems.

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Appendix 1

Landslides (debris flows & rockslides)	Coast mountains Rollerson et al. 2001	Vancouver and QC Islands Rollerson et al. 2001, Rollerson 1992	Queen Charlotte Islands Schwab 1995	Rennell Sound Schwab 1983	Queen Charlotte Islands Rood 1984	Clayoquot Valley Pearson 2000 (rockslides)	Clayoquot Sound Jakob 20000
Total area	8490 ha		All islands	150 km^2	27 basins 350 km^2	7608 ha	2546 km^2
Productive forest							
Number of disturbance patches			8240	264	1337	49	1004
Total area disturbed (ha)						183	2205
Total area disturbed (%)			Moderate (1-3/km^2): 24% Severe (4-7/km^2): 7% Extreme (>8/km^2): 1%	4.3% of clearcut terrain (126) 1.9% of road (25) 0.1% of forest (112)		2.4%	Logged: 3% Unlogged: 0.37%
Productive forest disturbed (%)			?				
Proportion associated with roads or cutblocks				43 times more in clearcuts 17 times more from roads			
Minimum size mapped	500 m^2	500 m^2	1:50,000 air photos				500m^2
Reference period	15 yrs	15 yrs	40? yrs	1 storm in 1978	20? years	1900?-1988	Logged: 20 yrs Unlogged: 40-60 yrs.
Patchsize range						0.2-29 ha	
Mean patch size						3.7+/-5.2 ha	Logged: 1.59+/-1.62 ha Unlogged: 1.67+/-1.86 ha
Median patch size							Logged: 1 ha Unlogged: 1 ha
Density	0.8-1.2/km^2 clearcuts	8-17/km^2 clearcuts	2.6/km^2 (all islands) but up to 18/km^2 on some (all natural?)	1.76/km^2 (logged and unlogged) 15 times more in roads and clearcuts	3.82/km^2 (logged and unlogged) 34 times more in logged terrain	(0.64/km^2)	0.39/km^2 (forested) 0.12- 0.85/km^2 Logged: 1.94/km^2 Unlogged: 0.22/km^2
Frequency	0.05 – 0.08 /yr/km^2	0.5 –1.1/yr/km^2	0.065 /yr/km^2 (all natural?)		0.19/yr/km^2 (unlogged and logged)	0.0073/yr/km^2	Logged: 0.0097 yr/ km^2 Unlogged: 0.0037-0.0055/yr/ km^2
More likely sites			More scouring and volume movement in flows caused by roads			Steep slopes > 35, most above 500 m elevation	E, SE, S slopes Logged: 30-40deg Unlogged: concave, > 40 degrees, < 5 km to coast

Wind	Prince of Wales and associated islands SE Alaska (Harris 1989)	Kuiu Island SE Alaska (Kramer et al. 2001, Kramer 1997)	SE Chichagof Island SE Alaska (Nowacki and Kramer 1998)	NE Chichagof Island SE Alaska (Nowacki and Kramer 1998)	Clayoquot Sound Vancouver Island (Pearson 2000)	1906 Vancouver Island Windstorm (Pearson pers. comm.,Keenan 1993)	North Coast Forest District (based on data from Mitchell 1998)
Total area (ha)	870,000	197,000	110,000	104,000	48,000	78,766	119,130
Productive forest	59.5%	65%	54.9%	64.1%	-	-	100%
Number of blowdown patches	1010	1886	1118	444	0	208	62
Total area disturbed (ha)	7414.8	26,588	4737.6	6196.8	0	2830	1531
Total area disturbed (%)	0.9%	13.5%	4.3%	6%	0%	3.6%	1.3%
Productive forest disturbed (%)	1.6%	20.8%	7.9%	9.3%	0%	-	1.3%
Proportion associated with/adjacent to clearcuts	13.9%	-	-	-	N/a	-	8%
Minimum patch size mapped	0.8	0.8	0.4	0.8	4.5	0.2	Forest cover polygons
Reference period	15+ years	150 years	-	-	~ 140 years	N/a	37 years
Includes partial blowdown?	yes (up to 90% of trees left standing)	yes	yes	yes	yes	yes	yes (up to 70% of trees left standing)
Patch size range (ha)	0.8 – 70	0.8 – 400	0.4 – 100	0.8 – 308	N/a	0.2 - 508	0.8 - 118
Mean patch size (ha)	7.2	15.6	4	14	N/a	14	10.8
Median patch size (ha)	-	5.6	2	7.6	N/a	4	6.2
Interval between major (stand-replacing or partially stand-replacing) events	-	50 – 300 years in exposed locations, gap-phase dynamics elsewhere	-	-	N/a	N/a	> 3000 yrs for NC (see section 3.1)
Predominant vegetation type	hemlock / spruce	hemlock	-	hemlock	N/a	hemlock / amabilis fir	-
Predominant topographic position	windward slopes, flats and sideslopes parallel to predominant storm direction	ridge noses and flanks, exposed[a] stands	-	-	N/a	-	-
Predominant soil characteristics	shallow and/or highly productive	nonhydric	-	nonhydric	N/a	-	-

[a] Determined using EXPOSE simulation model; elevation and slope were also significant factors.

Avalanches[a]	Clayoquot Valley Pearson 2000	Invermere TFL 14 Ferguson and Pope	Glacier Nat. Park Walsh et al. 1990	Kananskis Johnson 1987
Total area (ha)	7000 ha	151,866 ha		
Productive forest (ha)				
Number of disturbed patches	14	336	121	2
Total area disturbed (ha)	176	14,731		
Total area disturbed (%)	2.3%	9.7%		
Productive forest disturbed (%)				
Proportion associated with roads or cutblocks				
Minimum size mapped (ha)		0.5 ha		
Reference period	1900? -1988			
Patch size range	2.6-34 ha	2-885 ha		
Mean patch size	12.5+/-8.9 ha	44 ha		
Median patch size				
Density	0.002			
Frequency			< 10 years in a path	< 20 years in non treed zone of path, < 130 years in treed zone
More likely areas		More frequent on slopes > 30-50° and/or on those likely to experience snowpack warming such as on south aspects (Weir 2000)	Steep (30-45°), open slopes or gullies Smooth or unvegetated terrain	More frequent in top than bottom

[a] We examined the size distribution of avalanche paths in the North Coast using Baseline Thematic Mapping data (range: 0.9 – 39,850 ha, median: 87 ha). We did not include BTM data here because some patches delineated as avalanches were questionable – e.g., the maximum of 39,850 ha is more likely to be an interpretation error. 7 out of the 963 patches were > 10,000 ha likely causing an overestimation of the actual average size of a path. BTM data are also likely at too coarse of a spatial scale for determining patch size distributions (D. Morgan pers comm.). PEM data available in the fall may be more appropriate (A. Banner pers. comm.).

Fires	Clayoquot Valley Gavin 2000	Clayoquot Valley (lake sediment) Gavin 2002	North Coast MOF Protection Branch Database
Total area studied (ha)	700	110	1.76 million
Productive forest			
Number of disturbed patches			45
Total area disturbed (ha)			8.5
Total area disturbed (%)			
Productive forest disturbed (%)			
Proportion associated with roads or cutblocks			
Minimum size mapped			
Reference period	tree dates AD 1550-1886 radiocarbon dates 280-10,330 BP	AD 200-present	1950-1997
Patch size range			0-4 ha
Mean patch size	Rarely extended beyond 250 m in diameter		0.19 (stddev 0.59)
Median patch size			
Density			
Frequency range	time since last fire: 64 - 12,000 yrs BP	Mean return interval for lake catchment*): 50 (AD 200-900) 350 (AD 1100- present)	greater 1000 yrs
Frequency median	hillslopes = 750 yrs terraces = 4500 yrs*		
More likely areas	south facing slopes, well drained Cw/Hw slopes		

*) Note: this is the return interval between any two fires that occurred somewhere within the catchment area. Since fires in the study area were generally small (much smaller than the catchment area), the interval between consecutive fires on a given site would typically have been considerably longer.